Chapter 3

Resource-Efficient **Residential Architecture**

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CHAPTER 3
Resource-Efficient Residential Architecture

Introduction

Shelter has always been one of mankind's most basic needs, but in the past the relationship between shelter and the local environment was much closer than it is today. Buildings were necessarily built with materials that were locally available, and their designs usually responded to the local climate. Steeply sloping roofs in northern New England, for instance, prevented snow from accumulating; similarly, the flat roofs and open breezeways of the Southwest made for comfortable living in a hot, arid climate.

In the last 30 years, however, as climate control systems became more sophisticated, as energy became cheaper, and as building materials became standardized and more easily transported, the need for indigenous styles of architecture declined. It became possible to build similar homes in Virginia and Vermont, and indeed this was often done.

Recent developments are changing this trend. Energy is growing much more expensive, as are building materials and the cost of transporting them over long distances. Once again there is both a need and a demand for architecture that utilizes resources more efficiently in construction and minimizes the energy needed to maintain acceptable comfort. As a result, the development of resource-efficient housing has become a significant movement in U.S. architectural design and construction.

The case studies in this chapter illustrate the great diversity of this movement and the wide variety of energy -saving strategies that it has made available. This progress, which has been achieved through individual efforts in numerous locations, has advanced the goal of residential energy conservation by making a wide range of strategies available (singly and in combination) for achieving the best results in diverse sites and climates. The diversity and adaptability of these technologies seem to suggest that conservation is a strategy that can be successfully pursued in all regions of the Nation.

This chapter discusses the larger context of resource-efficient architecture, its potential benefits and problems, and two major approaches to resource-efficient design and construction: solar heating, which uses the energy of the sun to supplement or replace fossil fuels for space heating; and heat retention, which tightens the "thermal shell" of a house to reduce the total energy needed for space heating. The five case histories present innovative examples of both approaches:

- Solar heating greenhouses in New Mexico, which are attached to houses and collect heat from the sun for use in both the greenhouse and the rest of the house.
- The "Ark II," a solar-heated home designed by Solsearch Architects for the Cooley family of Washington, Corm.
- The "Conserver Home" on Prince Edward Island, Canada, also designed by Solsearch Architects, which requires very little space heating because of its heavily insulated shell and many other heat-retaining design features.
- An energy-efficient house developed by students and faculty of Kuskokwim Community College in Bethel, Alaska, which uses a variety of nonconventional construction techniques to produce a house that is energy efficient and uses few imported materials.
- A "thermal envelope" house in Lake Tahoe, Calif., owned by Tom Smith. The house is literally a "house within a house, " combining principles of solar heating with those of a highly heat-retentive structure.

In this and the following chapters, case studies of individual applications of the technologies will be followed by a discussion of critical factors that may affect their future diffusion and adoption. Each chapter will close with a discussion of relevant Federal policy and issues and options for further action.

Residential Housing and Energy Conservation

Total energy consumed for residential space heating and cooling is estimated to be 17 Quads, or about one-quarter of total U.S. energy consumption in 1977.[1] Typical residences constructed in the 1970's using standard building technology and practice require between 10 and 15 Btu per square foot per heating degree day (Btu/ft^2/dd) to maintain acceptable inside temperatures. Older, poorly insulated or uninsulated residences may require as much as five times this energy input.

Some housing being constructed today requires less than 2 Btu/ft^2/dd input from fossil fuel sources. This low energy consumption is being achieved by a wide range of strategies. At one end of the spectrum are active solar houses, which have standard levels of insulation and airtightness, but to which solar collectors and heat storage have been added to reduce the need for backup energy. Next come the passive solar homes, which are somewhat better insulated and in which the solar collector and storage are integral parts of the structure. These homes also achieve low backup energy needs. The Cooley house described in this chapter is an example of integrated passive design, which also reduces backup energy needs.

At the other extreme are heat-retentive houses, superinsulated structures that reduce the heating load to near the levels of energy released by occupants and their normal activities. The Conserver Home and Bethel House described below are examples of superinsulated structures. The "thermal envelope" house described in the final case study is a hybrid, which combines elements of both solar heating and heat retention with a number of other energy-conserving design features.

As experience is gained, the best aspects of these various strategies are being incorporated into new designs for very energy-efficient houses that can be built and marketed widely by local contractors and builders. For example, the Tennessee Valley Authority has designed and built, and is currently testing 11 different designs for their seven-State service area.[2] The Mid-American Solar Energy Complex (MASEC) is sponsoring a "Solar 80" home design program, through which houses using less than 2.5 Btu/ft^2/dd of fuel energy are being constructed and demonstrated.[3] The program requires that the construction costs of these houses are not to exceed by more than 5 percent those of a similar house without any special energy-conserving features. This cost requirement is possible because the added costs of high-insulation, low-infiltration, and simple passive solar features are largely offset by the reduced size and cost of space-heating equipment, which in some cases may be eliminated entirely.[4]

Reducing the fuel requirements for heating and cooling existing homes present more complex problems. Adding insulation or reorienting window locations, even in recently constructed houses, is often not feasible; and weatherizing older structures, while essential, cannot reduce space-heating loads to the low levels that can easily be achieved in new construction. However, low-cost solar retrofits offer an additional strategy for reducing fuel needs in existing housing. Attached solar heating greenhouses are proving to be a popular and apparently cost-effective solar retrofit.

[1] *Residential Energy Conservation* (Washington, D. C.: office of Technology Assessment, U.S. Congress, July 1979), vol. 1, p. 4.

[2] "Solar Homes for the Valley Project," W. C. Adkins, Chief Architect, Tennessee Valley Authority, Knoxville, Term.

[3] David Pogany and Don Kraft, "Mid-American's passive Homes," *Solar Age*, vol. 5, No. 4, April 1980, p. 107.

[4] R. W. Besant, R. S. Dumont, and G. Schoenau, "Saskatchewan House: 100 Percent Solar in a Severe Climate," *Solar Age*, vol. 4, No. 5, May 1979; and E. H. Leger and S. D, Gautam, "An Affordable Solar House," Proceedings *of* the *4th* National Passive *Solar* Conference, Kansas City, Me., Oct. 3-5, 1979, p. 317.

A Case Study of the Solar Heating Greenhouse, New Mexico[5]

The Community Setting

New Mexico was particularly well suited for the initial development of solar greenhouse designs. The winter in the northern part of the State is cold but very sunny, with an average January solar availability of over 70 percent. Under such conditions, the daily heat gain of even a crude greenhouse will often exceed its heating load. But New Mexico was also suited to greenhouse development because of the human and institutional resources that were available.

During the late 1960's, northern New Mexico was the site of a number of alternative communities. They attracted young people from middle-income backgrounds, many of them college educated, who brought design skills and a sense of adventure to the development of small-scale alternative technologies. One such community was the Lama Foundation in Taos, N. Mex., which (with the help of designers Steve Baer and Day Charoudi) developed a pit greenhouse based on the "biosphere concept."

The pit greenhouse, often called a "grow hole," is simply a hole dug in the south side of a hill and glazed over; they have been used for centuries to extend the growing season. The biosphere concept adds heat storage, in the form of plastic jugs of water and thermal mass in the walls and floors, to keep the greenhouse warm at night and during periods of cloudiness. The result is a freestanding, integrated passive solar greenhouse in which plants can be grown year-round. (See ch. 4 for further discussion of freestanding solar greenhouses.)

In 1973, Bill Yanda from Nambe, N. Mex., also became interested in pit greenhouses. After visiting the Lama Foundation's solar grow hole, he built one for his own family. The following winter was an unusually cold one in northern New Mexice, but to their surprise the plants in their pit greenhouse did not freeze. The design collected solar heat so effectively, in fact, that despite the cold weather the Yandas had to vent excess heat during the day. This led them to the idea of an attached solar greenhouse that produced heat as well as food: "Why not help heat your house with that excess heat, instead of venting it to the outside?"

Development

Drawing on their personal experience, the Yandas felt that the attached solar greenhouse had sufficiently low cost, in terms of its heat- and food-producing potential, to be a viable approach to solar heating for low-income families.

In the spring of 1974, they applied for and received an initial demonstration grant from the Four Corners Commission, a regional agency funded by Federal and State governments. They built 12 attached solar greenhouses in mountain villages in northern New Mexico, for houses occupied mostly by low-income families of Spanish, Indian, and Anglo heritage. In the spring of 1976, the Yandas received a contract from the State Energy and Resources Board (now the New Mexico Department of Energy and Minerals) to build 12 more attached solar greenhouses throughout the State.

This second project was different from the first because it utilized the workshop process to build the greenhouses. The greenhouse workshop was like a barn-raising: homeowners, neighbors, and friends came together for a long weekend to learn about and build a solar greenhouse. Usually the greenhouses were three-quarters completed at the end of the weekend. According to Bill Yanda, the process had a multiplier effect: "For every workshop, ten more greenhouses were built in the community."[6]

[5] Material in this section is based on the working paper, "New Mexico Solar Greenhouse Study," prepared by the New Mexico Community Study Team (see appendix),

6 S t a t

To date, the Yandas have built 30 solar greenhouses in New Mexico. In 1977, they setup a work group, the Solar Sustenance Team, which has helped facilitate the building of solar greenhouses on a broader scale and by organizing workshops to train people all over the United States. The team supplied leaders for workshops that built community greenhouses for the Wooster (Ohio) Food Cooperative in 1979 and for the Cleveland Hunger Task Force in August 1980.

The workshop concept is now being widely emulated across the country. Although no hard data is available, evidence for the spread of workshops can be seen in the number of reports on statewide greenhouse construction programs. The 1978 National Passive Solar Conference heard only one such report—from the Yandas—while in 1979 there were reports from 5 States: Colorado, Missouri, Ohio, Wyoming, and Arkansas.[7]

Solar Greenhouse Technology

A greenhouse is a glazed structure that admits visible and infrared solar radiation, which is converted to heat by absorption on surfaces within the greenhouse. This heat is trapped in the structure by the glazing materials, most of which are opaque to the long-wave infrared radiation emitted by objects at about room temperature. Simply stated, it is easier for radiant energy to get into the structure than it is for it to escape again. Glazing materials are very poor insulators, however, so heat losses at night and on cold cloudy days can be considerable. For this reason, the conventional "glass houses" are prodigious users of energy during winter months.

Solar greenhouses, on the other hand, are designed to provide adequate light for plant growth, but to limit heat losses and to store sufficient heat to achieve a net heat gain during the heating season. Several design modifications are needed to achieve these results:

- glaze only the south-facing surfaces;
- use two layers of glazing in most northern climates;
- seal the greenhouse shell carefully in order to prevent unwanted air infiltration;
- insulate heavily all nonglazed exterior surfaces; and
- provide sufficient heat storage that nighttime and cloudy day heat losses can be drawn from storage and not from a backup source burning fossil fuels (adequate storage also moderates temperature swings).

The result is a greenhouse that looks quite different from conventional greenhouses, which have low-pitched roofs and all-around glazing.

Although a solar greenhouse may be freestanding (see figure 1), most residential applications of this technology are attached to the house: "lean-tos" built against the south wall of the structure or extended from the east or west walls but facing south (see figure 2). This type of construction reduces costs, permits transfer of excess energy from the greenhouse to the main structure, usually allows access to the greenhouse from a heated space, and often adds an attractive living space to the dwelling.

Glazing materials include glass, fiberglass, and various plastic films. Most plastics, including fiberglass, are damaged by the ultraviolet radiation in sunlight. The plastic material used in greenhouses is protected by ultraviolet inhibitors and has an expected lifetime of 10 to 20 years. Plastics are lightweight, easy to cut, and available in large sheets; for these reasons, many greenhouse-building groups working with relatively unskilled workshop participants use plastics exclusively. Glass is also an excellent glazing material, but it is generally more expensive than plastics, heavier, and more difficult to mount successfully.

Heat storage is usually provided by incorporating thermal mass into the greenhouse structure (such as a concrete floor slab or a rock or gravel bed below the floor) or by placing thermal mass in the greenhouse (such as water-filled 55-gal drums or plastic milk jugs stacked along the north wall, or rocks held against a wall by wire mesh). Thermal mass that is in direct sunlight functions more effectively than mass to which heat must be transferred by air movement or conduction. Because heat storage mass placed in the greenhouse can be added or removed quite easily, adjustment and

[7] *Proceedings of the 2d National Passive Solar* Conference, Philadelphia, Pa., Mar. 16-18, 1978; and Proceedings of the 4th National Passive Solar Conference, Kansas City, Me., Oct. 3-5, 1979.

Figure 1 .—Two Freestanding New Mexico Solar Greenhouses

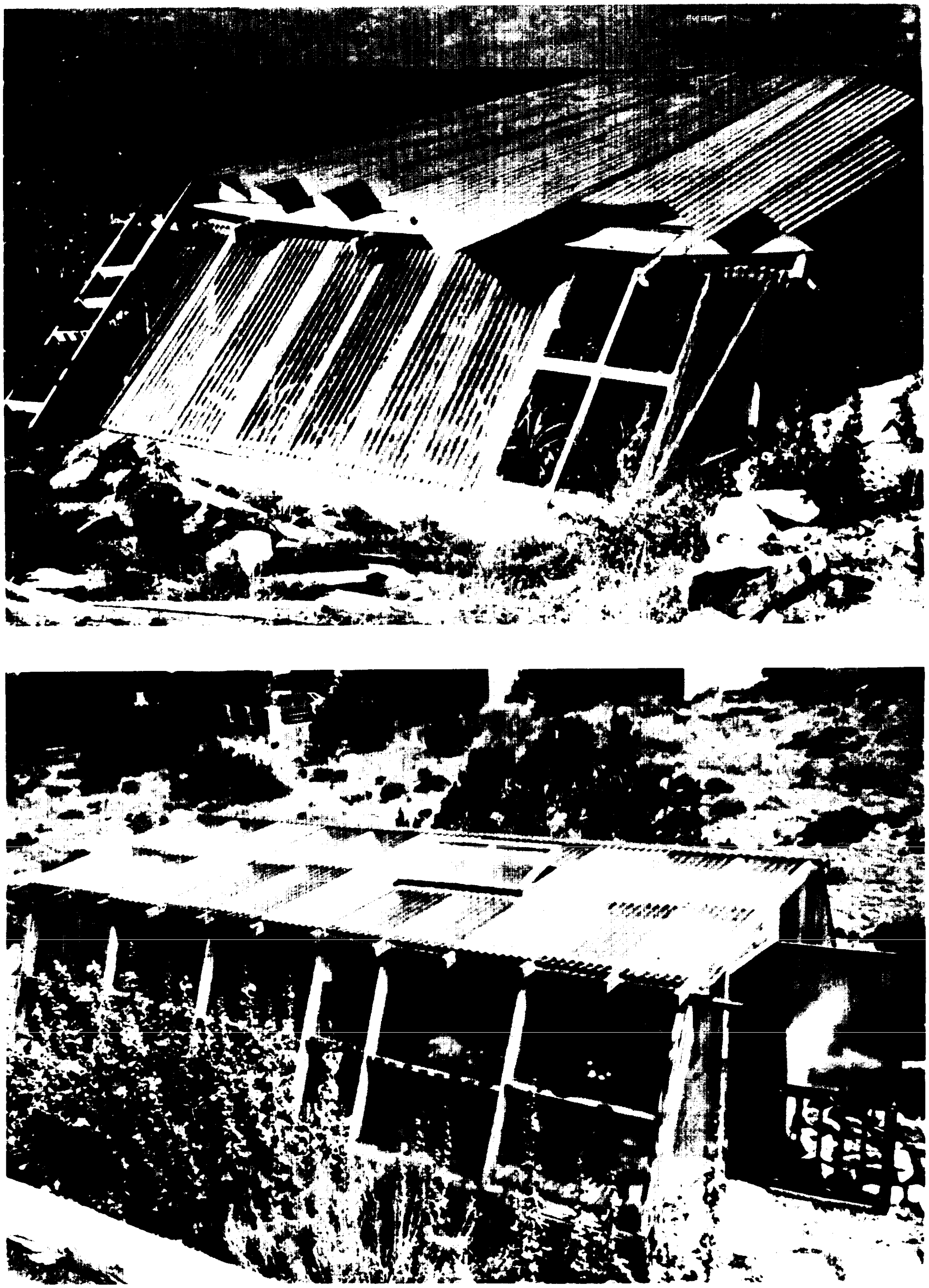
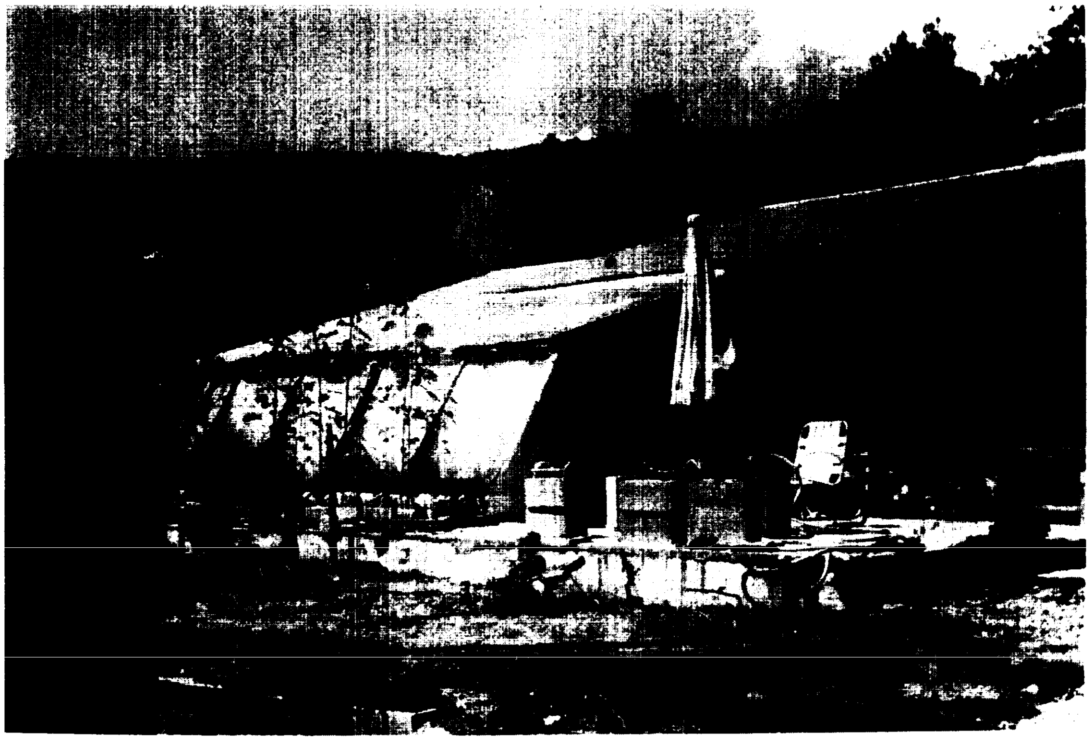


Photo credit: Office of Technology Assessment

Figure 2.—Attached New Mexico Solar Greenhouses



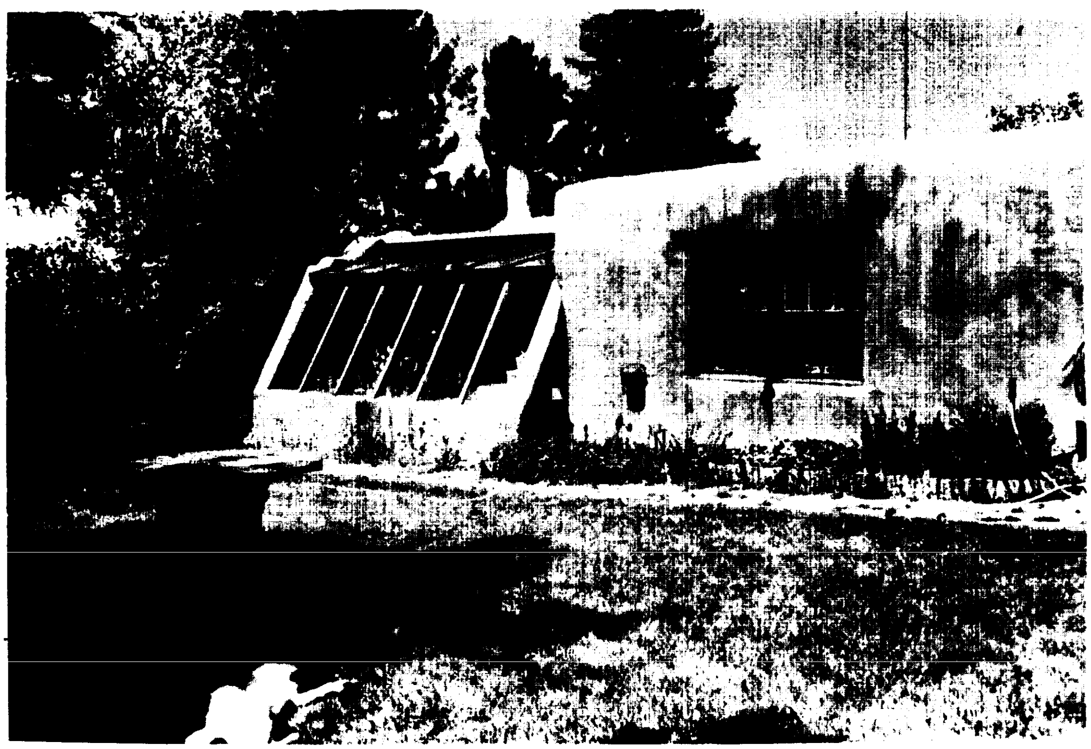


Photo credit: Office of Technology Assessment

"fine tuning" is possible; built-in heat storage requires more precise design and construction.

Existing modeling techniques are not adequate predictors of greenhouse thermal behavior, because the interaction of solar input, variable weather, greenhouse heat losses, thermal mass, and heat exchange with the main structure is so complex. Fortunately, the solar greenhouse has turned out to be a rather forgiving and adjustable technology so that relatively crude design procedures are adequate.

Solar Greenhouse Performance and Costs

The thermal performance of attached solar greenhouses as heat producers depends on a number of factors. In areas of high solar availability, such as New Mexico, adequate sunlight will regularly be captured both to charge the greenhouse storage and to provide excess heat for an attached residence. In cloudier areas, such as Ohio, the average monthly gain will still exceed losses in a well-designed and well-constructed greenhouse, but the excess energy available to the residence during December, January, and February will be small. The excess energy can be increased by reducing the thermal mass in the greenhouse, but then freezing is likely on the coldest nights. An insulating "night curtain, " which reduces nighttime losses through the glazing, can greatly enhance performance in poor solar climates.

Thermal behavior has been measured for a number of existing greenhouses, but reports of measured net energy production are not yet available. Tables 2 and 3 give the results of limited measurements of heat delivered by one attached greenhouse in New Mexico and another in Hinesberg, Vt. Table 4 presents theoretical measurements for the performance of the Hinesberg design, extrapolated to 12 major metropolitan areas.

The out-of-pocket cost of building a solar greenhouse varies greatly. In many cases the owner or workshop members volunteer their labor, and they frequently make use of salvaged materials, particularly glass. In most areas of the country, few contractors are prepared to bid on or undertake the construction of greenhouses. Typical material costs, if new materials are used, range between \$8 and \$12/ft^2 (1979 dollars) of floor area. The most important cost variables are the type and number of layers of glazing, the quantity of concrete, and the quality of wood used for the frame.

Only 19 of the 150 New Mexico greenhouse owners interviewed by OTA's community study team had enough data to perform any kind of economic analysis. Those 19 had average costs, including estimated labor costs, of between \$4 and \$17/ft^2, and they estimated their simple payback periods at between 4 and 8 years, based on fuel savings alone. However, unlike solar collectors (whose cost must be justified solely by the value of the net energy they produce), greenhouses are multipurpose devices which can pay the owners back in terms of food production and desirable living space, as well as heat energy production.

Table 2.—Chavez Greenhouse, New Mexico

Performance data

Location	Anton Chico, N. Mex.
Latitude.	35°N
Elevation.	5,000 ft
Heating dd	3,795
Percent sun winter average	70%

Greenhouse

Orientation	15° East of South
Glazed area.	420 ft^2 65°/0 wall, Slope 75° 35% roof, slope 15°
Floor area	432 ft^2 (36 x 12 (dirt floor)
Glazing material.	fiberglass outer polyethylene inner
Net transmission.	0.65 (estimated)
Thermal storage.	Nine, 55-gal water-filled drums 18" thick adobe (house) wall 36' x 9 '
cost	$2.50 ft^2 materials only (workshop constructed)

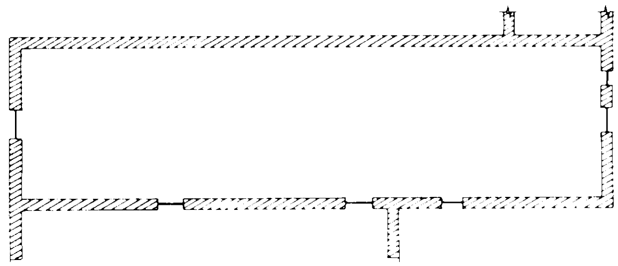
House

Type.	Adobe (no insulation)
Floor area	896 ft^2
Annual heating load. . .	51 MMBtu (estimated)
Annual internal sources.	13 MMBtu (estimated)
Net load.	13 MMBtu

Performance

Annual greenhouse load	**62** MMBtu
Solar energy captured (heating season only).	90 MMBtu
Net available energy . .	28 MMBtu
Solar fraction (whole house, supplied by greenhouse.	**0.73**

SOURCE Sandia Laboratories, "Passive Solar Buildings," report No SAND 79 0824

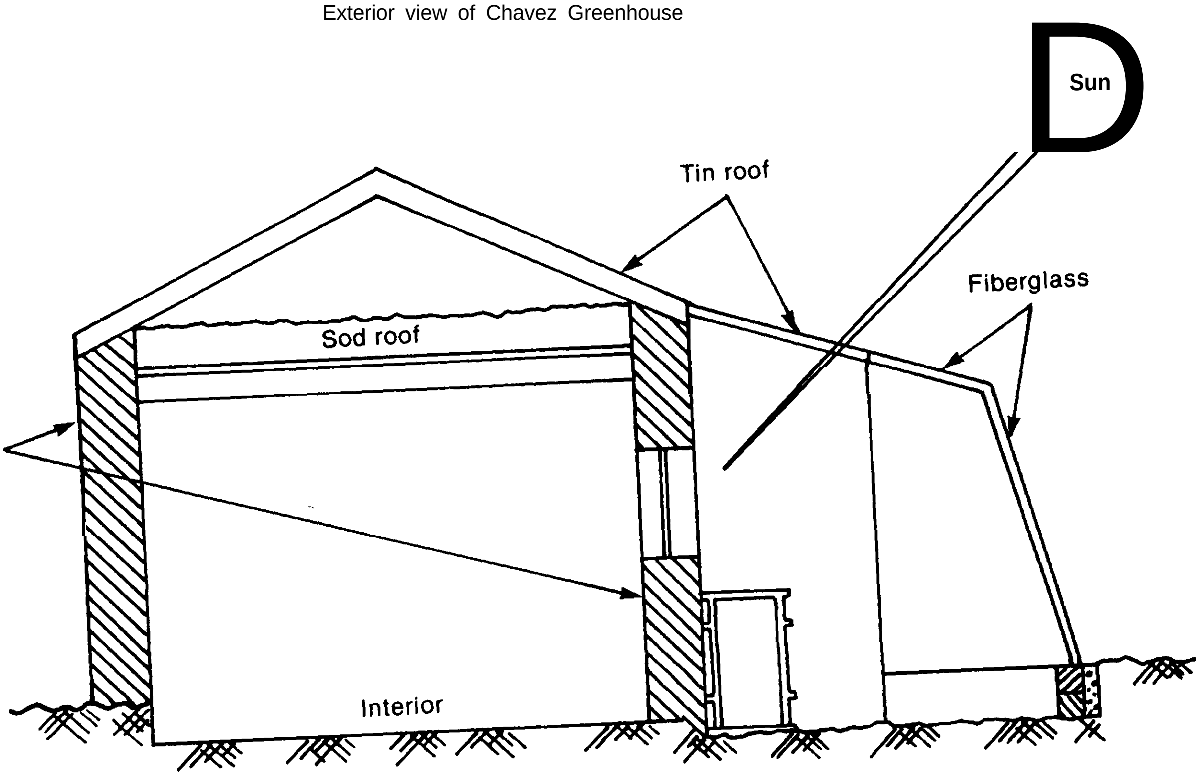


Plan of Chavez House and Greenhouse

Photo credit: Tech Repos, Inc.

Interior of Chavez Greenhouse

Exterior view of Chavez Greenhouse



Thermal Flow Diagram

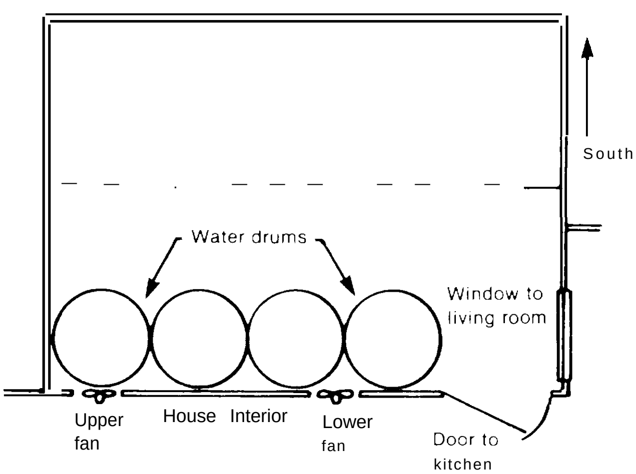
Table 3.—Hinesberg Greenhouse, Vermont

Performance data

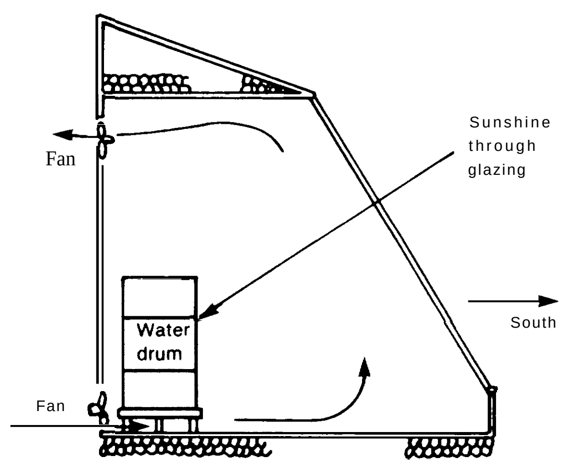
Location	Hinesberg,Vt.
Latitude	44°N
Elevation	150ft
Heating dd	8,100
Percent sun winter average	36%
Greenhouse	
Orientation	South
Glazed area	96 ft^2 wall, slope 60°
Floor area	98ft^2 (12' x8')
Glazing material	2 layers fiberglass
Thermal storage	four 55-gal water-filled drums
cost	$9.10 flt2 (1976)

House	
Type	Older, frame
Floor area	1,800 ft^2 (whole house)
Kitchen	360 ft^2 (estimated)
Kitchen load	26 MMBtu
Performance	
Greenhouse load	10 MMBtu
Solar energy captured	19 MMBtu
Net available to kitchen	9 MMBtu
Solar fraction (kitchen load, supplied by greenhouse)	**0.23**

SOURCE: Sandia Laboratories, Passive Solar Buildings, report No. SAND 79-0824.



Plan for the Hinesberg Greenhouse



Thermal Flow Diagram of the Hinesberg Greenhouse

Exterior view of Hinesberg Greenhouse

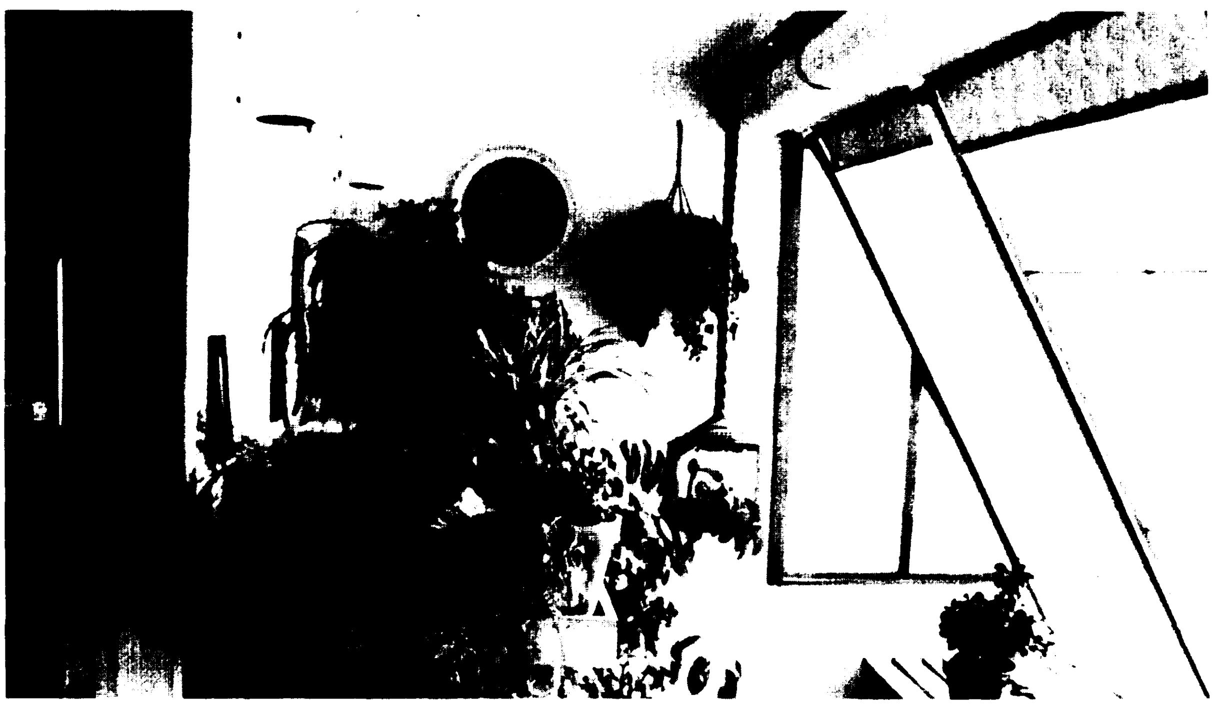


Photo credits: Office of Technology Assessment

Interior of Hinesberg Greenhouse

Table 4.—Theoretical Performance and Fuel Reduction Contributed by an Attached Solar Greenhouse in 12 U.S. Metropolitan Areas

City	Annual degree days (65° base)	Solar heat produced by greenhouses (kWh)	Heat loss[b] of greenhouse (kWh)	Ratio of heat gain to heat loss	Dwelling fuel[c] reduction (%)	Savings[d] ($)
New York, N.Y.	4,871	5,652	2,007	2.8	32.1	$324.85
Boston, Mass.	5,634	5,592	1,856	3.0	28.5	227.90
Burlington, Vt.	7,865	4,476	2,931	1.5	8.4	77.25
Philadelphia, Pa.	5,251	5,452	1,548	3.5	32.0	206.91
Baltimore, Md.	4,654	4,818	1,414	3.4	43.5	156.58
Chicago, Ill.	6,155	4,993	2,159	2.3	19.8	130.36
Springfield, Ill.	4,561	5,754	1,821	3.2	37.0	173.05
Milwaukee, Wis.	7,205	5,965	2,735	2.2	19.2	125.97
Denver, Colo.	6,283	7,897	1,996	4.0	40.3	224.24
Dayton, Ohio	5,597	4,803	2,042	2.4	21.1	99.40
Cincinnati, Ohio	4,870	5,003	1,356	3.7	32.1	124.00
Duluth, Minn.	10,000	6,809	3,968	1.7	12.2	—

aEnergy available after transmission and reflection losses subtracted.
bBased on 55° nighttime setback.
CDwelling is assumed to use 2.33 kWh/dd (base 65°). This quantity of heat is typical of an average U.S. home.
dValue of energy is based on available electrical costs during January 1976.

A Case Study of Solar Architecture-- The Cooley House, Washington, Corm.[8]

Designing and orienting buildings to take advantage of solar energy is an ancient practice. The Remans used passive solar design to warm their baths and public buildings. Native Americans built whole towns in the Southwest based on these principles.

Interest in passive solar architecture, in which solar energy is collected and stored through structural design and orientation, is growing rapidly in the United States. Four national passive solar energy conferences have been held and attended by thousands of engineers, architects, builders, and public officials. Hundreds of passive solar structures have been built during the past 5 years, ranging from the airport terminal at Aspen, Colo., to entire residential subdivisions in California, New Mexico, and Ohio. The Cooley house is one example of this emerging architectural trend.

[8]Material in this and the following case study is based on the working paper, "Energy-Efficient Architecture," prepared by Teresa Canfield and James Greenwood for the Harvard Workshop on Appropriate Technology for Community Development, Department of City and Regional Planning, Harvard University, May 15, 1979.

Development

In 1976, Ruth and Frank Cooley contacted the New Alchemy Institute of Falmouth, Mass., and asked how they could go about leading the kind of energy-conserving self-sufficient life that the New Alchemists advocate. They were referred to the Institute's architectural consultants, Solsearch Architects of Cambridge, Mass. Solsearch designed an integrated solar house for the Cooleys based on the firm's "Ark II" house (see figure 3).

The "Ark II" is a scaled-down, single-family version of the Ark, a $354,000 experiment in self-sufficient living funded by the Canadian Government. The original Ark, which opened in 1976, is intended to house, feed, and provide a livelihood for a family without dependence on outside energy sources.

The Cooleys were active participants in all aspects of the construction of their home. For 6 months they lived in a tent at the building site, where Ruth Cooley acted as the general contractor. She, four college students, and a retired carpenter did most of the carpentry, but she hired subcontractors to perform a number of specialized tasks, such as plumbing and wiring. A neighbor with 40 years of experience as a general contractor helped her to find good subcontractors at competitive prices. The Cooleys moved into their partially finished house in December of 1977, and the house was largely completed by the spring of 1979.

Integrated Solar Technology

The Cooley House has 2,500 ft^2 of living area, 700 ft^2 of which is a daylight basement. The rest is divided among three bedrooms and the main living area. The house is an example of "integrated" design, employing active as well as passive solar principles and advanced technological materials.

The entire south roof is glazed by a patented system called the "solar staircase," which is designed to admit sunlight in winter and deflect it in summer (see figure 4).[9] The system uses multiple layers of glazing: two outer layers of "Acrylite SDP;" the "staircase," which alternates polished aluminium horizontal steps with transparent vertical risers; and an inner layer of "Tedlar" film. The downward facing surfaces of the aluminium "steps" reflect heat and thus help reduce thermal losses through the roof.

Sunlight passing through the roof in winter (rays 2 and 3 in figure 4) is absorbed by the interior, and its heat transferred to the air, in the same manner as in a solar greenhouse (see above). The heated air rises and collects along the roof peak, where it is drawn into ducts by two fans and delivered into a rock bed under the floor of the main living area. The thermal storage contains 100 yd^3 of graded river rock and will store about 65,000 Btu for every 10 F in temperature change. Heat may be recovered from the storage either by radiation from the floor slab above the storage bed, or by fans that draw air through the warmed rock and into the living space. Backup heat is provided by a wood-burning stove.

In summer, as the altitude of the sun increases, the majority of the light (ray 1 in figure 4) is reflected by the aluminum "steps" of the "solar staircase." Excess heat can be vented through a louver along the north end of the roof ridge; a noticeable breeze fills the house when the louver is opened.

Performance and Costs

The major source of solar input is the glazed roof, which has an area of about 1,100 ft^2. However, the effective aperture of this "collector" is equivalent to the sum of the area of the risers, or only about 600 ft^2. This area is enhanced by double reflection from the steps, as is shown for ray 3 in figure 4. Sunlight directly penetrating the roof undergoes transmission losses through four layers of glazing; reflected light has two additional reflection losses. It is expected that an average of 50 to 60 percent of the incident radiation will enter the house.

The heat resistance of the south roof depends on the effectiveness of the reflective staircase in reducing heat losses by radiation. The projected gross heating load is about 8 $Btu/ft^2/dd$, of which solar heat is estimated to provide about 50 percent. Backup heat is provided by a wood stove; the expected auxiliary winter load is about 45 million Btu, or approximately 3 cords of firewood. At $120/cord, these costs would be under $360/yr. Average winter electricity bills are $24/me, including lights, cooking, and the heating system fans.

The Cooley house has already cost almost $81,000 to build, with the solar features (the roof and rock storage bed) accounting for about $7,000, or 9 percent of incremental costs. However, these costs do not include the value of the labor donated by the owners and other volunteers, which in the case of the Cooleys (as in several other cases studied in this chapter) was significant. The Cooleys were forced to sell about half of their 5-acre lot to raise the money that will be needed to complete the house.

Because of a change in Frank Cooley's job, the family will soon be moving to Oregon, where they hope to build a totally passive house that will allow them to become more fully self-sufficient. As they prepared to sell their present house, however, they became aware of three factors that might affect its marketability. First, it may be difficult to

‘The solar staircase was invented by Norman Saunders of the Circuit Engineers Co., Weston, Mass., who allowed the Cooleys the use of this design for $15 on condition that they document its performance. See his "The Overall Solution to Solar Heating," Proceedings of the Conference on Energy Conserving Solar Heated Greenhouses, Marlboro, Vt., Nov. 19-20, 1977, p. 39.

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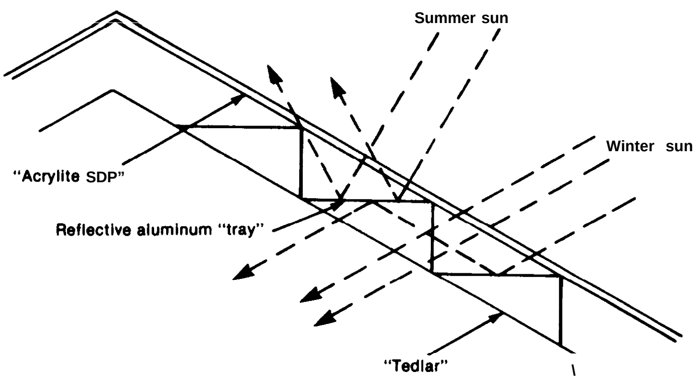
Figure 3.—Solsearch "Ark II" Low-Energy House

Figure 4.-Solar Staircase Roof



Section through the "solar staircase" roof

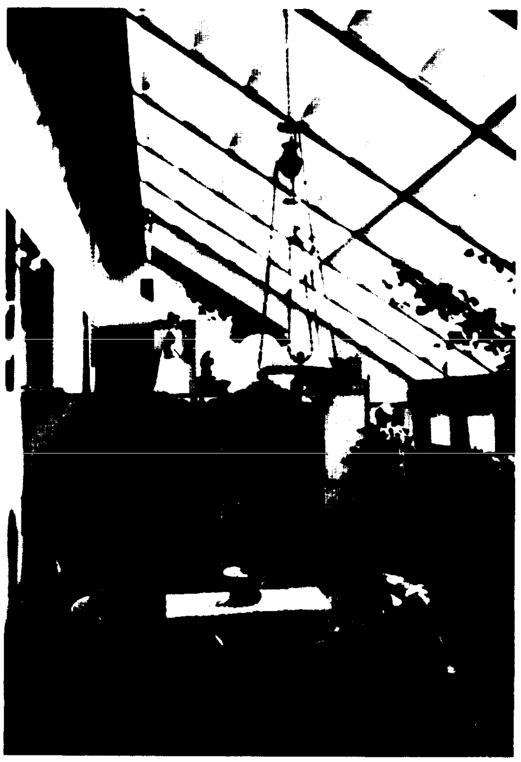


Photo credits: Office of Technology Assessment

Greenhouse interior

find a buyer (or a lender) willing to take a risk on such a new technology and an unconventional house. Second, prospective buyers may not be willing to tolerate the fluctuations in indoor temperature that are characteristic of this passive design. Third, people with enough money to buy the house may not be willing to perform the necessary operational chores, such as opening and closing vents and feeding the wood-burning stove that provides backup heat. If, for these or other reasons, the full value of the additional solar features cannot be recovered when the house is resold, the difference should properly be considered an additional cost of the house.

A Case Study of Heat= Retentive Homes (l)– The Solsearch "Conserver Home," Prince Edward Island, Canada

Development

Solsearch Architects, the designers of the Canadian "Ark" and the Cooley house in Connecticut (see above), feel that passive solar energy systems work reliably and can be built at a reasonable cost. However, although they welcome the current interest in passive solar architecture, partner Ole Hammarlund has written that solar is not the only way to go. Solar energy may have advantages in terms of the health of the occupants or the esthetics of the house, he writes, but in terms of economics it rates much lower than insulation and other conservation measures. Once a house has been designed with heat retention in mind, "there is no economic justification for [active] solar, since there is no need for any additional solar heat. "[10]

Drawing an analogy to the human body, Hammarlund points out that a person can be warmed by standing in the sunlight or by putting on a coat and relying on the retention of body heat. A house, too, has internal heat sources–people, appliances, lights, and water heater—and Hammarlund contends that with a proper "coat" of insulation the heat from these internal sources can be retained and will provide much of the space-heating needs of the house.

Solsearch developed its Conserver Home to demonstrate this principle, and to show that a design based on heat retention could produce a low-cost, resource-efficient house that would meet the needs of home buyers who want to reduce energy consumption but who cannot afford the relatively high price of more elaborate solar designs. The first two Conserver Homes were built during 1977-78 on Prince Edward Island, Canada, a region of long, cool, and cloudy winters—not an ideal location for a solar house, but a good one for a low-cost, heat-retentive house. The population is largely blue-collar and is primarily employed in mining and fishing. One Conserver Home has been occupied by a local family since September 1978; the second remains unoccupied while its interior temperature and heat loss are carefully monitored by the Canadian Institute of Man and Resources.

[10]Ole Hammarlund, "With Body Heat Who Needs Solar?" unpublished paper, 1978.

Conserver Home Technology

Table 5 shows the estimated heat energy generated by activities inside a house. "Activity" energy is released by people, lights, and appliances; a further increment of solar energy is added by south-facing windows and glass doors, even if the total

Table 5.—Daily Activity Energy for a Family of Four

People	29,000 Btu
Cooking	18,000 Btu
Motors, appliances, lights	59,500 Btu
Water heater losses	10,000 Btu
Activity total	116,500 Btu[a]
Winter average solar input	20,000 Btu[b]
Winter average total nonauxiliary heat available	136,500 Btu

aEstimates by other workers for "activity" energy range from 50,000 Btu (Illinois Lo-Cal House) to 90,000 Btu/day (P. S. Lumont's average internal energy estimate for 13 Saskatoon houses plus 29,000 Btu/day for 4 people).
b402 Btu/day/ft^2 for 86 ft^2 of south glazing.

SOURCE: Ole Hammarlund.

glazed area is no more than is commonly expected. The challenge for Solsearch was to design a cost-effective and livable home that would use these energy sources as the major source of heat without increasing the complexity or costs of construction.

The Conserver homes use "Arkansas framing," a construction technique that has been widely publicized by Owens/Corning, an insulation manufacturer.[11] This system permits 12 inches of fiberglass batting in the ceilings (R-38), 6 inches of fiberglass batting in the walls (R-19), and a continuous vapor barrier to prevent moisture and air infiltration (see figure 5). In addition, headers over doors and windows are box framed and insulated, as is the band-board. Doors are foamed-filled metal, and windows are triple-glazed on the north, east, and west and double-glazed on the south. The foundation is treated wood rather than concrete, primarily because of high concrete costs ($50/yd^3) on Prince Edward Island, and is insulated to R-10. The total glazed area in the windows and patio door is 135 ft^2, or about 9 percent of the 1,540-ft^2 floor area. (Window area equaling 10 percent of floor area is at the low end of typical current tract housing.) Of this glass area, 65 percent faces south and only 4 percent faces north.

The projected gross heating load for this home is about 5,400 Btu/dd for every 10 F temperature difference between the inside and outside, or about 3.5 Btu/ft^2/dd. Since an estimated 136,000 Btu would be generated each day by the normal activities of the residents and by solar input, these heat sources would support the heating load so long as the average temperature difference between the inside and outside of the house is less than 25^{0}F.[12] In other words, no additional space heating will be needed to maintain an average indoor temperature of600 F (650 F day, 500 F night) until the daily average outside temperature falls below about 350 F. The feasibility of the system does not require this low temperature range which was the basis for the designers' calculations: aver-

[11] Owens-Corning, Inc., "Energy Saving Homes: The Arkansas Story," 1977. Arkansas framing was developed by Henry Tschumi (HVAC Engineer), Les Blades (Arkansas Power & Light), and Frank Holtzclaw (HUD design and construction analyst).

[12] $(136,500\ \text{Btu}) \div (3.5\ \text{Btu/ft}^2/\text{dd}) \div (1,540\ \text{ft}^2) = 25.32$ dd.

Figure 5.—The Conserver Home

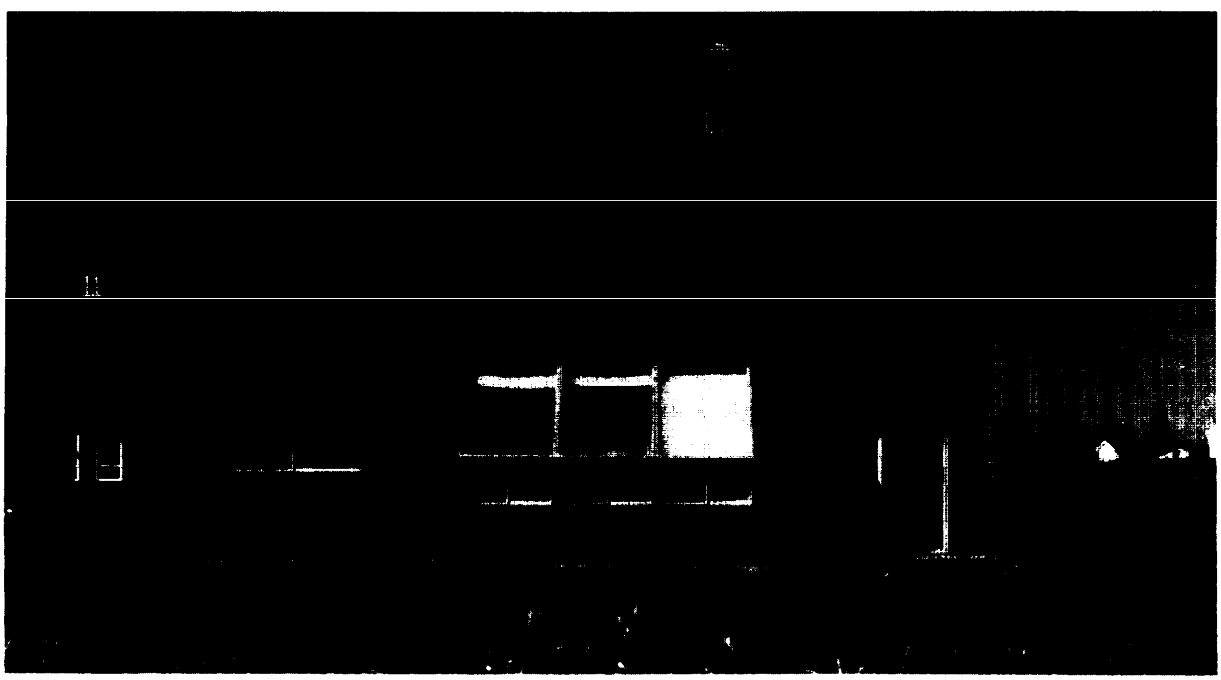


Photo credit: The Institute of** Man **and Resources, Charlottetown, P.E.I.

age indoor temperatures of650 F (700 F day, 55” F night) can be maintained without auxiliary heating when average outdoor temperatures are 400 F or above.

The house’s low rate of heat loss also means that temperature variations tend to be damped: surplus energy generated during high-activity periods (morning and evening) will be carried over into low-activity hours. The Conserver Home contains no separate furnace; instead, backup heat is provided (through a base-board hot-water system) by a conventional hot water heater. This system, combined with activity and solar inputs, is adequate to meet design heating load requirements of 15,000 Btu/hr. It will thus keep inside temperatures at 600 F even when average outside temperatures falls to – 5°F.[13]

[13] (15,000 Btu/hr) × (24 hr) ÷ (3.5 Btu/ft²/dd) ÷ (1,540 ft²) = 66.79dd.

Performance and Costs

Over the Prince Edward Island heating season of about 8,300 dd, about 50 percent of the expected space-heating load will be met by “activity” energy of the occupants and 20 percent by solar energy. The remaining energy, about 15 million Btu will be drawn from the hot water heater, which is gas-fueled in Conserver I and oil-fueled in Conserver II. At $1/gal for fuel oil, total heating season costs for the Conserver II are expected to be about $150.

Conserver I was commercially constructed and sold for $26,000 in 1978. Conserver II has been sold for $30,000. These low prices, about $17/ft², apparently reflect very economic design (including the wood foundation) and the lower labor costs in the Canadian Maritimes. Current construction costs for conventional homes in the United States range from about $30 to $50/ft².

A Case Study of Heat-Retentive Homes (II)–The Bethel House, Bethel, Alaska[14]

The Community Setting

In contrast to the scenic beauty of much of Alaska, Bethel is a drab and depressing place. Many houses are dilapidated and would be considered substandard by the criteria of the lower 48 States. The land is flat, and there is almost no vegetation. During the spring breakup, when snow and ice are melting, the entire town (except for the two paved streets) is 6 to 12 inches deep in mud. During the summer, he mud turns to dust (see figure 6). There are no roads to Bethel. Everything must be flown or barged in, and therefore everything is expensive. Milk is over $5/gal, propane $16/gal, electricity 37 cents/kWh.

Bethel offers excellent examples of inappropriate applications of housing technology from the lower 48. In villages which have been electrified, housing authorities have equipped many homes with electric stoves and central heating. Many of the houses, however, are designed for California; the cost and difficulty of heating them in the Alaska winter are enormous, and (as one resident reported)”. . . when the power fails, as it often does, the homes are uninhabitable. ” Heat leakage through the thin floors of prefab houses melts the

Figure 6.- Bethel, Alaska

Photo credit: Office of Technology Assessment

[14] Material in this case study is based on the working paper, “Energy-Efficient House Construction, ” prepared by Steven Klein and Richard DeSanti for the Harvard Workshop on Appropriate Technology for Community Development, Department of City and Regional Planning, Harvard University, May 15, 1979.

tundra and causes them to settle. Standard housing is not structurally rigid enough to withstand the forces imposed by seasonal thawing and freezing of the tundra. Thus houses rapidly become out of square, with ill-fitting doors and windows and a dilapidated appearance.

The Bethel House is the result of ongoing efforts within the local community to develop a housing technology appropriate to the resources, economy, and environmental conditions of the area.

Development

Several years ago, the Kuskokwim Community College (KCC) in Bethel began a Maintenance Technology Program. KCC's student body is largely Eskimo, and is drawn from surrounding villages as well as Bethel itself. The original purpose of the program was to train students in repair and construction skills in the context of the hunting and fishing subsistence economy that is still dominant in the villages. The design for the structure that became known as the "Bethel House" evolved over the years as the students (as part of their coursework) built several small prototype houses, which KCC then sold on the private market to recover their administrative expenses and cost of materials.

The ultimate goal of the KCC faculty is to influence the design of subsidized public housing built for Alaska natives by the State Housing Agency and the Bureau of Indian Affairs. However, they are using the private market to test, refine, and demonstrate the soundness of their design. When their latest house, called the "Mark IV" (see figure 7), is completed, they hope to build a small subdivision of houses to be sold in the private market.

In developing appropriate housing for the needs and conditions of Bethel, therefore, KCC designers have addressed five vital concerns:

1. *Energy conservation.*—Sub-zero winter temperatures, combined with the high cost of fuel oil in this remote location, make well-insulated, energy-conserving homes an economic and physical necessity.
2. *Structural* stability.—Bethel is in a permafrost tundra area, which means that a conventional foundation is impractical and that houses need to be engineered for greater solid-

Figure 7.—The "Mark IV" Bethel House

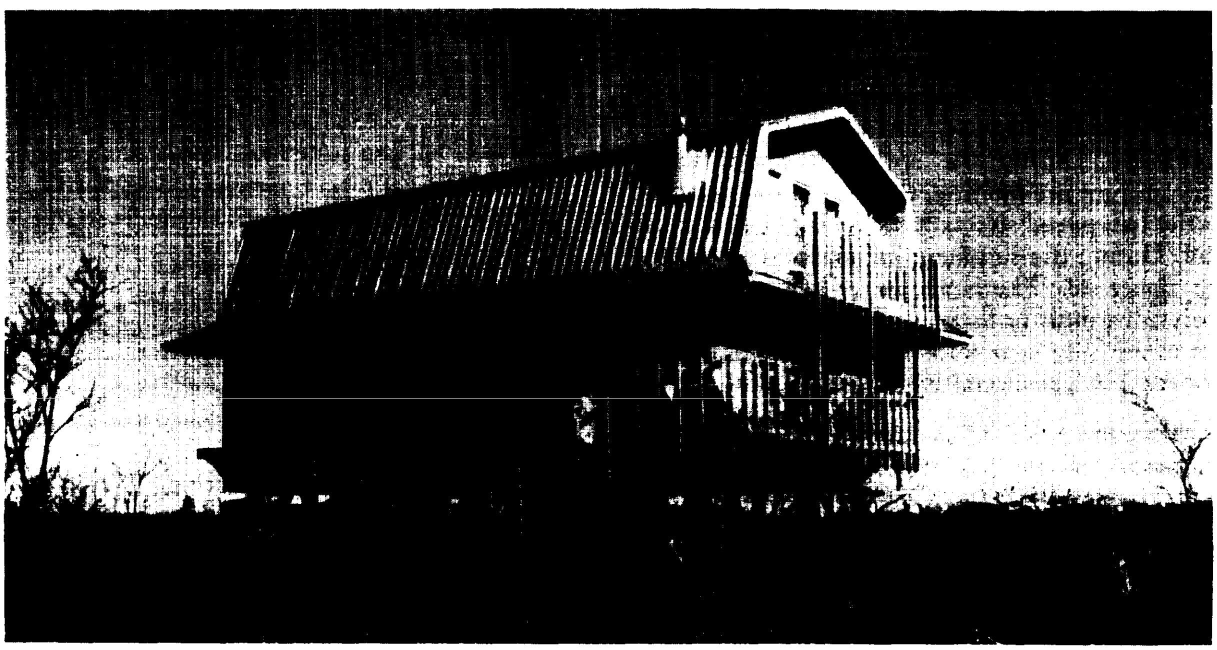


Photo credit: Office of Technology Assessment

ity. Typically, heat loss from a poorly insulated house causes the underlying tundra to melt, which in turn causes the house to shift and settle. This can cause walls to separate from floors, windows and doors to fit poorly, and air infiltration to become a major problem.

3. *Materials cost.*–Almost everything in Bethel has to be shipped in from the outside–either by plane, or, during the summer months, by barge from Seattle. This adds substantially to the cost of all products, especially bulky building materials. There is thus a need for a home design that provides improvements over existing structures without increasing the already-high cost of materials.
4. *A pleasant living environment.–Another* goal is to create a house that is roomy and pleasant, in order to alleviate some of the psychological and social pressures of life in an isolated community with few amenities and very long winters.
5. *A regional architectural style.–The* traditional native sod huts have long since disappeared, and Bethel has no typical architectural style. Buildings tend to be an assortment of designs, consisting of whatever was cheapest or easiest to build, or whatever was available from the "lower 48" in prefabricated form.

The Bethel House Technology

The three principal features of the Bethel House design (figure 8) are:

- extensive use of insulation;
- use of structural members made from plywood in many places where a conventional design would use solid wood timbers; and
- use of glue to reinforce joints and create a more solid structure than would result from the use of nails and screws alone.

In addition, KCC designers have developed a number of innovative structural features.

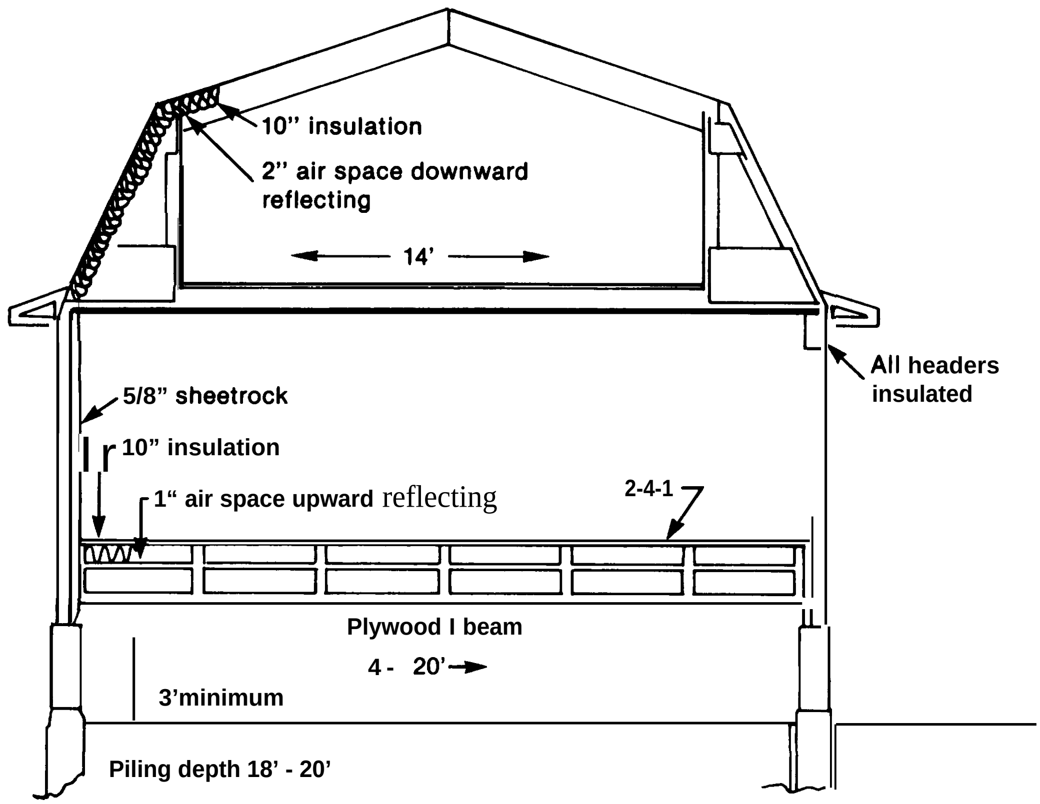
Foundation.–The house is elevated several feet above the ground on a "pad and post" assembly (figure 9), which involves placing pilings into the tundra on pads of sand. This elevated design, plus extra floor insulation, prevents heat from seeping through the floor and melting the tundra underneath the house.

Floor.–In a conventional house, solid 2- by 12-inch timbers (or "joists") spaced 16 inches apart are used to support the floor. These joists account for up to 15 percent of the floor area and account for a substantial heat loss, since solid wood is a relatively poor insulator. The KCC design substitutes a "plywood I-beam" (figure 9) for these solid wood joists. The I-beam is simply a piece of 5/8-inch thick plywood, held vertically between horizontal 2- by 4-inch "spacers" to prevent warping or twisting. Because the plywood sections of the I-beam are only 5/8-inch thick, heat loss through the floor framing is reduced. Because of its shape, the plywood I-beam is stronger than a solid wood beam; only 7 I-beams are needed, instead of 24 conventional joists. Heat loss through floor framing is reduced from 15 percent to only 2 percent, and savings are also realized on the cost of materials.

Similarly, the KCC design replaces solid wood perimeter timbers with plywood "box beams" (figure 9). The box-beams are constructed of four pieces of vertical plywood, 5/8-inch thick, sandwiched between two 2- by 4-inch spacers placed horizontally across the top and bottom. The hollow space within the box-beams can be stuffed with insulation. The result is a very strong insulated beam, which reduces the heat loss and can be constructed with materials costing about one-third as much to ship to Bethel as conventional solid beams. The system also provides a very rigid floor, which requires only 10 support posts instead of nearly 20 for a conventional floor system.

Wall-to-Floor Joint.–In a conventional house, the walls rest on top of the floor. In the KCC house, the I-beams and perimeter box-beams are joined together such that the I-beams project above the box-beams (figure 9). As a result, the walls rest on the perimeter box-beams "outside" the floor, actually extending below it. This design, which is similar to framing techniques used in the 19th century, allows the builders to anchor the walls vertically to the box-beam and horizontally to the I-beams, thereby increasing the rigidity and strength of the house. Second, it also allows them to install continuous insulation through the walls

Figure 8. Cross-Section of the Bethel House



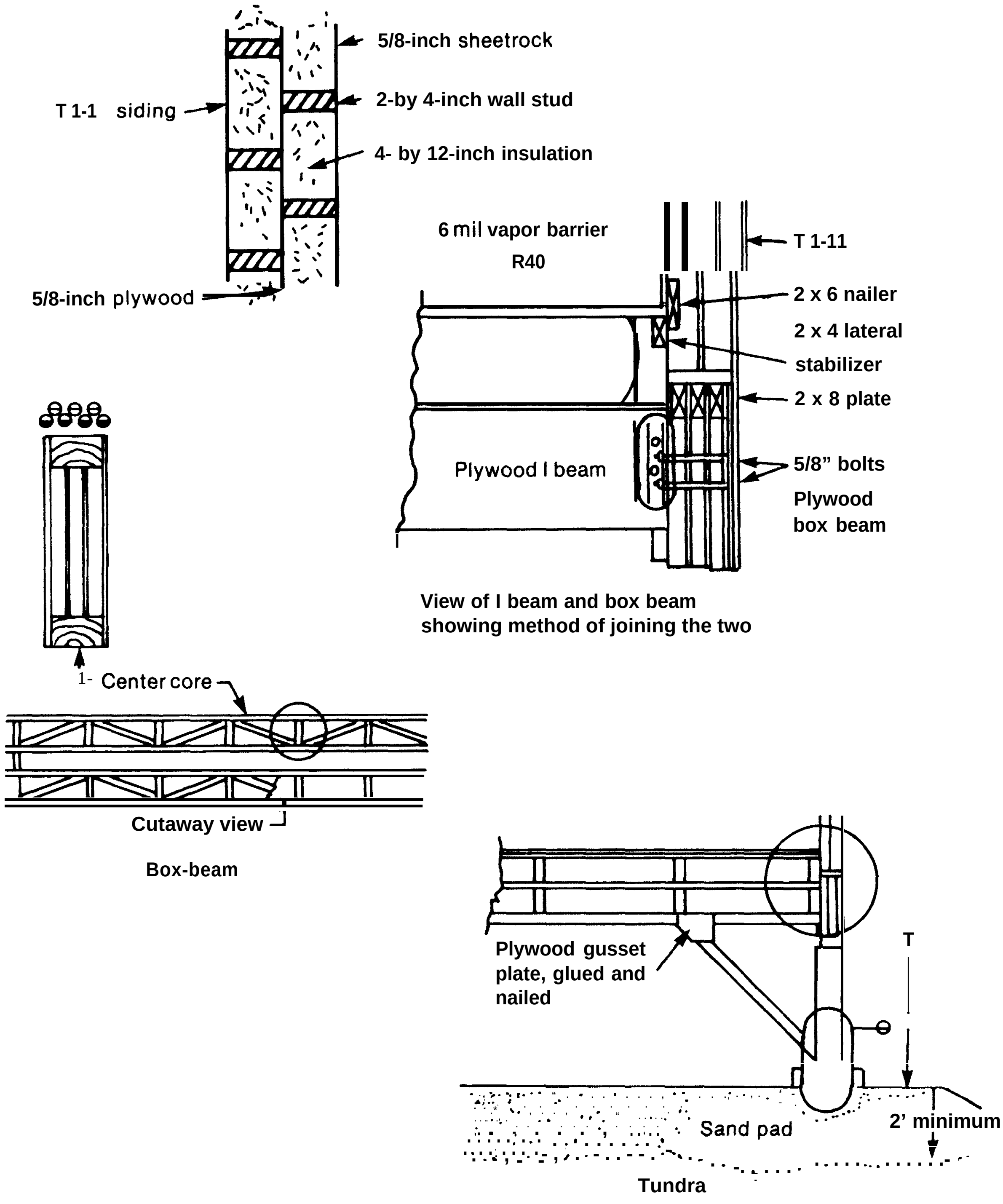
Cross-section of KCC house

and under the floor. In a conventional house, the wall insulation stops at the point of juncture with the floor. In the KCC design, where the walls extend below the floor, it is possible to pull the insulation through and continue it across the bottom of the floor in an unbroken blanket.

Walls.–KCC determined that 8-inch thick wall insulation would repay its cost through reducing heating bills in 5 years under Bethel conditions. In conventional houses, however, wall studs comprise about 15 percent of the wall area and offer solid heat-loss paths to the outside. KCC therefore employed a "double wall" construction technique (figure 9). Studs are 12 inches apart, but are staggered on either side of a central sheet of plywood. As a result, a 24-inch wide, 4-inch thick batt of insulation can be placed between the studs on the interior and exterior walls, thus achieving a total 8-inch thickness of insulation in the wall. In addition, since the studs alternate between the interior and exterior walls, there is at least 4 inches of insulation everywhere in the wall and no solid heat-loss paths to the outside.

Roof.—There are three distinctive features of KCC's roof system design. It has a gambrel, or barnlike, roofline rather than the more conventional gable. The gambrel design increases the usable space on the second story of the house in comparison to a typical gable roof, which may reduce by as much as one-fourth the habitable volume of a structure. The second distinctive feature of the KCC roof system is that the wall-to-ceiling joint (like the wall-to-floor joint) is designed so that an unbroken wrap of insulation continues up from the walls and across the roof. Third, the trusses that support the roof are designed to be

Figure 9.— Innovative Structural Details, Bethel House



View of pad-and-post assembly
for elevating the house above the tundra

partially assembled at the building site before installation, which should make them easier to install without machinery or a large number of people.

Windows and Doors.–Bethel is at latitude 60° N, which means that midwinter solar energy availability is small. However, the climate is fairly sunny and solar availability is quite good from January through May. Most of the windows are located on the south side of the Bethel House to take advantage of solar energy for lighting and heating, and are double- or triple-glazed and tightly sealed.

costs

KCC estimates that the two-story version of the Bethel House, built commercially, would cost $55,000 to $65,000. Construction is more labor intensive—time is required to fabricate building elements such as box-beams and floor framing—but less materials intensive than conventional construction. And in an economy where general costs are very high, $40/ft^2 (1977 dollars) seems hardly out of line (current construction costs in the lower 48 States are between $30 and $50/ft^2.

Clearly, however, if the Bethel House is to penetrate the Government-subsidized housing market, its costs must be brought down. The one-story Mark IV house is an attempt to do this, and KCC estimates the cost of this design can eventually be reduced to about $30,000. By comparison, recent public housing units in Bethel cost only $20,000 to build, but they suffer from all of the problems that the Bethel House is designed to avoid. As a result, they incur much higher maintenance, repair, and heating costs than the KCC design. Detailed lifecycle cost estimates would allow better economic comparison to be made between the Mark IV and the conventional alternatives.

One local builder is currently building six houses that include several–but not all–of the Bethel House principles. His modifications of the KCC design have often been intended to make it more acceptable to his native Alaskan customers, many of whom are skeptical of the kind of technological "fixes" that have been sold to them in the past. This builder may play an important role in the ultimate dissemination of the technology, since he is also the owner of the local lumber yard. He is already convinced enough of the merits of gluing joints that he automatically includes the proper amount of glue with any lumber order from a bush village, whether his customers have asked for it or not.

A Case Study of Hybrid Resource= Efficient Homes—The Tom Smith "Thermal Envelope" House[15]

Development

The original idea for Tom Smith's "thermal envelope" house came from a house in Taos, N. Mex., that was based on passive solar principles. The house was to be built from adobe with cool rooms on the north side and a heating solar greenhouse on the south, a design with strong parallels to the Indian pueblo, the original indigenous architectural style in the area.

In 1977, Smith began making plans to build his own passive solar home near Lake Tahoe in California. He designed the house with several goals in mind: it should use standard construction techniques and conventional, locally available materials; it should also be comfortable to live in, esthetically pleasing to the general homebuyer, and easy to finance through conventional mortgage borrowing; finally, the design should be adaptable to other climates. After consulting a number of experts, he arrived at a design that is now frequently called a double or thermal envelope.

Thermal Envelope Technology

The Smith house (figures 10, 11, and 12) consists of an inner and an outer structure, which share common east and west walls. The inner north wall is separated from the outer wall by

[15]Material in this case study is based on the working paper, "Energy-Efficient Architecture," prepared by Teresa Canfield and James Greenwood for the Harvard Workshop on Appropriate Technology for Community Development, Department of City and Regional Planning, Harvard University, May 15, 1979.

Figure 10.—Thermal Envelope House, Heat-Gain Cycle

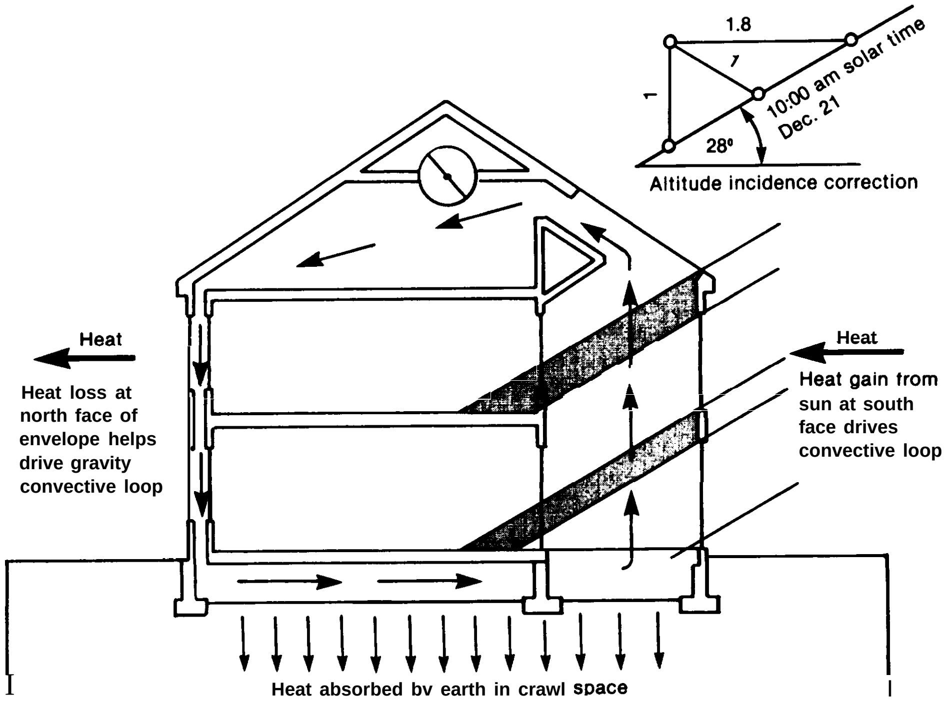


Figure II.—Thermal Envelope "House, Heat"Loss Cycle

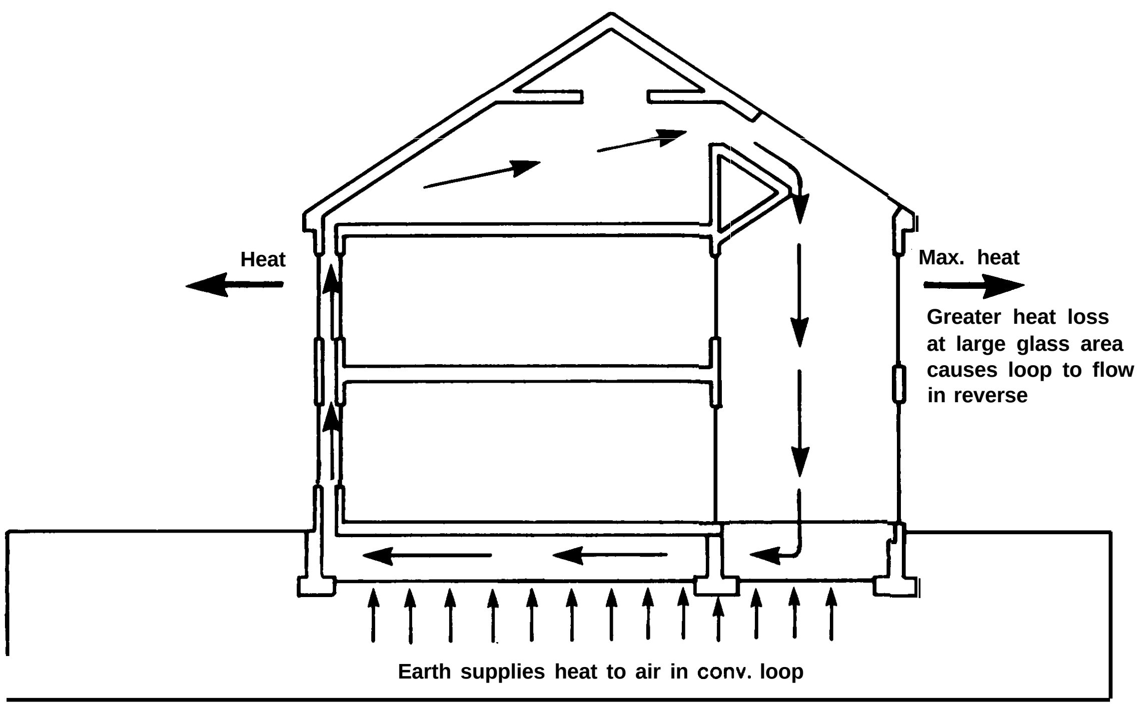
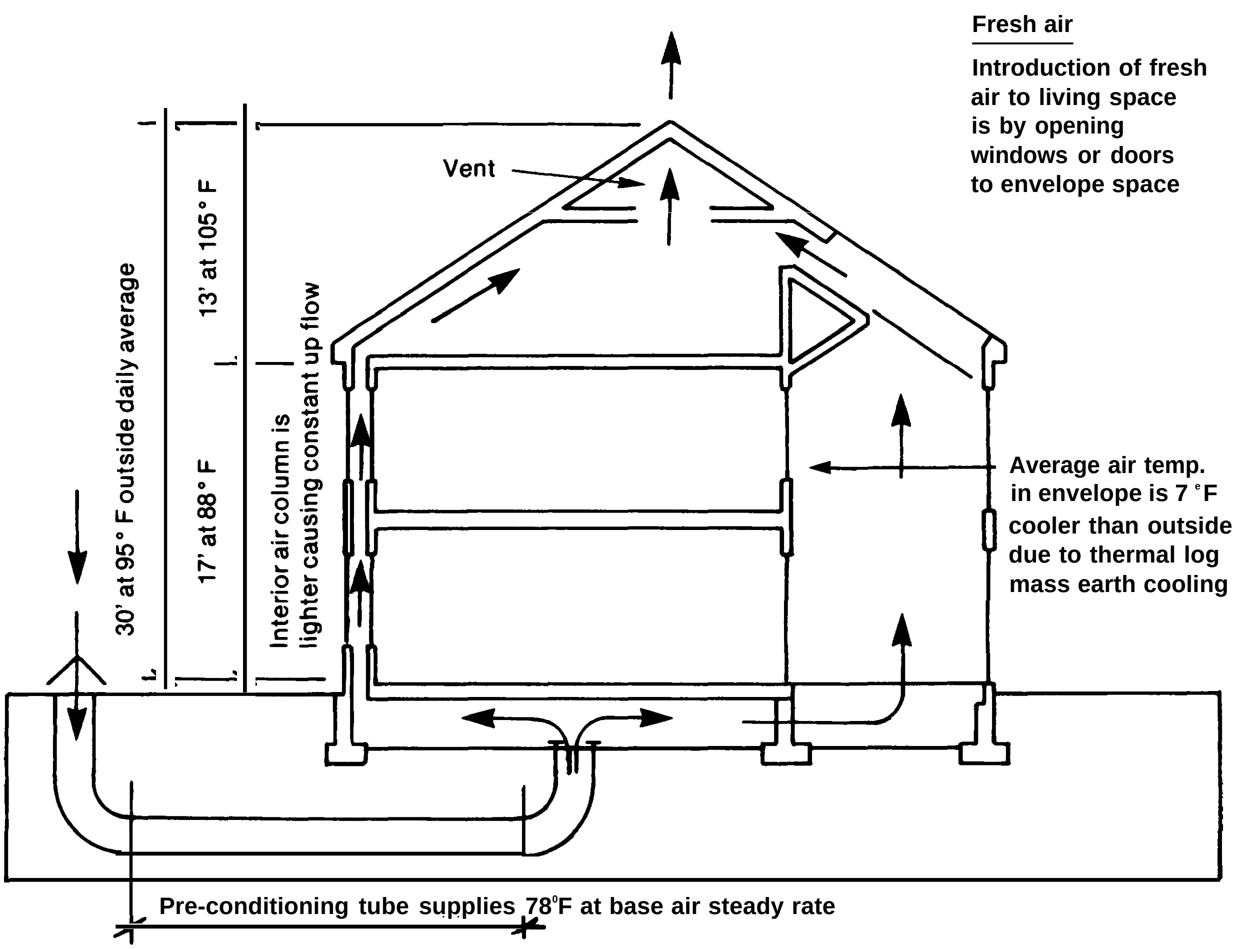


Figure 12.—Thermal Envelope House, Ventilation and Cooling Cycle



about 12 inches This gap is connected to a basement crawl space and the attic plenums, which in turn are open to the floor and ceiling of an attached greenhouse or solarium. As a result, air can pass in a large loop around the inner structure. Both the inner and outer walls of the double envelope are insulated.

The principles on which the double envelope house is designed to work are straightforward. On a sunny day (figure 10) the air in the greenhouse heats up and rises between the inner and outer ceilings, losing heat to both the outside and inside space; as its density increases due to cooling, the air flows down the north cavity and through the crawl space—where it gives additional heat to the earth—and back into the greenhouse through openings in the greenhouse floor. At night or on cold cloudy days (figure 11) when the greenhouse is cooler than the cavity spaces, a reverse cycle occurs: the coldest air gathers at the floor level of the greenhouse, flows through the crawl space where it picks up heat from the earth—and then up the north wall cavity, across the ceiling, and back into the greenhouse. (It should be noted that the greenhouse can be closed off from the inner house to limit direct cooling of the living space at night.)

As a result of these air flows, most of the inner envelope (all except the east and west walls) is buffered from the outside both by the outer shell's insulation and by the convective flows of air heated by the greenhouse or the earth storage. Summer cooling (figure 12) is also enhanced by natural convection: warm air is released through an operable vent in the ceiling plenum and vented from the attic cavity. In the Smith house, replacement air enters through open windows, in some other designs, replacement air is drawn through buried "preconditioning" tubes and the crawl space, to be cooled by the earth before entering the living space.

Performance and Costs

Ultimately, heat loss is governed by the heat resistance of the outer shell and by the temperature difference between the exterior and the air flowing between the shells. The most interesting but least understood aspect of the design is the passive heat exchange between the various elements of the design: greenhouse, living space, and crawl space thermal storage.

That the convective processes described above in fact explain the performance of Smith's or other envelope houses has been questioned. Whatever the precise operation, however, those living in the houses uniformly report very stable temperatures in the living space and very low auxiliary heat requirements, although none have been monitored consistently and few have been occupied for more than one heating season.

Tom Smith built his house in late 1977 with the least expensive materials available at a cost of approximately $\$30/ft^2$. This figure compares favorably with the average cost of \$35 to $\$37/ft^2$ for conventional new housing constructed in the Lake Tahoe area.

Discussion of Solar-Heated and Heat-Retentive Houses

Performance

Table 6 summarizes performance and cost information for a variety of passive solar, superinsulated, and hybrid houses, including several of those described in the preceding case studies. The reader should be cautioned, however, that the extent and reliability of performance data varies from house to house. The construction of such resource-efficient houses is a very recent phenomenon, and most of the houses have been occupied for less than 5 years, many for only one or two heating seasons. Consequently, although a number of them have been monitored for temperature behavior, few of them have had the kind of rigorous, detailed study that would be necessary to draw firm, experimentally verified conclusions about their precise thermal performance.

In addition, occupied houses are particularly difficult to study, largely because the behavior of the occupants has a significant effect on the thermal performance of their house. For instance, many passive designs require the residents to interact with the passive system by opening and closing windows, shutters, vents, etc., at different times in the daily heating cycle. Some owners find these to be easy and even satisfying chores, others find them inconvenient. Similarly, transferring heat into and out of the thermal storage requires a daily temperature cycle, often in the range of IO ^{0} to 200 F. Some people find this temperature cycling acceptable; others may level out the cycle by using auxiliary heating or by venting excess heat. In short, occupant behavior—the human factor—is a significant but largely unmeasured variable in the performance of many of these resource-efficient houses.

Column 5 of table 6 gives estimated values for the *gross heating loud* of the houses—the amount of heat required to maintain an average inside temperature of 60° F, assuming *no* internal "activity heat" input and *no* solar input, Many of the passive solar designs have projected loads of a magnitude similar to the "standard practice" house (typical conventional stock built after *1977).* On the other hand, heat-retentive houses have gross loads around or below the $2.5\text{-Btu/ft}^2\text{/dd}$, a widely accepted standard for energy efficiency.

Column 6 gives estimated seasonal net loads after solar and activity heat inputs have been taken into account. Column 7 presents the cost of the auxiliary fuel-based heat required by each house, adjusted for size and location. These low

Table 6.—Cost and Heating Performance of Selected Resource-Efficient Houses

House	Location	Size (ft²)	Heating degree-days	Gross load[a] (Btu/ft²/dd)	Net load[b] (Btu/ft²/dd)	Total cost[c]	Net cost of solar[d] and conservation features	Adjusted seasonal cost of auxiliary heating[e] ($/1,000 ft²/1,000 dd)
Conventional								
1. "Standard practice"	New York	1,600	6,450	11.0	8.0	$61,000 (79)	$ 0	$94.19
Passive solar								
2. Green Mountain	Royalton, Vt.	1,264	8,269	7.0	3.2	40,000 (77)	1,350	39.03
3. Hunn	Los Alamos, N. Mex.	1,955	6,300	10.0	3.2	67,000 (77)	5,400	38.97
4. Cooley	Washington, Corm.	2,500	5,840	8.0	5.0	81,000 (78)	7,000	36.99
5. Shankland	White Rock, N. Mex.	2,000	6,155	11.0	2.7	65,000 (77)	4,000	32.17
6. Mobile/Modular	Los Alamos, N. Mex.	1,090	6,000	13.0	1.2	25,000 (77)	4,000	14.68
7. Star Tannery	Star Tannery, V.I.	1,250	4,224	9.0	1.1	34,000 (77)	NA	13.64
8. Balcomb	Santa Fe, N. Mex.	2,300	5,797	7.0		80,000 (76)	12,000	9.90
9. Kelbaugh	Princeton, N.J.	1,850	4,980	7.0	0.7	55,000 (77)	8,000-10,000	9.12
Heat retentive								
10. Leger	Pepperell, Mass.	1,100	6,800		2.6	54,000 (79)	400	30.48
11. Average of 13 residences	Saskatoon, Canada	1,100-3,500	11,000	3.0	1.7	—	—	—
12. Arkansas framing	Arkansas	1,200	4,300	4.5	1.2	30,000 (76)	0	13.95
13. Conserver	P. E. I., Canada	1,536	8,300	4.0	1.0	26,000 (78)	0	13.18
Combination								
14. MASEC 27008	Eau Clair, Wis.	2,000	8,000	6.0	2.5	80,000 (80)	2,200	21.00
15. MASEC 27004	Cedar Rapids, la.	1,200	6,500	3.0	1.0	56,000 (80)	1,200	12.31
16. ZumFelde	Wauseon, Ohio	3,760	6,000	2.7	0.8	84,000 (79)	5,000	10.11
17. Saskatchewan	Regina, Canada	2,016	10,800	2.0	0.2	NA (77)	{ 4,000 cons. / 15,000 active	2.76 / 0.00
18. Northfield	Northfield, Minn.	1,800	8,250	2.3	0.1	55,000 (77)	{ 1,800 cons. / 6,000 active }	1.62

aExcluding solar and activity heat inputs.
bIncluding solar and activity heat inputs.
cTotal construction costs, excluding donated labor.
dTotal cost of special solar or conservation features, less savings due to size reduction or elimination of conventional heating system.
eSeasonal heating costs, adjusted for differences in size and climate; assumes fuel costs at $12/MMBtu, or about $1/gal for oil burned in a 70-percent efficient furnace, or about $0.04/kWh for electricity used in a resistance system.

SOURCES:
1. Department of Housing and Urban Development, "Passive Design Ideas for the Energy-Conscious Architect," National Solar Heating and Cooling Information Center. The standard-practice home is a two-story frame structure with R-13 insulation in the walls, R-19 in ceilings, double-glazed windows (21 percent of floor area), and an unheated, uninsulated basement.
2, 3 and 5-9. Sandia Laboratories, "Passive Solar Buildings," SAND report No. *79-0624,* July 1979.
4 and 13. Solsearch Architects.
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11. R. S. Dumont, H. W. Orr, C. P. Hedlin, and J. T. Makohon, "Measured Energy Consumption of a Group of Low-Energy Houses," prepublication copy, National Research Council of Canada, Division of Building Research, May 1960.
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14 and 15. Mid-American Solar Energy Complex, "Solar 80 Home Designs," 1960.
16. Dale and Paul ZumFelde, "A Passive Solar Energy House That Works," 1960. An independently designed double-envelope house similar to Tom Smith's thermal-envelope design.
17. Ft. W. Besant, R. S. Dumont, and G. Schoenau, "Saskatchewan House: 100 Percent Solar in a Severe Climate," *Solar Age,* vol. 4, No. 5, May 1979. A small (192 ft²) active solar collector is used to supply auxiliary heat.
18. David A. Robinson, "The Art of the Possible," *Solar Age, vol.* 4, No. 10, October 1979.

costs are indeed impressive and tend to confirm the occupants' claims that very little auxiliary heat is needed. If all U.S. housing required these levels of auxiliary energy, say 2 to 4 Btu/ft²/dd, U.S. residential heating energy consumption could be reduced by more than 80 percent, to only about 4 Quads/yr.

costs

Where estimates are available, column 8 of table 6 lists the incremental costs of solar and/or superinsulation features. Whenever possible, these are *net* cost figures: any savings due to reduced size or elimination of conventional heating systems have been deducted from the added cost of the solar system or extra insulation. The incremental costs are generally small and, in the case of superinsulated homes, can be almost incidental. These figures are somewhat speculative, but to the degree that they prove accurate and typical, incremental costs do not appear to be a barrier to achieving substantially improved thermal performance in new residential housing.

One of the most important implications of table 6 is that excellent thermal performance can be achieved by a wide variety of residential designs. It will not be necessary to demand drab uniformity in the name of efficiency, nor to vastly change consumer tastes concerning styles of housing, nor to plat every subdivision with an eye to protecting solar access. It would also appear that energy-efficient houses can be constructed throughout the entire price range.

Potential Problems

The following are some of the problems which have been encountered with resource-efficient structures.

Air Quality .–Indoor air quality is a matter of increasing general concern.[16] Very tight houses like the heat-retentive homes listed in table 6 have measured infiltration rates as low as 0.05 air changes per hour under conditions in which conventional houses would have about 1 air change per hour. Low air-exchange rates allow buildups of nitric oxides and carbon monoxides from a gas stove, radon from masonry, formaldehyde from furniture and plywood products, and carcinogens from cigarette smoke or other sources. Humidity can also build up to the point where condensation becomes a problem. To cope with air quality problems without losing heat, air-to-air heat exchangers are being installed (e.g., in the Leger house, Saskatchewan house, and Northfield house) which can recuperate up to 80 percent of the heat in outgoing air. A small residential heat exchanger can be built for $150 or bought (from a Japanese company) for under $250.[17]

[16] J. L. Repace and A. H. Lowrey, "Indoor Air Pollution, Tobacco Smoke and Public Health," *Science*, vol. 208, May 2, 1980, p. 464.
[17] C. Conley, "Clearing the Air: Air to Air Heat Exchangers in Energy Efficient Houses," *Soft Energy Notes*, February 1980, p. 25.

Temperature Control.–Passive structures, particularly direct-gain designs, often exhibit rather large daily temperature swings, often as high as 20° F. Because the living space is the solar collector and often the thermal storage as well, control is sometimes difficult and may demand considerable attention from the occupants. Indirect-gain structures (Trombe walls, greenhouses, etc.) have fewer problems with temperature control. Superinsulated homes have a relatively low mass and therefore are sensitive to sudden increments of energy. A south window area of only 100 ft^2 on the Leger house is large enough to cause overheating on sunny days. A gathering of people will rapidly raise room temperatures, and small operable window areas may not provide adequate natural ventilation.

Internal Light Levels.—South-facing windows on passive solar houses may make the interior painfully bright on sunny days, particularly in winter with snow on the ground. Fading of colored furniture and cloth is sometimes a problem. Direct-gain designs are more often subject to this problem than other passive designs. Conversely, reducing total window area to reduce heat losses in superinsulated homes, or reducing glazed areas on walls other than south in many solar homes, may make north rooms dark and unattractive. Good architectural design is needed to deal with this problem.

Livability.–Livability is a matter of taste and lifestyles, so hard and fast statements are not appropriate. However, the open floorplan characteristic of many passive designs, which permits natural air circulation and light penetration, also permits sound and odor diffusion. As mentioned above, system operation and temperature cycling are acceptable to some people but not to others.

Maintenance. —Few maintenance problems have been reported, but most of these homes are less than 5 years old, and some future problem areas seem possible. If transparent glazing is used, the large glazed areas will require cleaning. The greenhouse in the Zumfelde home, for example, is glazed with insulated glass panels covering an area 13 ft high by 40 ft long, and additional windows separate the greenhouse from the living space. Maintaining a clear view in such a house might require a considerable effort. In the longer term, ultraviolet radiation will eventually darken and weaken plastic glazing. Accidental breakage and vandalism are also potential problems. Very strong glazing materials such as polycarbonates are available but are also quite expensive.

Safety. -In addition to the indoor air quality problems already mentioned, fire safety may be a potential problem in thermal envelope designs. Some fire codes require fireproof dampers that will close off the north wall or ceiling cavities in case of fire. Large expanses of glass, particularly when placed high above the living space, can also become a hazard to the occupants. Tempered glass should be used in these situations.

Critical Factors

Public Perception and Participation

The two approaches to improved residential energy efficiency that have been discussed in this chapter—solar greenhouse retrofits and the construction of new passive solar or heat-retentive houses–are both highly decentralized. Most new home construction is done by small businesses operating only in their local area, and the average builder produces fewer than 20 units per year. Solar greenhouse construction has been accomplished largely by do-it-yourself or by "barn raising" workshops involving neighbors and friends. Both instances reveal the virtues as well as the limitations of decentralization, one of the major criteria of appropriate technology.

Home builders, whether they work under contract with the new owner or work on speculation, must serve the perceived needs, tastes, and budgets of the prospective buyers. "Spec" housing in particular must be as low-risk as possible, and the current high interest rates make rapid turnover critical. As a result, spec housing (which represents well over half of all U.S. housing starts) is not the place to experiment with new designs and features whose marketability is not yet proven. The vast majority of resource-efficient houses are custom-built for their owners.

It is to be expected that innovative energy-efficient architecture will penetrate the custom market first: risks to the builder are reduced, and the owner tends to be well-educated, aware of the available technologies, and relatively affluent. Penetration of the speculative housing market, depends on three interrelated factors:

- public awareness and acceptance of new resource-efficient designs and construction practices, insofar as they affect a house's appearance, thermal behavior, operation, first costs, financing, and marketability;
- builder awareness and acceptance and the rate at which information about and experience with new designs and practices can be disseminated (see below); and
- the degree of standardization that can be achieve-d in the designs and materials, which will reduce or eliminate the need for special architectural and engineering services.

Public acceptance occurs in two stages: first interest and awareness, then confidence and demand. The first stage has come relatively easily in the case of solar energy. As one prominent solar builder has noted, "Anybody who has participated in the early solar demonstration programs knows the wonder of opening the door . . . and seeing thousands of visitors heading down the walk. " However, he adds, the question is "when will these lookers become buyers?"[18] Marketability is also a concern for the owner/builders of existing resource-efficient houses, as demonstrated in the case study of the Cooley house.

The construction of solar greenhouse retrofits, on the other hand, has been largely outside the commercial market and mainly by owners or volunteer workshops. Awareness and interest have been generated by word of mouth, newspaper and

[18] Wayne D. Nichols, "Marketing the Passive Solar Home," Proceedings *of* the *2d* National *Passive Solar* Conference, Philadelphia, Pa., Mar. 16-18, 1978, p. 704.

magazine articles, and a few nationally distributed books.[19] The influence of demonstration projects on public perception and demand is marked. In New Mexico, says Bill Yanda, "For every workshop, 10 more greenhouses were built in the community." In Yellow Springs, Ohio, a community of about 5,000 people, a greenhouse was constructed by a workshop in the summer of 1978; as of spring 1980 there were seven other attached greenhouses in the community, all owner or workshop constructed. Because there is little formal marketing of the greenhouse idea, the critical factor in public awareness is a sufficient number and distribution of these local demonstration projects, so that a large number of people can become aware of the idea through direct observation and through the experience of their neighbors. Workshop participation also builds confidence and encourages people to move from "lookers" to "builders."

Finally, many people who are aware of the technology are not interested in the do-it-yourself approach. This would appear to create an opportunity for commercial construction, but the home improvement industry does not as yet appear to be aware of this opportunity—or to be technically prepared to undertake solar greenhouse retrofits. In addition, while economic payback may not be the most important criterion in the eyes of some do-it-yourself builders, commercial participation will require better economic and performance analysis than is currently available.

Essential Resources

The resources required to apply these energy-conserving technologies vary widely from house to house, according to the type and size of the structure. These resources include a building site, standard building materials, a few special solar materials, and labor.

Most solar installations work best on a generally southfacing site with relatively unobstructed direct sunlight. This does not limit their applicability to low-density suburban and rural areas, however; many opportunities exist for attached solar greenhouses and other retrofits on high-density urban housing. In addition, solar designs perform best in areas with high sunlight availability, which makes them more appropriate to a location with sunny winters like New Mexico (average solar availability 70 percent in January) than to an area with cloudy winters like Prince Edward Island or Ohio (25 to 35 percent availability).[20] In the latter locations, the greenhouse or glazed area would have to be larger (and more expensive) to give the same benefits. On the other hand, the heat-retentive designs in table 5 could be cost-effective under these conditions.

Most of the building materials for the houses described in the case studies were standard supplies, available at the local lumber yard or construction supply store. One of the goals of the Bethel House designers was to conserve materials in an area where all supplies are expensive. They did this by using plywood instead of solid wood and by making use of scrap wood where possible. Solar greenhouse builders in New Mexico also kept materials cost low by using salvaged glass and lumber when they were available, and Tom Smith made a point of using the cheapest materials possible in building his thermal-envelope house. Similarly, Solsearch Architects built their low-cost Conserver Home with as few special design features as possible. Some of the more elaborate passive solar and double-envelope designs do require specialized materials that may not be readily or cheaply available, such as glazing materials and ventilating fans.

Most of the labor required for construction was unskilled or semiskilled, and building contractors or subcontractors are generally available for skilled items such as plumbing and electrical wiring. The barn-raising approach of the New Mexico workshops was an effective way of developing the necessary local skill base, as well as a way to finish most of an attached greenhouse in a single weekend. This approach is less appropriate to the larger projects, however, but in some cases the owners provided a significant amount of labor—the Cooleys, for instance, lived in a tent on the construction site for 6 months, and were still working

[19] James McCullagh, ed., *The Solar Greenhouse Book* (Emmaus, Pa.: Rodale Press, 1978); and Rick Fisher and Bill Yanda, The Food *and* Heat Producing *Solar* Greenhouse (Sante Fe, N. Mex.: John Muir Publications, 1976, rev. ed. 1980).

[20] Paul S. Hoover and Phil Schneider, "Solar Availability in Ohio," AT, the Ohio Appropriate *Technology Bulletin*, vol. 1, No. 2, May 1980, p. 7., table 2.

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on their house almost 2 years after it was first begun. In addition, an increasing number of small contractors (like the local builder in Bethel) are mastering the construction techniques required by these solar and heat-retaining designs, which primarily require careful attention to details rather than unusual technical skills.

Technical Information and Expertise

General information on passive solar energy and solar greenhouses is available from Federal agencies like the National Solar Heating and Cooling Information Center, from State solar offices and regional centers, and from private organizations and publications such as Rodale Press, The International Solar Energy Society, *Alternative Sources of Energy,* Mother *Earth News,* and the Center for Renewable Resources. Most public libraries can also provide solar literature. If anything, the problem is selecting relevant sources of information from a very large and diverse pool.

However, *specific information* directly applicable to a particular locale, site, and design problem is not always easy to obtain. Much of the available information is national in scope or orientation, and too general to be of help to a builder or owner making vital design or construction decisions for a particular job. The lack of specific local microclimate information is a good example: it is desirable in most (but not all) areas of Ohio to orient glazing 15 to 20 degrees east of south, rather than due south, because winter mornings are clear more often than afternoons and because the prevailing winds are from the southwest. This sort of site-specific information is not readily available in many areas, although regional organizations like the Tennessee Valley Authority and the Mid-American Solar Energy Complex are developing designs that take advantage of local climatic conditions. KCC's Bethel House development is a good example of a design that is appropriate to local conditions; it and the other heat-retentive houses are less dependent on microclimate conditions than the solar designs.

Local demonstration projects have proven to be an effective means of disseminating technical information, since they give builders as well as buyers a chance to see that resource-efficient designs can work under local conditions. As in the Bethel case, some aspects of the demonstration design will be adopted by others in the same locality even though the entire design may not be. Arkansas framing, for example, is becoming common in the Midwest, due in part to the demonstration and publicity program of Owens/Corning. Similarly, more than 50 heat-retentive houses were privately constructed during 1978-79 in the Saskatoon area using principles developed and demonstrated at the Saskatchewan House.

As already noted, dissemination of solar greenhouse know-now and skills has been accomplished by a workshop process. In both design and construction workshops, the orientation is do-it-yourself and the information conveyed is very practical. However, as a means of transmitting technical information and expertise, the workshop approach is limited by a number of factors:

- The number of participants must be kept small (about 15 maximum for a construction workshop) to ensure safety and to give everyone a chance to participate.
- Management skills needed to organize, publicize, and supervise a workshop are considerable. If this effort were not voluntary, it might be cheaper to construct the greenhouse professionally.
- The programs do not always include follow-up, so the people participating in the workshop do not have continuing access to the expertise of those brought in to run the workshop.
- Only a limited number of people are interested in and prepared for undertaking solar greenhouse construction as a do-it-yourself or community project. Transfer of knowledge and skills to the private home-improvement sector may be necessary if these designs are to be adopted on a widespread basis.

In a few cases access to information or a technology is limited by proprietary interests, as with Norman Saunders' "solar staircase" roof. However, the ideas behind these systems are simple enough, and are discussed widely enough in the literature, that most architects and many builders should find no difficulty in producing similar designs of their own.

Financing

Skepticism regarding the workability, efficiency, and acceptability of passive solar homes often leads to problems in acquiring financing from local lenders, for owners and speculative builders alike. The Cooleys had difficulty obtaining a construction loan, and the Bethel House was possible only because KCC was willing to "loan" the funds needed for construction until the house could be sold. Obtaining a loan sometimes means that the lender just be educated or that the builder must accept design compromises, such as a conventional backup heating system that may increase building costs substantially and unnecessarily.

Single-family homes are financed primarily through local banks or savings and loan associations. There are some 23,000 lending institutions, so the task of educating lenders is considerable. The lenders tend to be risk-averse, and the appraisers who estimate sale values for them also tend to be conservative regarding the marketability of most innovations. These factors can pose a substantial barrier to the financing and diffusion of resource-efficient housing, and one housing developer notes that his first solar development "would never have happened if we had not been able to do the design, the financing, the land development, and the construction ourselves."[21]

Economic assessment of passive solar and heat-retentive houses is also difficult because their actual heating performance depends on uncertain and indeterminant factors such as weather, internal heat gains, and occupant behavior. Long-term *average* performance may be predictable, but potential owners and lenders are also concerned about day-to-day liveability. Similarly, the lifecycle analysis may be impressive, but lifecycle costing involves many uncertainties and is generally more important to society as a whole than to individual purchasers, lenders, or buyers.[22] The builder loses interest in the house when it is sold, the average purchaser moves within 5 years, and owners and lenders alike are more concerned about preserving equity and meeting monthly payments.

[21]Nichols, Op. cit., p. 706.

[22]M. A. Thayer, D. Brunton, and S. A. Nell, "Solar Economic Analysis: An Alternative Approach," Proceedings *of the 4th National Passive Solar* Conference, Kansas City, Me., Oct. 3-5, 1979, p. 241.

For the middle- and upper-income populations who are the major purchasers of new single family housing, energy costs of new conventional homes are a small part (10 to 15 percent) of the cost of home ownership. Thus, while low energy costs for passive and superinsulated homes have received attention and publicity, economic incentives may not be the only factor in decisions of current builders and purchasers. Noneconomic factors, such as achieving greater energy independence and security, concern about the environment, and the desire to innovate, also seem to play an important role.[23]

It is equally difficult to assess the economics of attached solar greenhouses. At least three potential benefits of this retrofit must be considered: added living space, food or flower production, and net heat energy production. Food production depends critically on the skills and attention of the gardener (see ch. 4), but limited analysis of the New Mexico greenhouses found construction costs in the range of $4 to $ 17/ft^2 and simple paybacks (in terms of heat and food production) of 4 to 8 years. In terms of heat production alone, the performance of the Hinesburg greenhouse, when extrapolated to 12 U.S. cities, shows a wide variation in fuel savings (see tables 3 and 4). This illustrates the difficulty of making generalizations about feasibility and points up the need for site-specific economic assessment, the lack of site-specific microclimate data (see above) may also be a barrier to commercial interest in solar greenhouse retrofits.

Institutional Factors

Other potential barriers to the diffusion and adoption of these resource-efficient housing technologies may arise from the patent system, the building industry, utility companies, and building and fire codes. Some of the designs, like the "solar staircase," are patented, although the owner of that patent allowed the Cooleys to use the design for a $15 fee if they would monitor its performance. David Bergmark of Solsearch Architects has indicated that low-energy house designers do not

[23]R. W. Gilmer, The *Social Control of* Energy: A *Case for the Promise of* Decentralized *Solar* Technology (Oakridge, Term.: Institute for EnergyAnalysis, March 1979).

always cooperate with one another in the exchange and improvement of concepts and designs.

Several of the designers have approached the builders of low-cost and tract housing about their designs, although with less success than in the Bethel case study. They attribute this lack of interest to the unfamiliarity of the technologies and the builders' aversion to risk.

A final barrier may arise from building and fire codes. In some of the case studies the local codes required electrical wiring installations that would reduce the depth of the insulation behind the outlet. Two owners wanted to install a Clivus Multrum comporting toilet, but code requirements forced them to build conventional septic tanks and drain fields. In other cases local codes forced the builders to enlarge the windows on the east, west, and north walls, or limited their use of glass panels on the roof. The double-envelope design raised concern because the free circulation of air around the structure might allow a fire to spread more rapidly. The designers believe they can remove this potential hazard by installing heat-activated dampers that will block air circulation in the event of fire.

Federal Policy

Background

Unlike some of the technologies studied in other chapters of this assessment, small-scale technologies for residential energy conservation enjoy widespread attention from the Federal Government. Congressional interest in solar and conservation programs can be found in a number of Acts, dating from 1973 to the present.

The Solar Energy Research, Development, and Demonstration Act of 1974 (Public Law 93-473) is the principal legislation authorizing broad-based solar energy research programs. The Solar Heating and Cooling Demonstration Act of 1974 (Public Law 93-409) calls for the commercial demonstration of solar heating and cooling systems; the Rural Development Act of 1972 (Public Law 92-419) authorizes a program of low-cost loans for energy-efficient retrofits and new housing; and the National Energy Act of 1978 (Public Law 95-618) provides purchaser tax credits for the home installation of solar devices as well as a loan program for solar devices through the Federal National Mortgage Association. Related legislation includes the Energy Policy and Conservation Act of 1975 (Public Law 94-163), which calls for the establishment of building energy efficiency standards and creates the Residential Conservation Service and Federal Energy Management Program. Other laws provide incentives to small businesses and farmers, encourage international programs, and mandate the use of solar equipment in military construction.[24]

In JuIy 1977, on the basis of these and other Acts, President Carter issued Executive Order No. 12003, setting forth energy performance standards for federally owned buildings. The order also calls for the development of a method for estimating and comparing the lifecycle capital and operating costs of Federal buildings, including residential.

Current Federal Programs for Residential Energy Conservation

The policies and programs mandated by existing legislation have been implemented by several Federal agencies in a large number of programs affecting resource-efficient architecture. The following discussion illustrates the scope and variety of these activities.

The Department of Energy (DOE), as the designated lead agency in these efforts, is involved not only in research, development, and demonstration programs, but also manages several different programs of technical assistance and information dissemination, as well as funding grants programs and providing much of the "pass through" funding for the programs of other Federal agencies. DOE is also responsible, under the Energy Conservation

2+ *Residential Energy* Conservation, op. cit., pp. 64-65.

and Production Act of 1976 (Public Law 94-385), for establishing and promulgating Building Energy Performance Standards (BEPS). The BEPS program has become the subject of some controversy, however, and the standards—which were to have been announced in August 1980 and included in State and local building codes by August 1981–have been delayed. Some of the objections to the BEPS program will be raised in the discussion of issues and options, below.

The residential energy-efficiency programs of the Department of Housing and Urban Development (HUD), like those of the Community Services Administration (see the section on Federal policy in ch. 4), emphasize self-help projects at the neighborhood level. One of HUD's major programs is its household counseling service, which provides conservation and other information through a network of 600 local community groups. Some of HUD's building energy-efficiency programs have been transferred to DOE, but one official at HUD's Office of Energy Conservation has suggested that technologies like those discussed in this chapter would fare better if DOE concentrated on R&D and HUD on financing and application. She points out that there is still some feeling at the Federal level that small-scale conservation technologies cannot have a large impact on the Nation's energy problems, and that the technologies might be adopted more rapidly if a greater portion of Federal funds went straight to the neighborhoods or if local groups were allowed a larger role in project planning.[25] In addition, around 400 VISTA volunteers are working on 90 energy-related projects nationwide, and an official says that VISTA hopes to raise the number to 1,000 volunteers in 1980.[26]

With pass-through funding from DOE, the U.S. Department of Agriculture (USDA) supports several research programs designed to promote the adoption and application of small-scale technologies. USDA, through the Farmers Home Administration (FmHA), also makes available low-cost loans for energy-efficient retrofits and new construction. USDA officials claim that their departments' energy standards for new rural housing are the strictest in the Federal Government, and in 1979 the FmHA loan programs provided for almost 175,000 new rural housing units. FmHA is also developing a "home energy indexing system" designed to "rate the energy efficiency of heating and cooling systems and construction features of specific house plans."[27] (Further discussion of the farm and rural energy programs of USDA will be found at the end of ch. 5.)

The Department of Defense (DOD), under its Energy Conservation Investment Program, has embarked on an ambitious program to retrofit existing military buildings (including residential) with solar energy systems and to include these systems in the designs of new buildings. The Military Construction Act of 1980 (Public Law 96-125) requires that DOD analyze all new family housing to determine whether solar designs would be cost effective, and, if so, to install or incorporate the systems. DOD is responsible for 400,000 housing units worldwide.

The Federal Home Loan Bank Board, the regulatory agency for the Nation's 4,400 savings and loan associations, is actively encouraging those associations to include energy-efficiency requirements in their home loan programs. There is no legislative mandate for these efforts, which the board has undertaken out of its concern for the national energy situation. In the past year it has conducted four workshops for local associations, providing technical and economic information on solar retrofits and solar systems for new housing and publicizing the different energy-efficiency standards that have already been adopted by *some* associations.

Issues and Options

The existing Federal programs for residential energy conservation, though extensive, have been variously criticized as misdirected, uncoordinated, or ineffective. The issues raised by these criticisms, as they relate to the technologies discussed in the case studies, fall into four related areas:

- program priorities and coordination;
- R&D;

[25] Gloria Cousar, Director, Office of Energy Conservation, HUD, personal communication, Aug. 15, 1980.
[26] Jack Colburn, VISTA, personal communication, August 1980.
[27] Donald L. Van Dyne, Policy Analyst, USDA, personal communication, and his presentation to the Northeast Agricultural Marketing Committee, Sturbridge, Mass., June 19, 1980.

- demonstration and information dissemination; and
- financing.

ISSUE 1:
Program Priorities and Coordination.

A number of studies, including those presented in table 6, suggest that energy-efficient architecture can reduce residential heating loads by an order of magnitude and that energy-saving retrofits and new housing are cost effective against present energy prices. Other studies also suggest that improving the energy efficiency of buildings could represent the fastest and the cheapest means to reduce national energy consumption and U.S. dependence on imported fuels. An earlier OTA report concluded that "the potential for conservation before the end of the century dwarfs that of solar."[28]

Nevertheless, the impact of Federal activity on the development and application of passive solar and heat-retentive technologies in residential housing has been relatively limited to date. In large part, this lack of impact reflects a lack of emphasis on residential conservation in the existing energy programs of the Federal Government. Another OTA study suggests that:

> Because of the wide variety of programs influencing both housing and conservation, many mechanisms exist to affect energy consumption in homes . . . . [But] energy conservation has not been a major priority for most Federal programs, and there has not been strong coordination of the various departmental efforts. A stronger commitment to energy conservation, combined with improved technical work and more sophisticated cost analysis, could mean a much stronger response to conservation goals from both the public and private sector.[29]

As the lead agency, DOE, and especially its Conservation and Solar Energy (C&SE) Programs, have been the subject of particular criticism. OTA's critique of these programs included the following findings:

- C&SE lacks a clear vision of where it is going and how it will get there.
- DOE does not appear to have set priorities among the various programs in C&SE to ensure that the total resources are being apportioned to achieve the maximum benefit.
- C&SE needs to develop the capability to determine what it can accomplish for the country, to make sound policy and program decisions to reach these objectives, and to keep the programs moving steadily toward the goals in the face of pressures to alter course in ways not necessarily in the national interest.[30]

The study also found that:

- C&SE could improve its coordination with other Federal agencies, such as HUD, and other government levels (State, local, and foreign).
- Closer cooperation between solar and conservation programs is needed to formulate a least-cost buildings strategy for combining passive features, active systems, and conservation measures in the most economical way for different types of buildings and climates. Several important areas are underemphasized, including building retrofits.
- The Office of State and Local Programs needs increased technical capability and discretionary monies to properly encourage flexible and responsible efforts to meet local and State needs as well as national goals.[31]

Option 1-A: Review Federal Policy and Program Priorities.–Congress may wish to exercise its oversight powers to order a thorough review of Federal programs for residential energy conservation and/or to direct DOE to modify its priorities and programs to give greater emphasis to conservation measures, particularly those appropriate to low-cost retrofits and new low-income housing.

Congress has agreed to DOE's request for a 1-year delay in the promulgation of the BEPS conservation standards (see above), originally scheduled for August 1980. These standards are likely to

[28] *Conservation* and *Solar Energy* Programs *of the* Department *of Energy:* A Critique (Washington, D.C.: Office of Technology Assessment, U.S. Congress, June 1980), p. 14.
[29] *Residential Energy* Conservation, op. cit., p.13.

[30] *Conservation and Solar Energy Programs of the Department of Energy:* A Critique, op. cit., pp. 3 and 13.
[31] Ibid., pp. 4, 5, and 32.

become the model for State and local building codes, and once established they will hasten the widespread application of the resource-efficient technologies discussed in this chapter.

Congress might also choose to investigate means of improving the programs of technical and financial assistance to State agencies and local organizations. The case studies suggest that locally based efforts are very successful in encouraging the adoption of these technologies.

Option 1-B: Redirect Federal R&D Efforts.–The case studies in this chapter and the studies cited in table 5 suggest that a variety of conservation measures can be taken at a reasonable cost, but much remains to be learned about the best combinations of features for different climates. OTA's *Critique* concluded that "DOE has paid insufficient attention to basic research directed at energy conservation and solar energy."[32] Similarly, OTA's *Residential Energy Conservation* found that:

> The short-term focus of current DOE conservation R&D ignores some longer term options that also have high returns . . . Research on attitudes, energy use patterns, institutional and legal barriers to conservation, and similar important areas have not received adequate emphasis. Research and policy decisions on energy technology do not adequately consider the conservation applications of new technologies, the potential of conservation to reduce demand and provide time for shifting to new energy systems is not fully appreciated. The policy appears to reflect an attitude by DOE and the Office of Management and Budget that conservation should be viewed as a stop gap that merits little Federal research funding, in sharp contrast to new production approaches.[33]

Congress may wish to direct DOE to reorganize its programs and redirect its residential energy R&D to reflect the findings of projects like those referred to above. In particular, there is a need to gather "social science" data on the attitudes and preference of home buyers and the effects of occupant behavior on the thermal performance of energy-efficient houses. This information would also be useful in determining the impact of resource-efficient design on the marketability and resale value of the houses to which these technologies have been applied.

Further R&D might also focus on the interaction of these technologies and the optimal combination of solar and heat-retentive features. Another area for further investigation is the cost of the conservation measures, particularly their lifecycle costs. An important technical area that has thus far been underemphasized is the potential benefit of energy-conserving retrofits for existing housing. Finally, because the application of these technologies is highly site specific, there is also a need for detailed microclimate information for different areas of the country.

ISSUE 2: Demonstration and information Dissemination.

Some demonstration projects have shown themselves to be very effective in increasing public awareness and interest in resource-efficient housing. The Cooley house has visitors almost every day, and when it was included on a local solar housing tour it had 450 visitors in a single day. Similar results were common in the other cases, and in the case of greenhouse retrofits a single demonstration house can lead to the adoption of this technology by a large number of families in the same community or region. The Federal Home Loan Bank Board's information program for lending institutions has also had a degree of success in disseminating information and changing attitudes about resource-efficient housing, as have some DOE efforts. DOE has three different information programs—the Energy Extension Service, the National Solar Heating and Cooling Information Center, and the Regional Solar Energy Centers—each located under a different deputy secretary and pursuing a separate mission. Some critics, however, have expressed concern that these programs are poorly thought out, poorly coordinated within DOE, and poorly coordinated with the efforts of other Federal information programs and the needs of State and local agencies.

Option 2: Establish a Central Clearinghouse.–Congress may wish to investigate the benefits of establishing a single office to gather and disseminate information on energy-efficient tech-

[32] Ibid., p. 26.
[33] *Residential Energy Conservation*, op. cit., p.13.

nologies for residential housing. Such a clearinghouse might also be given responsibility for developing a compendium of Federal programs for the use of State and local governments and for compiling handbooks of technical and microclimate data for local building contractors and owner-builders (see above). This information should include data on the design and cost of retrofits like the attached solar greenhouse. These goals might be achieved by expanding the National Solar Heating and Cooling Information Service, but a network of regional clearinghouses might also be effective.

ISSUE 3: . Financing.

The case studies in this chapter represent only a tiny sample of the thousands of resource-efficient retrofits, additions, and new houses that have been built in the last 5 or 10 years. Like most of the case studies, the majority of these applications have been made privately by middle- and upper-income families, without Federal funds and often without a tax incentive.

To increase the rate of adoption, however, and to ensure the application of these technologies to Government-subsidized and private low-income housing, will require further efforts to reduce the risks involved for owners, builders, and lenders alike, whether private or public. The Federal Home Loan Bank Board's efforts in this area have been particularly effective, but a board official has said that the local savings and loan associations would prefer not to have formal regulation issued in this area, so that they may keep as much flexibility as possible in their programs. The newly created Solar Bank will provide subsidized loans, another useful new effort is an information and training program for real estate appraisers, whose familiarity with the technologies often influences the resale value and marketability of resource-efficient houses.

Option 3-A: Gather and Disseminate Cost Data.—The availability of reliable economic information, including detailed lifecycle costing, would do much to eliminate remaining uncertainties about these technologies. Congress might direct DOE to include the gathering and disseminating of such data among the priorities of its research and information programs (see above).

Option 3-B: Increased or Earmarked Funding.—Congress may wish to demonstrate its commitment to residential energy conservation by increasing the funding level of the programs and proposals discussed above, or by earmarking funds for these purposes in authorizations for other programs. Current funding has been called "woefully inadequate" to the potential savings that could be achieved through energy-saving retrofits and new housing. In view of these potential benefits, such funding represents a highly profitable social investment, and the investment might best be protected (and its benefits best achieved) through self-help and self-sufficiency programs like those of HUD and CSA. Through such programs, the funds cease to be a continuing subsidy and become instead a way to permanently reduce the energy needs of local households. Direct funding of neighborhood groups for workshops and other local self-help projects may prove to be far more cost effective than subsidies in achieving the Nation's residential energy goals.