The Solar Handbook

Office of Energy Conservation
State of Colorado

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Colorado Office of Energy Conservation
Division of Renewable Resources
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About This Book

This book is about the growing number of Coloradans putting our abundant sunshine to use. We asked them what it's like living in a solar home, what problems they encountered, whether it was worth the investment, and what would they do differently. This book about their experiences was written so you can benefit from what they learned.

There is no "best" solar system for everybody. But there usually is a "best" solar system for each situation. This book describes a variety of working solar energy systems in Colorado, how much they cost, how well they have worked and factors that influence the solar decision-making process. Only you can make the best choice for your situation and your pocketbook.

Basics about how much solar energy is available and the principles used to collect it are discussed in the appendix section. Detailed information on these topics is widely available.

Some solar systems operate by themselves. Some are controlled by thermostats, pumps and fans. Still others are controlled by people. The goal of this book is to show you a variety of solar options to help you decide which, if any, is the most appropriate for you.

Energy and solar equipment cost data were obtained in 1977 when this research was conducted. Since that time, although the price of many energy resources has doubled, solar system costs have increased nearer to the pace of inflation. This trend will continue through the 1980s making investments in solar and energy conservation even more attractive today and tomorrow than investments made in 1977.

Solar Heating Systems

Heating buildings and water are two of the simplest and most economical ways to use solar energy. Solar energy systems for these tasks make sense because they match the intensity of the energy source to the use intended for the energy.

Systems used to convert solar energy to heat usually have four basic components: a collector, distribution system, storage, and a back-up heat system.

Collector. *The collector converts solar radiation to heat and accumulates the heat.* It can be anything from a house that uses south-facing windows to a flat-plate or concentrating collector. Buildings as collectors are common in natural or passive systems. Flat-plate collectors and concentrators can be used with both passive and active systems. Different types of collectors are described later in this book.

Heat Distribution System. *This component transports heat from the collector to the place where it is stored or used.* For classification purposes, the key component of a solar heating system is the method of heat distribution. Systems are grouped into three broad categories: **natural** or **passive** systems, **active** systems, and **hybrid** or **integrated** systems. A passive system relies solely on natural energy flows to move heat where it's needed. Mechanical power is used to achieve this in active systems, and a hybrid or integrated system combines both natural and forced heat circulation.

Storage. *Storage retains heat for use during nighttime and cloudy periods.* Heat storage is an important part of any solar conversion system. Thermal energy is stored in water, rock or other materials that have a capacity to hold heat. These materials may be in special insulated containers or built right into the walls and floor. This is called **sensible** heat storage because you can feel the warmth by touching the material.

Generally a large volume of material is required for sensible heat storage to carry through a few days of cold weather.

Another group of materials can be used to store heat you can't feel, called **latent** heat. These "phase-change" materials actually change their physical state—gas, liquid or solid—as they absorb and emit heat. Your refrigerator, freezer or air conditioner uses a phase-change material for cooling, usually freon gas that alternates between liquid and gas as the system operates. Phase-change materials like "eutectic salts" can store large amounts of heat energy while requiring less space than sensible heat storage materials.

Back-up Heat System. *This component supplies heat when thermal storage is depleted during extended cloudy or cold periods.* Back-up heat may be provided by a regular furnace, a heat pump, a wood stove, or a variety of systems. Although it's simple to design a solar system large enough to meet all your needs, it's usually very expensive. A system that provides 80-90 percent of your needs might have to be doubled in size to provide that last 10 percent during the coldest, cloudiest period of winter.

Every solar system represents a series of trade-offs. You can vary the collector size, storage size, and back-up system to meet your needs and budget. If you're willing to start a fire or put on a sweater, a passive system may provide the rest. If you prefer to be comfortable knowing your plants and plumbing won't freeze when you're away, it's better to have a thermostatically controlled back-up system.

This book explains a wide range of solar systems and the trade-offs their owners chose. People building new homes have different trade-offs from those renovating existing buildings. Everybody chooses a system that's compatible with their present needs. Solutions are as varied as the people who use them.

Planning To Build?

New construction offers the best opportunity for solar heating because you can build in energy-saving features much cheaper than adding them later. If you elect to buy an active solar energy system, the cost of including it in construction is generally less than adding the system once construction is completed. Building a passive solar home may cost only a fraction more than building a conventional house of the same size. No matter which system you choose, make use of the sun, the earth, wind, plants and other natural factors to keep your new home as energy-efficient as possible. Here are some simple considerations that don't cost much, but can save dramatic amounts of energy.

- The site should have a good southern exposure. The south slope of a hill is best. Your new home will receive maximum winter sunshine and the hill offers protection from wind.
- The long axis of the house should run east-west to allow for a large area of windows, collector panels, or possibly massive thermal storage material on the south side of the building.
- Make sure you insulate, weatherstrip and caulk thoroughly, and use double-pane glass or storm windows. Energy conservation saves money regardless of your heat source.
- The constant temperature of the earth (40-50 inches below frostline) can be utilized by building the house into the side of the hill or partially into the ground. You can also berm, or mound, the earth on the sides exposed to winter winds. The earth will keep your house warmer in the winter and cooler in the summer.
- Dense evergreen trees, such as blue spruce, on the north and northwest sides will act as windbreaks and reduce convective heat loss caused by winter winds.
- Low, dense evergreens planted on the north and northwest sides will create a dead-air space next to the wall and help insulate the house.
- Deciduous trees or shrubs, which shed their leaves in winter, can be located on the south, southwest and southeast sides of the house. Leaves provide shade in the summer, but allow sunlight through in the winter. Vines on trellises or against walls can serve the same function.
- Your house should be compact so it has minimal exterior wall surface. It will be easier to keep warm because heat distribution will be more efficient.
- A floor plan with high use areas (kitchen, dining, living and family room) on the south side and low use areas (bedrooms, garage, laundry, storage, etc.) on the north side will

How Many Building Tips Can You Find?

minimize energy demand. Rooms used the least can be kept at lower temperatures and act as thermal buffers to areas directly solar heated through south-facing windows.

- Total window area should be no more than 10-15 percent of the floor area, unless movable insulation is used. Glass is not a good insulator, so reducing window area will decrease energy use. The greatest window area should be on the south-facing side to obtain the greatest amount of solar heat gain.

- South windows should be shaded from high summer sun by overhangs, awnings, vines or deciduous trees. The size of overhangs can be calculated so that shading begins on a given date in the spring and ends on a given date in the fall.

- North windows should be kept at a minimum. They contribute no solar heat gain and are exposed to winter winds.

- Windows that open should be located on the southwest and northeast sides to allow for natural ventilation from prevailing southwest summer breezes. (Be sure to check prevailing wind directions at your site.)

- Entry doors can be protected by enclosed porches or vestibules to reduce the flow of warm air from the house when the doors open.

- Massive building materials, like concrete, stone or brick, will store heat inside the house and help keep the temperature steady. Try to locate massive building materials in direct sunlight inside the house.

These simple principles can save you energy and allow a portion of your heating needs to be supplied by the sun. More of your heating needs can be met with solar energy by using natural, active or integrated solar energy systems like those described in this book.

Natural or Passive Systems

We can design buildings that heat and cool themselves by taking advantage of the natural energies and materials around us. This is what natural, or passive, solar energy systems are all about. The structure itself collects (or rejects), stores and distributes energy. Structural elements of the building double as the solar energy system. When properly designed, these systems can be a highly cost effective, and natural, way to heat and cool buildings.

How a Passive System Works

The design factors outlined in the preceding section give you a good start on a passive system. Double-glazed, south-facing windows generally allow more heat to enter the building than is lost through the glass at night. The next step is to incorporate a material that absorbs and stores the heat collected during the day. Massive walls, floors and ceilings, or special storage components can all be used for this. Dense materials, such as masonry or water, are best for heat storage because they respond slowly to temperature fluctuations. This characteristic is called **thermal mass** or **thermal inertia.** Heat is soaked up during the day and slowly released into the building at night.

Concrete, brick and adobe are the most commonly used heat storage materials because of cost, availability and ease of construction. Water, also frequently used, can store large amounts of heat, but requires the use of special containers. A few companies now offer specially made fiberglass water storage tubes, although anything from recycled 55-gallon drums to plastic jugs have been used successfully. Phase-change materials like eutectic salts, although still primarily experimental, also can be used with passive systems. Tiles or concrete blocks filled with salts have been used in several passive applications.

How Much Storage? Calculating volume for collection and storage material in a passive system is crucial. Large volumes are required because storage temperature is low (usually less than 100 degrees), but too much storage will result in a cold house because "thermal lag" time is increased. Thermal lag time is the time required for collected heat to radiate back into the living space. Too little storage can mean overheating in the daytime and a cold house at night.

Storage capacity depends on many factors, including the amount of solar radiation received through the south glazing, the storage medium used, how the space is used and the size of your budget. However, rules of thumb have been developed as guidelines for storage sizing. Douglass Balcomb of the Los Alamos Scientific Laboratory in New Mexico has formulated some of these rules by testing different types of passive systems. He suggests that a thermal capacity of at least 30 pounds of water or 150 pounds of rock should be used for each square foot of south-facing glass. Storage should be located in the direct sun, or four times more mass is required.

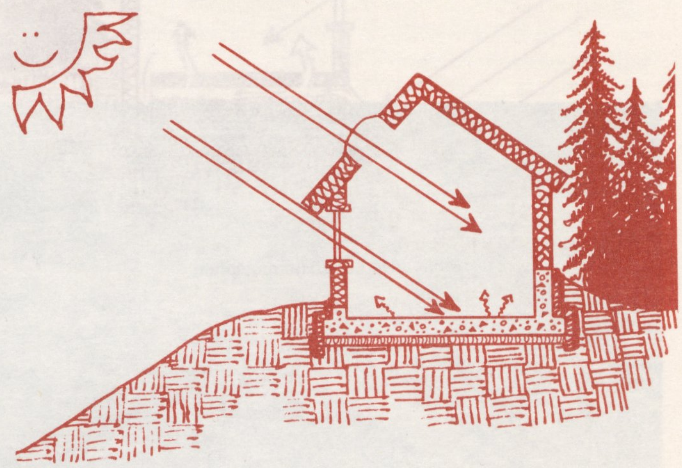
Insulation for Heat Storage

Movable insulation should be used to cover the heat collecting windows at night or during prolonged cold spells to retain heat in the building. Otherwise, much of the heat will escape back through the glass. Such things as insulating drapes, panels or shutters have been used for this.

Types of Passive Systems

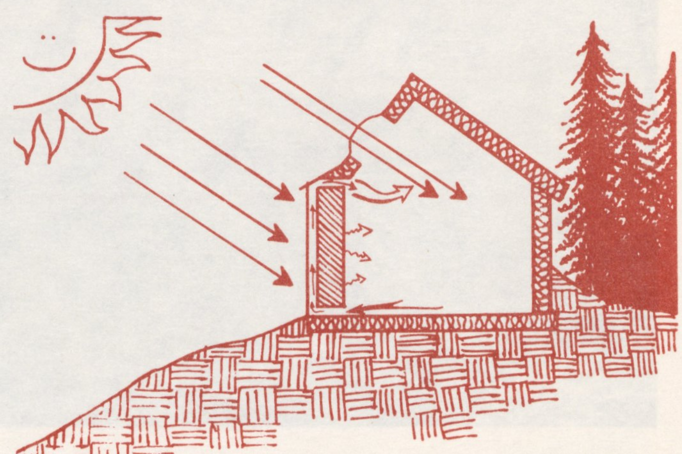
There are four basic types of passive solar energy systems: **direct gain, thermal storage wall, convective loop or thermosiphon** and **greenhouse.**

Direct gain systems use the simplest approach. Buildings are designed with large amounts of thermal mass inside an insulated shell. Walls and floors of poured concrete, filled cinderblocks, masonry or adobe are commonly used for thermal storage mass. The low winter sun shines directly through south-facing glass onto the mass, warming it so it can later reradiate heat into the space. All passive systems described here use direct gain to some extent.



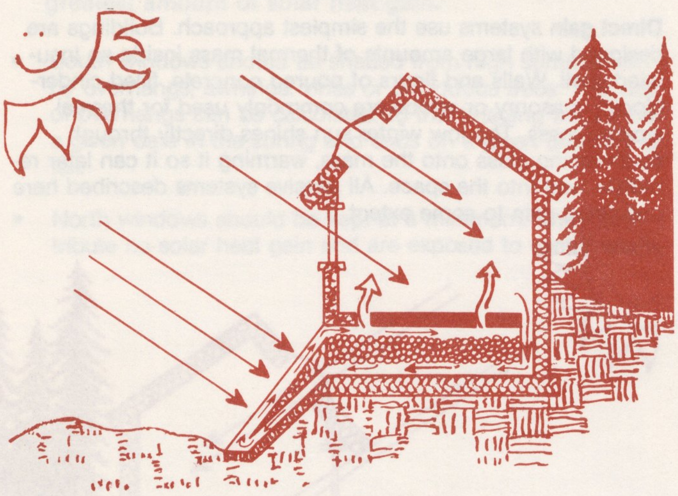
Direct Gain

Thermal storage or "Trombe" wall systems use large expanses of south-facing glass with a massive wall located directly inside the glass. Concrete walls or stacked water containers (such as tubes or barrels) are commonly used for thermal storage walls. Solar heat is absorbed by the wall and stored for later use. Popularized by French designers Trombe and Michel, this design concept is often called a Trombe wall.



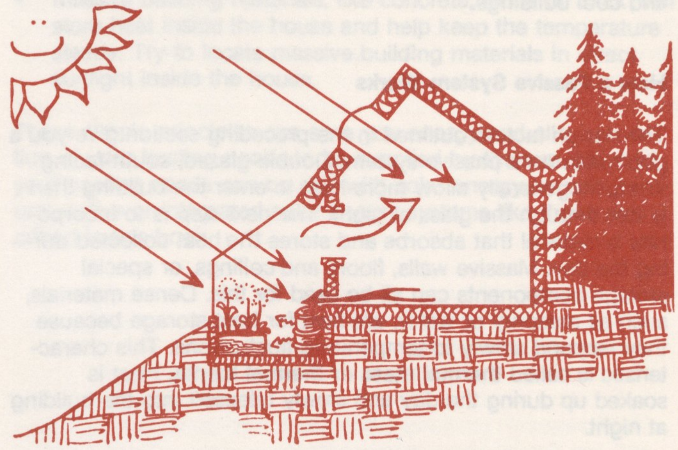
Thermal Storage Wall

Convective loops or thermosiphons work because heat rises. The heat collection area is located below the storage area or the area to be heated. The heated air or water rises naturally, while the cooler air or water flows back down to the collection area. The result is a circulation system driven by natural energy rather than fans or pumps.



Connective Loop/Thermosiphon

Greenhouses are popular for existing homes because they can often be attached to the south side of the building quite easily. They can supply heat, vegetables and additional living space all at once. Thermal storage inside the greenhouse could be an existing masonry wall or black water drums located between the greenhouse and the house. Solar energy normally provides all the heat needed for the greenhouse as well as an additional amount for the house. Movable insulation is recommended to retain heat at night.



Greenhouse

Mesa Verde Direct Gain

Built around 1200 A.D. in a south-facing cave, the Longhouse Pueblo in Southwestern Colorado's Mesa Verde National Park still stands as a working demonstration of intelligent use of the sun's natural energies. The Longhouse Pueblo is a classic example of a direct gain passive solar heating system.

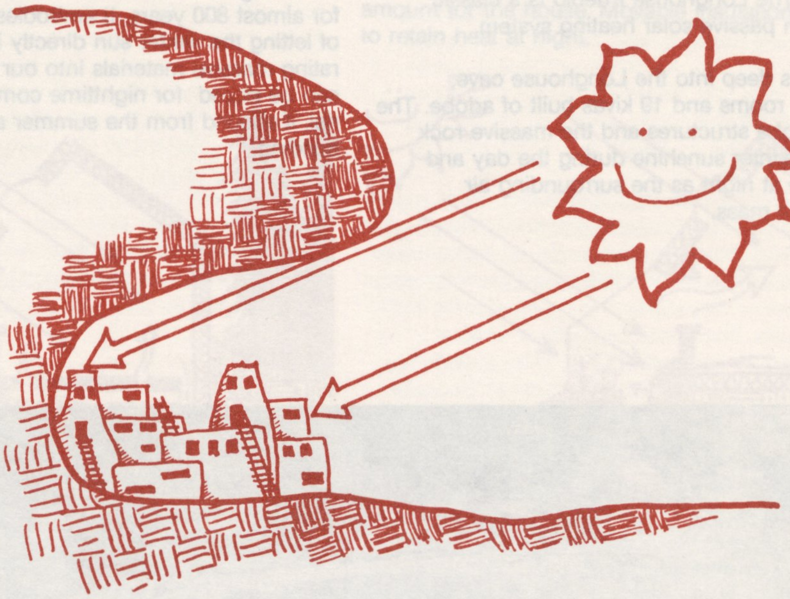
In winter, the sun shines deep into the Longhouse cave, directly heating the 180 rooms and 19 kivas built of adobe. The thermal mass of the adobe structures and the massive rock cave itself soak up the winter sunshine during the day and release it into the space at night as the surrounding air becomes cooler than the mass.

In summer, when the sun is higher, the cliff overhang above the dwellings shades them, and the thermal mass stays cool. The summer sun only strikes the sheer south face between midmorning and midafternoon, while the winter sun shines continuously during the day on the cliff face.

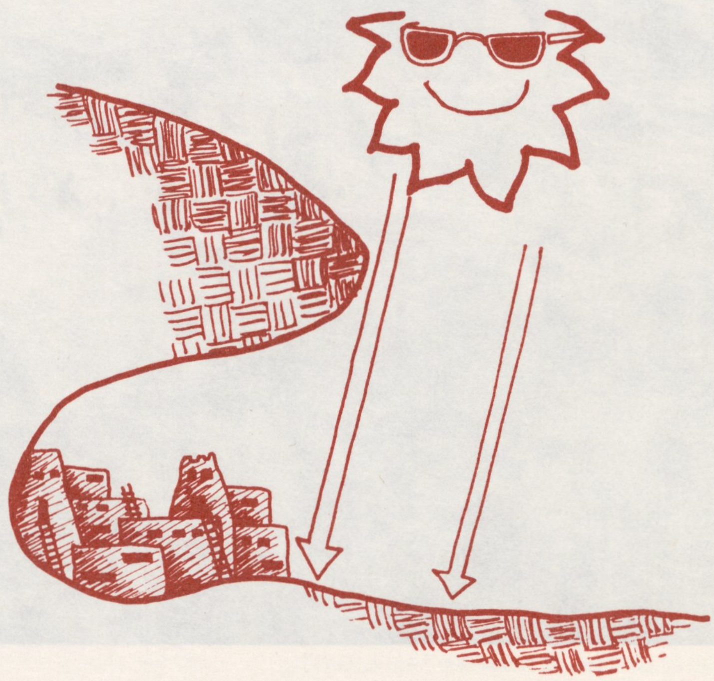
The Longhouse Pueblo has been heated and cooled naturally for almost 800 years. It embodies the common sense approach of letting the winter sun directly into our buildings and incorporating massive materials into our structures so daytime heat can be stored for nighttime comfort. The same massive material, if shaded from the summer sun, will also help cool the building.

Colorado's oldest solar-heated dwelling is the Longhouse Pueblo in Mesa Verde National Park on the north border of the Ute Indian Reservation near Cortez, Colorado. (Photo courtesy of the United States Department of the Interior, National Park Service).

MESA VERDE



Winter—Warm



Summer—Cool

Pixler House Thermal Storage Wall

System Data:

Application:	*New home designed for solar.*
Location:	*Durango, Colorado.*
Owner:	*Paul and Betty Pixler.*
Residential:	*Single-family home, 2,400 square feet.*
Insulation:	*R-38 in ceilings; R-19 in walls; Beadwall in Trombe wall; double-glazing.*
Back-up:	*Electric resistance duct heater and Autocrat Americana woodstove.*
Orientation:	*Long axis of building faces true south.*
Construction:	*2 x 6 frame walls with celotex and stucco.*
Solar Collector:	*Two-story Trombe wall (approximately 400 square feet) with Beadwalls for night insulation; solarium with pool for thermal storage; radiator coil mounted inside Trombe wall for domestic hot water preheat.*

Heat Distribution: *Conventional forced air ducting with fan; natural convection; fan on woodstove; copper pipe with pump to domestic hot water preheat tank.*

Storage: *16-inch solid concrete Trombe wall, two stories; two 2½-ton rock columns between solarium and living room in direct sunlight; solarium floor and walls of 8-inch solid concrete plus brick floor; solarium pool.*

Heat Exchanger: *Water-to-water exchanger transfers heat from Trombe wall to preheat tank for domestic water supply via ½-inch copper tubing coils.*

Controls: *Differential thermostat for fan; thermostatically controlled Beadwalls.*

Solar Cost: *Approximately $9,000.*

An electric back-up heater in the Pixler's house has not come on since they moved into their new home in November of 1977. "Our main back-up heating is wood, so we don't have any heating we're actually paying for," Paul Pixler says. "The wood has been free. Even on sunny days, we usually have some fire in the evening. Although at the end of February (1978) we had five or six sunny days when we didn't build a fire at all." About two cords of wood are used each winter to supplement the solar heat.

Trombe Wall

The two-story Trombe wall is a 16-inch thick poured concrete wall, painted black, with two layers of glass in front of the south-facing surface. The wall is partitioned at the second floor level, and has openings in the concrete at the top and bottom of each story. Sunlight passes through the glass and heat is absorbed by the massive black concrete wall. The air between the glass and concrete gets very hot, rises and circulates into the house through high openings in the concrete. Because hot air is vacating the space, cool air from the floor-level inside the house is sucked in to replace it. A continuous current of hot air is delivered into the living space as long as the sun is shining, without the aid of an electrical fan. Heat stored during the day in the massive wall is radiated into the house at night.

The same natural convective current that heats the house in winter helps cool it in summer. High windows in the glass wall

The home of Paul and Betty Pixler in Durango is totally heated by a Trombe wall and solarium, supplemented by a woodstove.

can be opened so hot air can escape from the house. Cooler air is sucked into the living space through openings on the shaded north side.

Beadwall

All the glass covering the Trombe wall is actually a large Beadwall that is automatically filled with styrofoam beads to prevent heat loss when the outside temperature drops below 62 degrees. A thermostat does the job. It kicks on and a small vacuum motor fills (or empties) the 3½-inch space between the two layers of glass. It takes about a minute to fill up and convert a double glass wall into an effective insulating barrier between the warm concrete and the cold outside air. When the sun comes out and the outside temperature hits 65 degrees, the motor empties the glass wall, funnelling the beads through plastic pipes into three storage tanks.

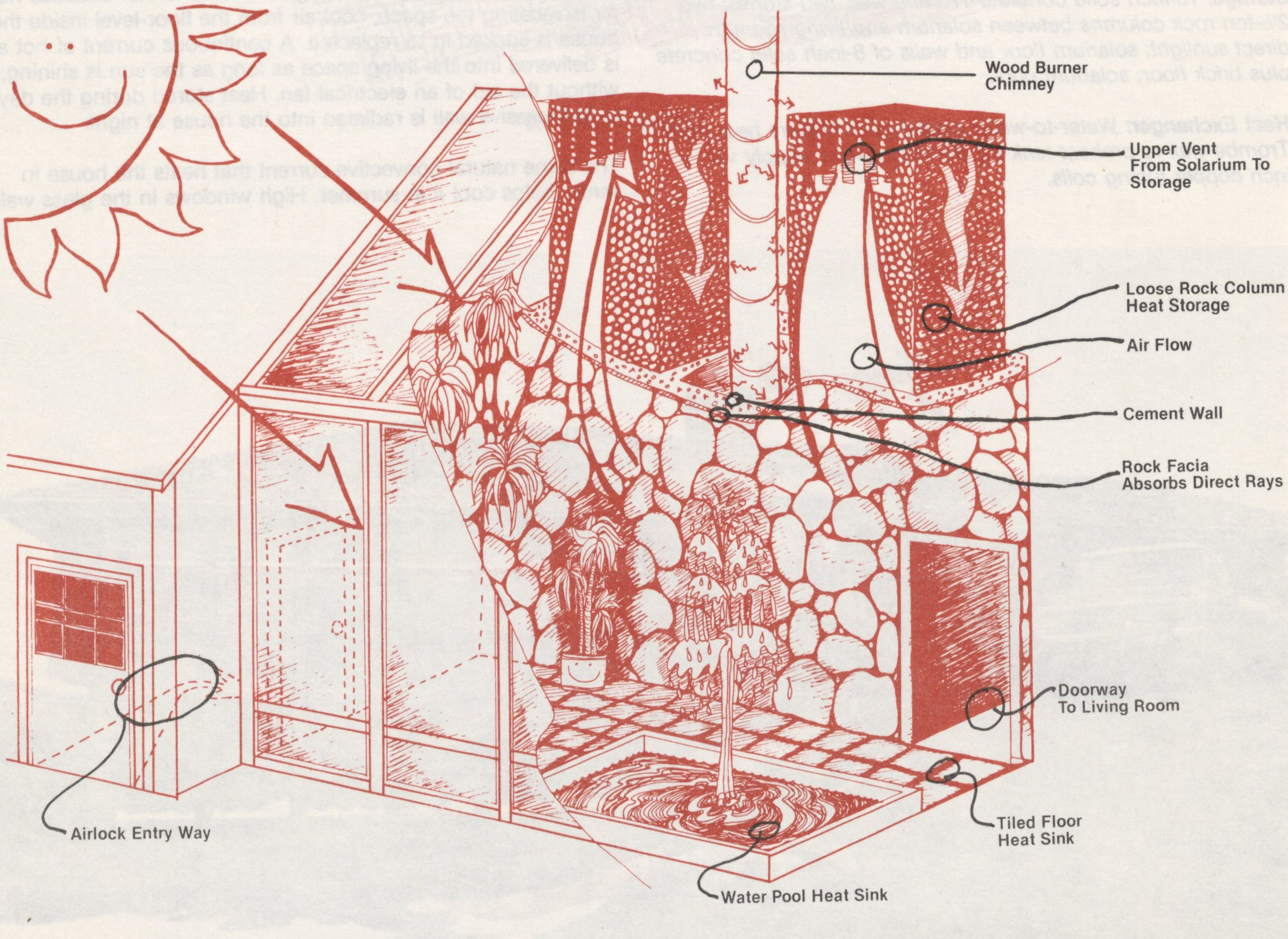
The Pixlers have added some beads to their Beadwall because of settling since the original installation. They've also added an antistatic solution to the beads to keep them from sticking to the glass.

Hot Water

Forty-feet of radiator coils are mounted low on the sunny side of the Trombe wall and painted black. Water from a tank next to the hot water heater passes through the coils, where it's heated to about 80-100 degrees by the sun. The water then goes to the "cold" inlet supply in the electric hot water tank and is heated up to normal hot water use temperature, around 140 degrees. If he did it again, Paul says he would put more radiator coil in the Trombe wall and place the coil higher on the wall to get higher temperatures and provide a greater percentage of their hot water.

Solarium and Water Storage Pool

In addition to the Trombe wall system, the home has a sola-



PIXLER HOUSE
Durango, CO
Solarium
Heat Collection Mode

rium with south-facing windows and an insulated floor made of rocks covered by red stone tiles, which serves as thermal mass for storing heat. The solarium also acts as a protected entry way to the house during winter months.

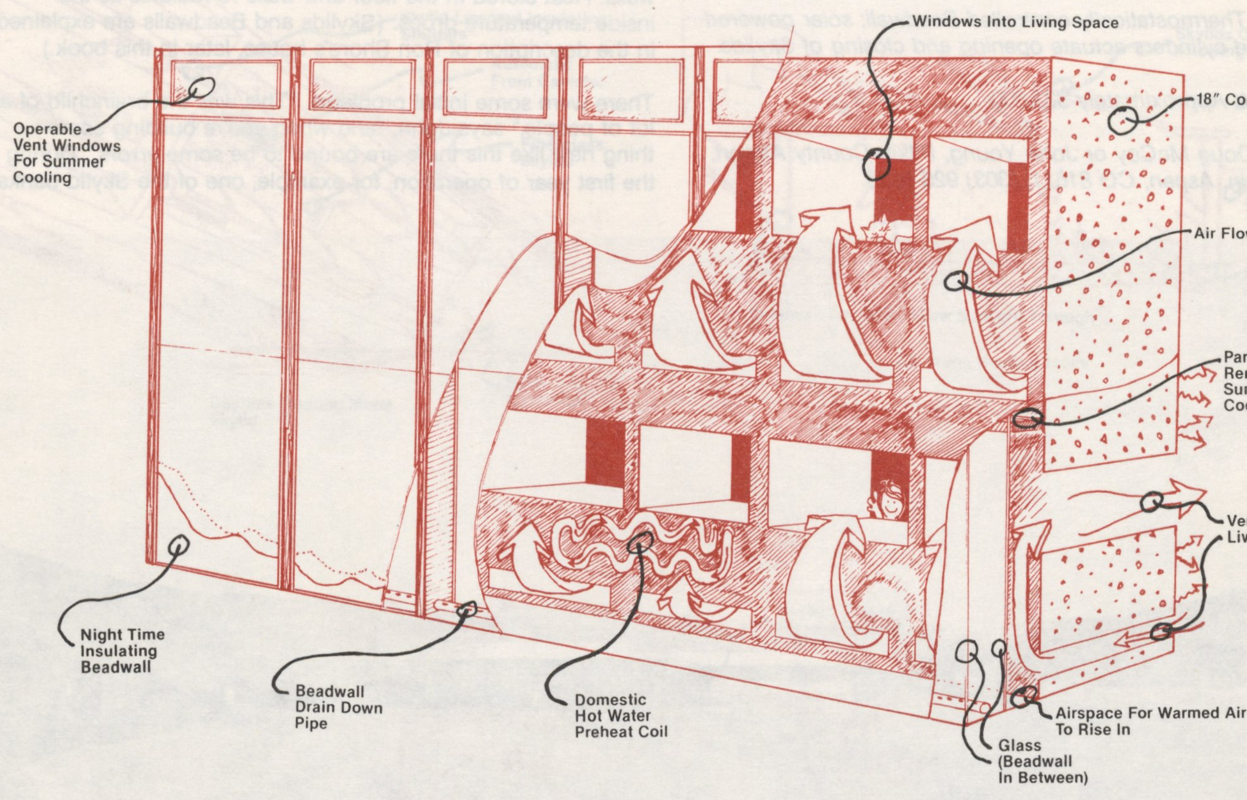
The Wall

A massive concrete wall separates the solarium and the living room. The wall contains a chimney for a woodstove in the living room and two large columns each filled with 2½ tons of rock. The wall is designed to store heat from the chimney and collect heat from the solarium ceiling through vents on the top of the wall. A fan assists in collecting warm air from the solarium, but Paul says it doesn't seem to be any better than natural convection through rock columns. Hot air can be drawn off the bottom through ducting connected to a fan on the back-up electric furnace and then circulated through the house. "The duct system may be superfluous," Paul comments. "We only need it for the basement." Natural convection distributes heat evenly to the rest of the house.

Wood Stove

The first line of back-up at the Pixler's is a thermostatically controlled, air tight, jacketed wood stove with a fan to blow hot air from the jacket and the double-walled flue pipe into the room. The fire uses combustion air piped in from the outdoors, so it is not consuming heated house air as it burns.

"In general, the house is being kept warm pretty well, and the Trombe wall seems to be a good system, if you can keep the cost controlled," Paul says. The Pixlers spent an estimated $9,000 more to build their house with a solar system. Paul says he can see ways now how the finishing on the inside could have been done somewhat less expensively. But the Pixlers seem quite happy with their solar system, and cannot complain too much because the "heat bill so far has been zero."



PIXLER HOUSE
Durango, CO
Trombe Wall
Heat Collection Mode

Pitkin County Airport Direct Gain

System Data:

Application: *New building designed for solar; commercial.*

Location: *Highway 82, 4 miles west of Aspen, Colorado.*

Owner: *Pitkin County.*

Airport: *3 rectangular-convecting portions totaling 16,800 square feet.*

Insulation: *R-20 in ceilings and walls; earth berms on north walls; double glazing on north and south view windows; Beadwall; Skylids.*

Back-up Heat: *Gas-fired boiler with forced air.*

Orientation: *The 3 connecting segments of the building are staggered in a southeast to northwest array.*

Construction: *8-inch concrete block exterior walls and 5-inch concrete slab floor.*

Solar System: *Direct gain, through 750 square feet of south-facing double glazed windows which fill with Beadwall for insulation; direct gain through 1,750 square feet of skylights insulated with Skylids.*

Heat Distribution: *Re-radiation of heat from thermal mass; convection.*

Controls: *Thermostatically controlled Beadwall; solar powered Freon-filled cylinders actuate opening and closing of Skylids.*

Solar Cost: *Approximately $23,000.*

Contact: *Doug McCoy or John Young, Pitkin County Airport, 506 E. Main, Aspen, CO 81611, (303) 925-8698.*

The Pitkin County Airport is one of the largest buildings in the nation to be heated passively by the sun and the first public building to use a movable insulation system. According to John Young, assistant manager of the airport, the system has been performing well. Tests show that on clear days the sun provides 40 percent of the heat required, and on partly cloudy days, 18-22 percent.

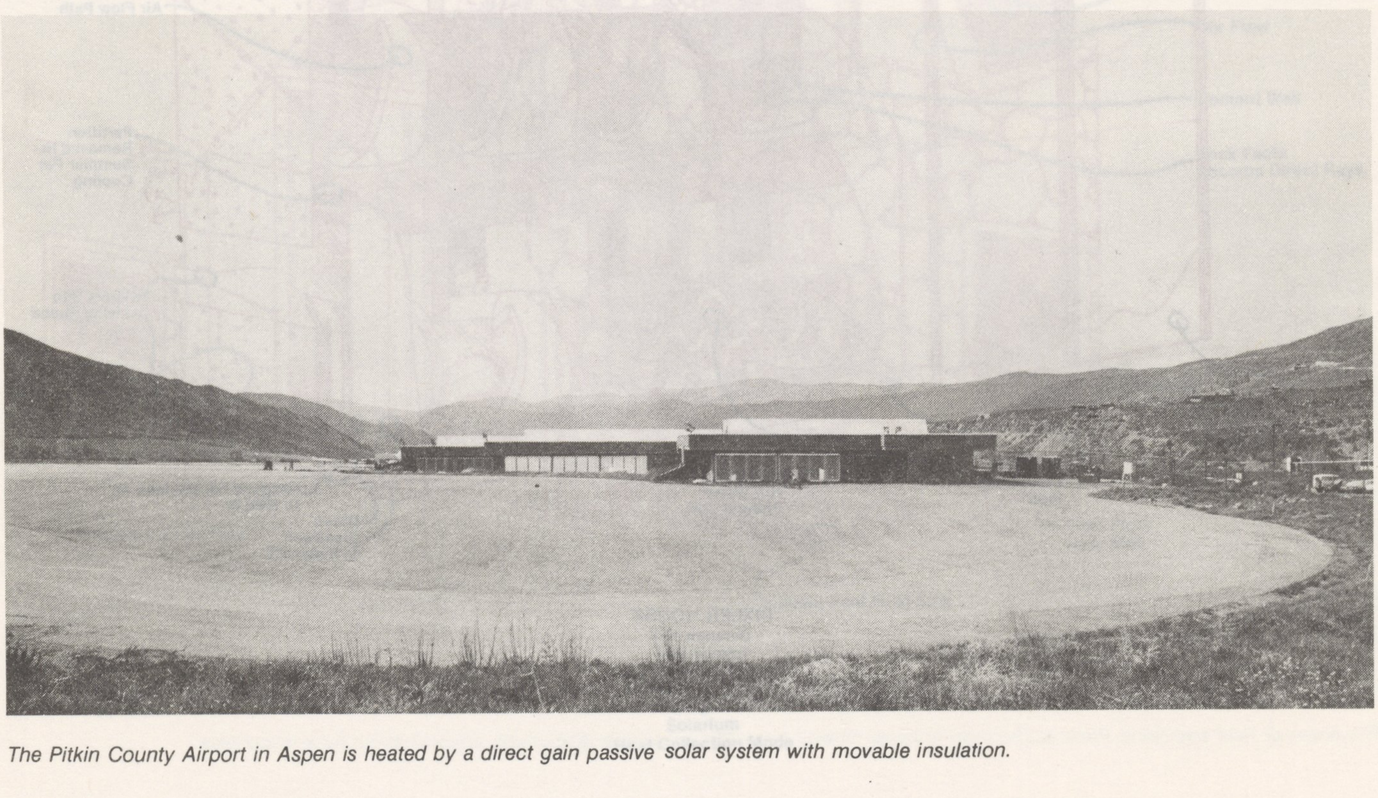
"From the third week in March to the third week in October we rely totally on solar for heating needs," says John. "Sometimes in the first hour or two in the morning the temperature is down to 62 degrees, but we've convinced the terminal people that we can live with it being a little nippy."

Direct Gain with Beadwall and Skylids

Solar radiation enters the airport through a south-facing 750-square-foot vertical wall of double glazed, reinforced fiberglass windows, and through two arrays of fiberglass skylights that total 1,750 square feet. The windows are insulated at night and during very cold periods by Beadwall, small styrofoam beads that are blown into the 2¾-inch air space between the sheets of glazing. The skylights are insulated by a series of movable louvers called Skylids, which open automatically during periods of heat gain.

Sunlight entering through the windows and skylights strikes a 5-inch concrete slab floor and 8-inch thick concrete block walls. Heat stored in the floor and walls re-radiates as the inside temperature drops. (Skylids and Beadwalls are explained in the description of Ron Shore's house, later in this book.)

There were some initial problems. "This was the brainchild of a lot of people," says John, "and when you're building something new like this there are bound to be some errors." During the first year of operation, for example, one of the Skylid banks



The Pitkin County Airport in Aspen is heated by a direct gain passive solar system with movable insulation.

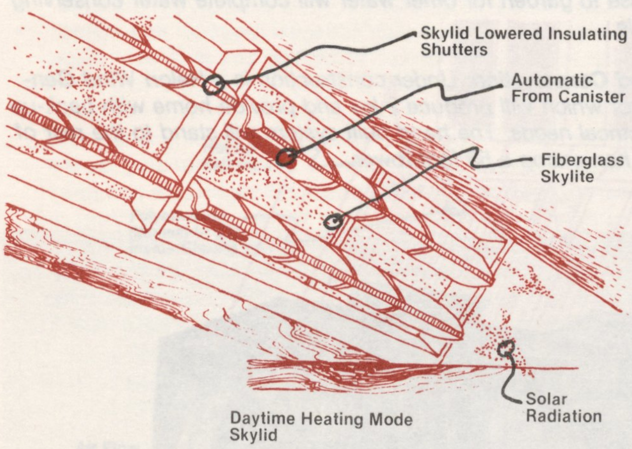
had to be kept shut. The sun struck a row of vending machines instead of the wall, resulting in "lots of melted candy and ice cream," he recalled. "The people who did the design work simply miscalculated the angles. They felt the sun would be high enough to avoid this, but in January and February it was so low that it came shining right in on the machines. We ended up moving them, which cost us about $1,000."

Another problem cropped up with the Beadwall when thermal expansion and settling of the building caused the glazing to pull apart from the frame. "We ended up with beads all over the floor," John Young remembers. "It was a simple design problem. We haven't run into any snags since it was corrected." Originally, the framing overlapped the glazing by only ¼-inch, which wasn't enough. The overlap was increased to handle expansion and contraction of the glazing material.

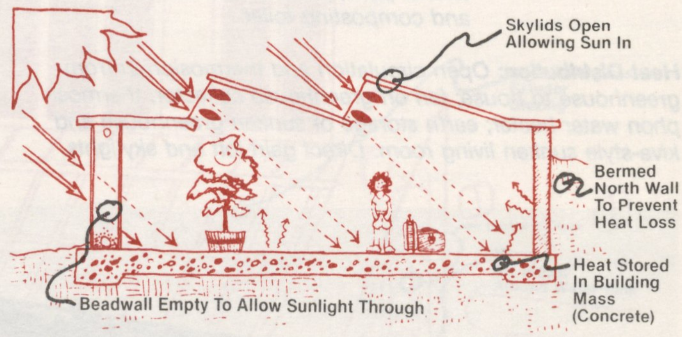
Cost

The total cost of the solar system was $28,000, but the true cost, according to John, was $23,000. "You have to subtract what it would have cost you to put in a regular wall and ceiling," he says. "We felt that we could attribute at least $5,000 to that. Originally we estimated that the solar portion of the building would pay for itself in 15 years, but since then the price of natural gas has doubled, so we've lowered that figure to 10 years. And the number could change. It all depends on the price and availability of natural gas."

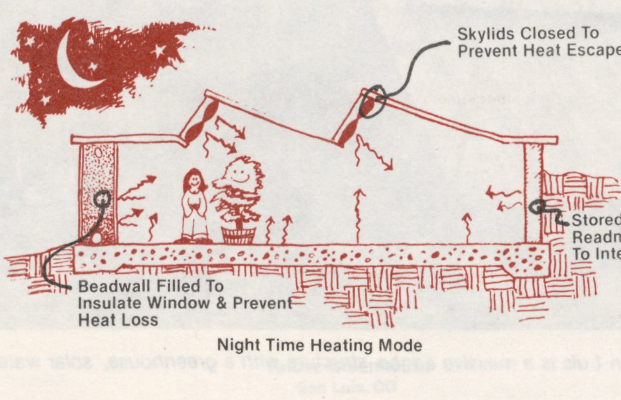
Pitkin County Airport, Aspen



Daytime Heating Mode Skylid



Day Time Heating Mode



Night Time Heating Mode

Valdez Home
Integrated Passive

System Data:

Application:	*New home designed for solar with integrated wind and water energy efficient systems.*
Location:	*San Luis, Colorado.*
Owners:	*Arnie and Maria Valdez.*
Residential:	*Single-family home, 3,000 square feet.*
Insulation:	*R-30 in ceilings; R-15 in north, northeast, and northwest walls; 20-inch uninsulated adobe on southeast, south, and southwest walls; double-glazing; 600 square feet thermoply reflective board and loft.*
Back-up Heating:	*Rightway wood stove; Waterford cook stove; fireplace; Magamex wood water heater.*
Orientation:	*Long axis of building is 5 degrees east of true south.*
Construction:	*20-inch adobe; adobes made on site and 100 year old, recycled.*
Solar Collectors:	*Passive direct gain through windows; greenhouse and adobe mass; active air to water collector integral with greenhouse; passive thermosiphon water heater (water); direct gain loft and skylights; passive thermosiphon food dryer (air); greenhouse for heat and food; passive outhouse; passive animal pens; passive cold frames; wind mill and composting toilet.*

Heat Distribution: *Open circulation and thermosiphon from greenhouse to house; fan on greenhouse collector; thermosiphon water heater; earth storage of sunken greenhouse and kiva-style sunken living room. Direct gain loft and skylights. Passive vents upstairs—room to room. Heat distributed fan tube (convective floor vents—under construction) from loft to downstairs living room.*

Storage: *20-inch thick adobe walls (elongated hexagon six sided two stories high); earth floor under block planters; second floor exposed floor brick pavers (perimeter insulation); 115 gallons of water in hot water system in greenhouse and bathroom (two tanks, 65 gallons and 50 gallons); 300 square feet of greenhouse back wall exposed to winter sun.*

Heat Exchangers: *Homemade air-to-water heat exchanger between air collector and solar hot water tank. Zomework single wall heat exchange tank (65 gallons).*

Controls: *Differential thermostat and for air collector with manual override; manually operated insulating shutters consisting of 1 inch styrofoam and masonite, interior.*

Solar Cost: *Under $2,000 in materials only, not counting adobe; cost about $30,000 with improvements to land. Home cost about $10 per square foot.*

Water Conservation: *Millbank Composting Toilet/Gray Water System. The Valdez home is also integrated with water conserving systems. The Millbank Composting Toilet with small heat coil and fan and potting soil will provide for waste system. Twice a year the toilet will be emptied and compost put outside under ornamental trees, etc. A Gray Water System from house to garden for other water will complete water conserving cycle.*

Wind Conservation: *Under construction is a Helon Wind Generator which will produce 2 kw and provide home with back-up electrical needs. The hand built system will stand to the rear of the home atop a 50 foot tower.*

The home of Arnie and Maria Valdez in San Luis is a massive adobe structure with a greenhouse, solar water heaters, a solar food dryer and a woodstove.

Arnie and Maria began building their homestead on the summer solstice, June 21, 1976, after two years of planning and waiting to secure a Farmers' Home Administration loan. The 3,000 square foot adobe home is a passive solar collector, and combined heating and utility costs for wood and electricity averaged $5.00 per month during the winter of 1977-78. Early morning temperatures in the winter, long after the fire goes out, range from 55-65 degrees, because of nighttime solar heating supplied by the thermal lag effect of the massive 20-inch native adobe walls of the house and the thermal mass in the 300 square foot greenhouse.

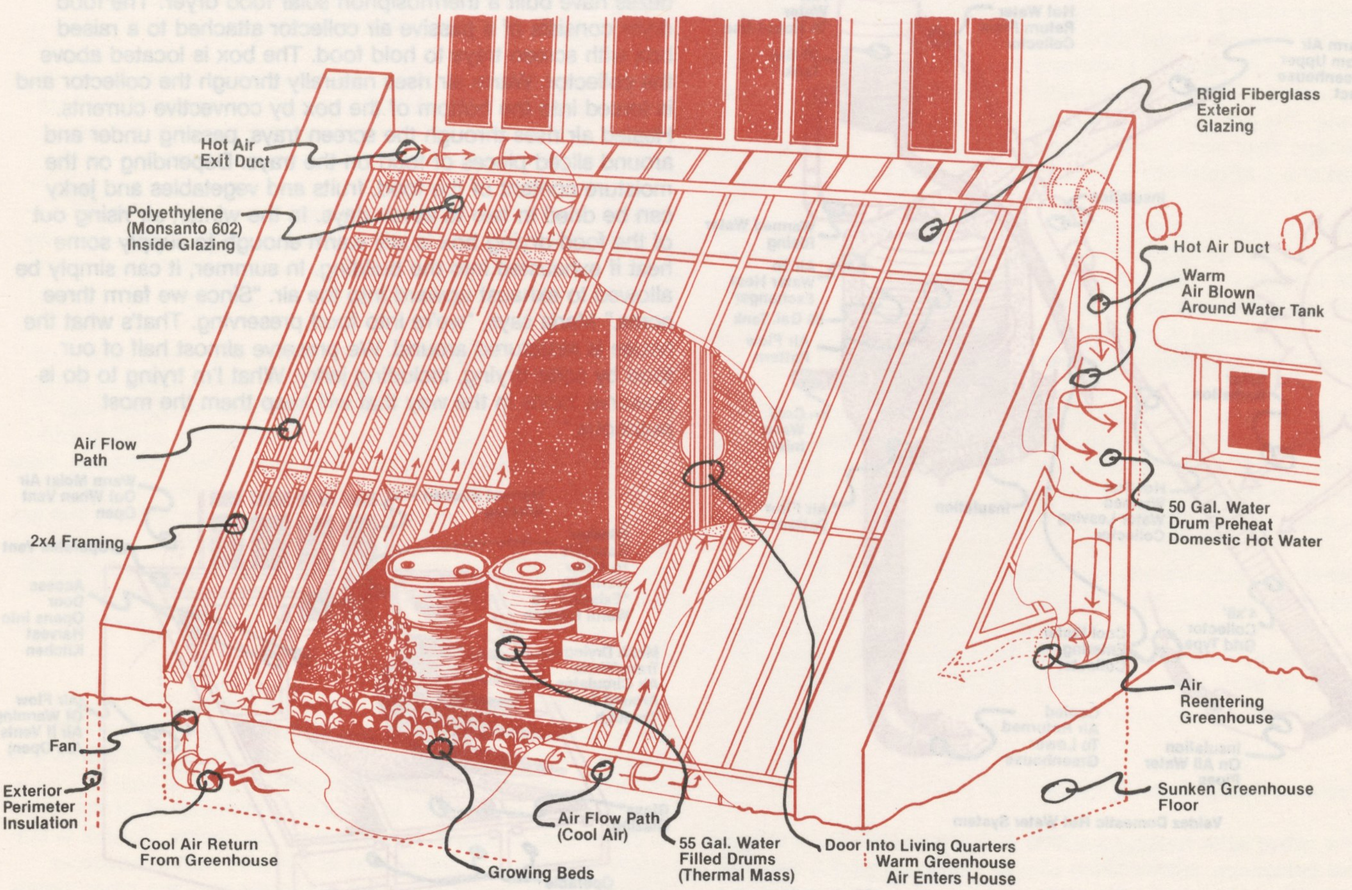
Direct Gain

The Valdezes built their home out of adobe (bricks made of pressed earth). The soil on their land was used by Arnie's cousin's adobe factory to make bricks and they recycled adobes from 100 year old buildings. "Our home ran $10 a square foot because we used native materials and did a lot of scrounging, recycling, and bartering. Some of the vegas (structural beams) and adobes are about 100 years old. The foundation is hand-laid basalt. Earthen adobes vegas and native basalt rock are not only inexpensive; they also can absorb and store heat.

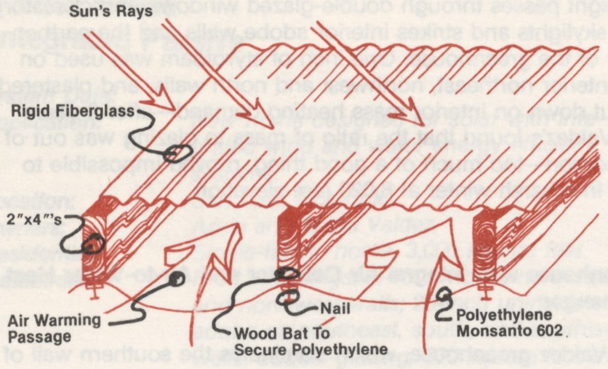
South, southeast and southwest adobe walls 20 inches thick absorb and store heat during the day for re-radiation at night. Sunlight passes through double-glazed windows and clerestory and skylights and strikes interior adobe walls and the earthen floor of the greenhouse. One inch of styrofoam was used on the interior northeast, northwest and north walls, and plastered to cut down on interior mass heating demand—after 3 years the Valdez's found that the ratio of mass to glazing was out of proportion—too much of a good thing, proved impossible to heat in a harsh winter at 8,020 feet elevation.

Greenhouse with Integral Air Collector and Air-to-Water Heat Exchanger

The Valdez greenhouse, which dominates the southern wall of the home, acts as a direct-gain solar heater with a dark adobe wall, and the earth floor and cinder block planters storing heat. With massive walls performing so well the six original water barrels in the greenhouse were taken out to prevent over massing. The greenhouse also acts as an active (fan-powered) air-to-water collector. The greenhouse is built of 2 x 6s with double-glazed rigid fiberglass on the outside and inside. Between those two glazings, air is heated and rises naturally. It is collected by a duct along the top of the greenhouse. A small fan sucks the heated air into a homemade heat exchanger which transfers much of the heat from air to water.



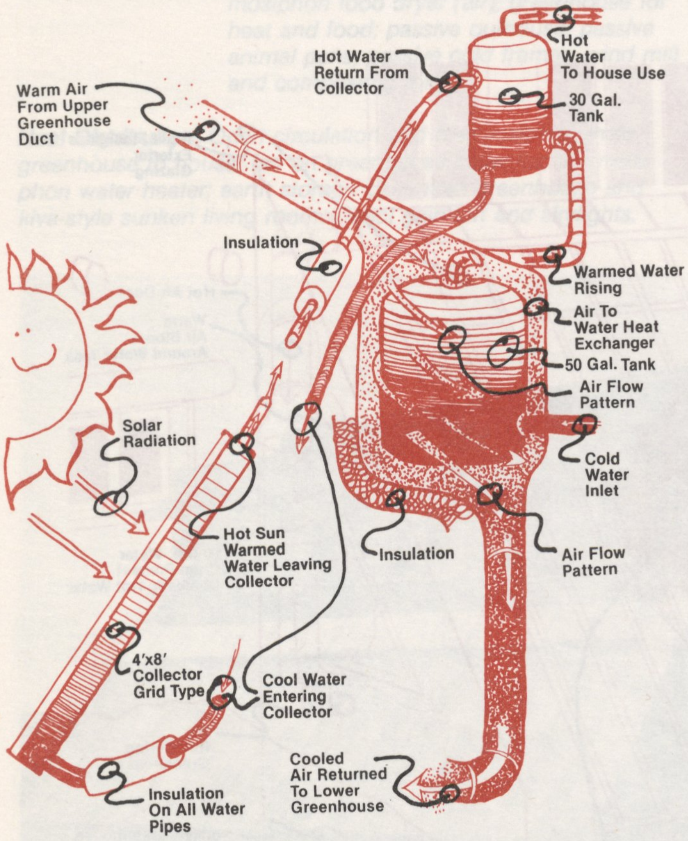
Valdez Greenhouse
San Luis, CO



Detail — Greenhouse Glazing

Homemade Air-to-Water Heat Exchanger

The heat exchanger is a 50-gallon steel drum filled with water and encased in a welded metal shell. Hot air from the exterior collector along the top of the greenhouse is taken down an interior duct and blown into a buried and insulated metal shell, heating the drum and the water in it so it may be drawn off for washing and bathing.



Valdez Domestic Hot Water System

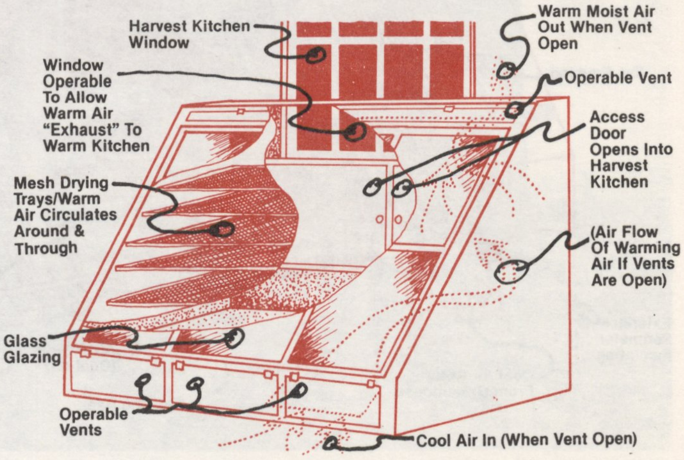
Arnie says the heat exchanger could be more efficient if metal fins or wire mesh were spot-welded to the drum inside the metal shell, increasing the surface area for heat transfer. This also would increase air turbulence around the drum, which would make the air give up its heat to the metal more efficiently.

Passive Thermosiphon Water Heater

The Valdezes also use a thermosiphon water heater for supplemental heat. A collector in the second floor annex bathroom below the level of the hot water storage tank (65 gallon Zomeworks tank with heat exchange jacket). The south-facing collector is made of copper pipes attached to a metal absorber plant with wire clamps and thermo cement insulated on the back and sides and glazed with fiberglass. Hot water from the top of the collector rises naturally by convection into the tank above it. The cool water in the bottom of the tank returns by gravity flow to the bottom of the collector, where it is heated enough to make it rise through the collector and back into the top of the tank. The thermosiphon water heater upstairs and the air-to-water heater in the greenhouse allow the Valdezes to keep their hot water supply at about 130 degrees. Supplementary back-up wood burning water heater provides almost instant boiling water by a 14 gallon Mexican-made system which is tied in to the regular plumbing system.

Passive Thermosiphon Food Dryer

Attached to their "harvest kitchen" on the southeast corner of their home (which also serves as an airlock entryway), the Valdezes have built a thermosiphon solar food dryer. The food dryer consists of a passive air collector attached to a raised box with screen trays to hold food. The box is located above the collector. Warm air rises naturally through the collector and is forced into the bottom of the box by convective currents. Heated air rises through the screen trays, passing under and around sliced pieces of food on the trays. Depending on the moisture content of the food, fruits and vegetables and jerky can be dried in two to seven days. In the winter, air rising out of the food-drying box is still warm enough to supply some heat if exhausted into the building. In summer, it can simply be allowed to exhaust upward into the air. "Since we farm three acres," Maria says, "we're into food preserving. That's what the house is structured around. We preserve almost half of our food by solar drying, including jerky. What I'm trying to do is preserve foods in the way that will keep them the most nutritious."



Valdez Food Dryer

The Valdezes have been demonstrating low-cost solar heating in Costilla County for several years and have motivated local residents to use the sun's power in practical ways, like greenhouses, water heaters and food dryers. "People are basically doubting Thomases," Maria says. "I like to have people come in, have it be kind of cold outside, and then let them burn their hands on the hot water heater or taste tomatoes in December."

Arnie and Maria are Spanish-speaking natives of the area. Their projects have provided technical assistance by helping residents and community projects to build solar devices on homes and offices in Costilla County, through workshops, personal contacts, and visits to their homes. Maria says, "You can reach a lot of people on very small grants. If you have less, it gives you the incentive to do more. We ran the Future Power and ARCA projects like we run our house, on a budget. We shop around; we have resources who give us scrap materials; it means more time looking, but it helps the project out; we've really bartered a lot. We have also found a source for purchasing recycled materials for self-help projects at a minimal cost. We are trying to make solar energy an access to low income people."

Low-cost solar energy **can** be very effective, as the Valdezes have shown. "We rely on the sun, on an average, pretty close to 75 percent," they explain. "We expected the house to do what it's doing, to provide heat and space to grow food." But Arnie cautions, "it takes a lot of hard work, devotion, and manpower."

Active Systems

Active solar systems usually use collector panels, pipes or ducts, and pumps or fans. The flat-plate collector panel, most commonly used with active heating systems, is probably the most visible piece of equipment popularly associated with solar heating. Although passive systems can be relatively inexpensive to design into a new building, active systems are more versatile because they can be located on existing walls, roofs, or backyards. But they can be expensive. Active systems are easier to automate and control. They are especially practical for applications like heating domestic hot water. Active collectors have been around since the beginning of the century. They were commonly used for domestic water heating in California and Florida during the early 1900s.

Flat-plate Collectors

Flat-plate collectors are relatively simple devices. Varying designs are available, but they all have the same basic features. A flat-plate collector consists of a well-insulated box, covered with glass or plastic glazing, which houses a black or dark absorber surface. These units are about the size of a door and are approximately three to five inches thick. They can be connected together to supply as much collection area as necessary.

Flat-plate collectors can collect up to 70 percent of the solar energy striking them and produce temperatures in the range of 90-200 degrees. When solar radiation enters the collector through a transparent cover and strikes the inside surface. it's converted to heat and absorbed by the "flat plate," or absorber plate. The plate is usually made of copper, aluminum or galvanized steel and is often coated with a selective surface, which is a special black coating that absorbs light readily.

Glass or plastic covers, used on collectors designed for winter use, help prevent heat from escaping out the top of the collector. Insulation on the back and sides of the collector box also help keep heat inside the panel. The only place the heat can go easily, once it is trapped inside the panel, is into liquid or air moving through the collector and into pipes or ducts.

From the collector, the pipes or ducts take heated fluid either to a storage area or directly to the space where heat is needed. Thermostatically controlled pumps, fans, and valves direct the fluid to the right place at the right time. At night and during sunless periods, the fluid won't circulate at all.

Flat-plate collectors are categorized as either liquid or air collectors, depending on what fluid is forced through the collector (usually either water, antifreeze solution, or air). The distribution system (pipes or ducts) and the storage system (water, rocks, or salts) usually depend on which type of collector is being used.

Types of Active Solar Systems

The active solar heating systems in this book fall into four general categories, within which almost infinite variations are possible. These are **liquid flat-plate systems, air flat-plate systems, concentrator systems,** and **heat-pump assisted systems.**

Liquid-Flat-plate Systems. In liquid type flat-plate systems, water or a solution of water and antifreeze is used. Liquid systems are popular, primarily because water has such a high capacity to hold heat. It can retain over three times more thermal energy than an equivalent volume of air.

The flat-plate collector used in a liquid system generally has tubes attached to the absorber two to eight inches apart. The liquid circulates through these tubes to pick up heat from the plate. To get as much heat as possible, a good thermal bond between the plate and the tubes is important. Tubes can be soldered into place, clamped or pressed into the plate, or attached with wires. Liquid is heated inside the absorber and pumped to a water storage tank. Water provides excellent thermal storage because it conducts heat easily throughout its whole mass. Water stores heat better than most natural substances. Oceans are the earth's natural solar heat storage system.

In Figure 9, a typical tube plate collector is shown. The coldest water from storage is fed into the tubes via a supply pipe called a manifold or header, travels through the tubes (risers) and picks up the heat. Another manifold at the top of the collector carries the liquid to the place it will be used.

The simplest absorber plate for liquid systems is the trickle type, developed by solar inventor Harry Thomason. In this collector, the plate is simply a sheet of black corrugated metal. Liquid runs down the grooves in the sheet and is collected in a trough at the bottom of the collector. The trickle type is not as efficient as most others, but is usually less expensive and is well-suited to do-it-yourself construction.

Below freezing temperatures are common in Colorado, so fail-safe precautions must be taken to avoid freezing in liquid collectors. Water expands when it turns to ice, which can break pipes and cause considerable damage to a system.

There are several ways to avoid freeze-up danger. Two of the most common are to drain the system automatically when the pump shuts off, or circulate an antifreeze solution through the collector rather than plain water.

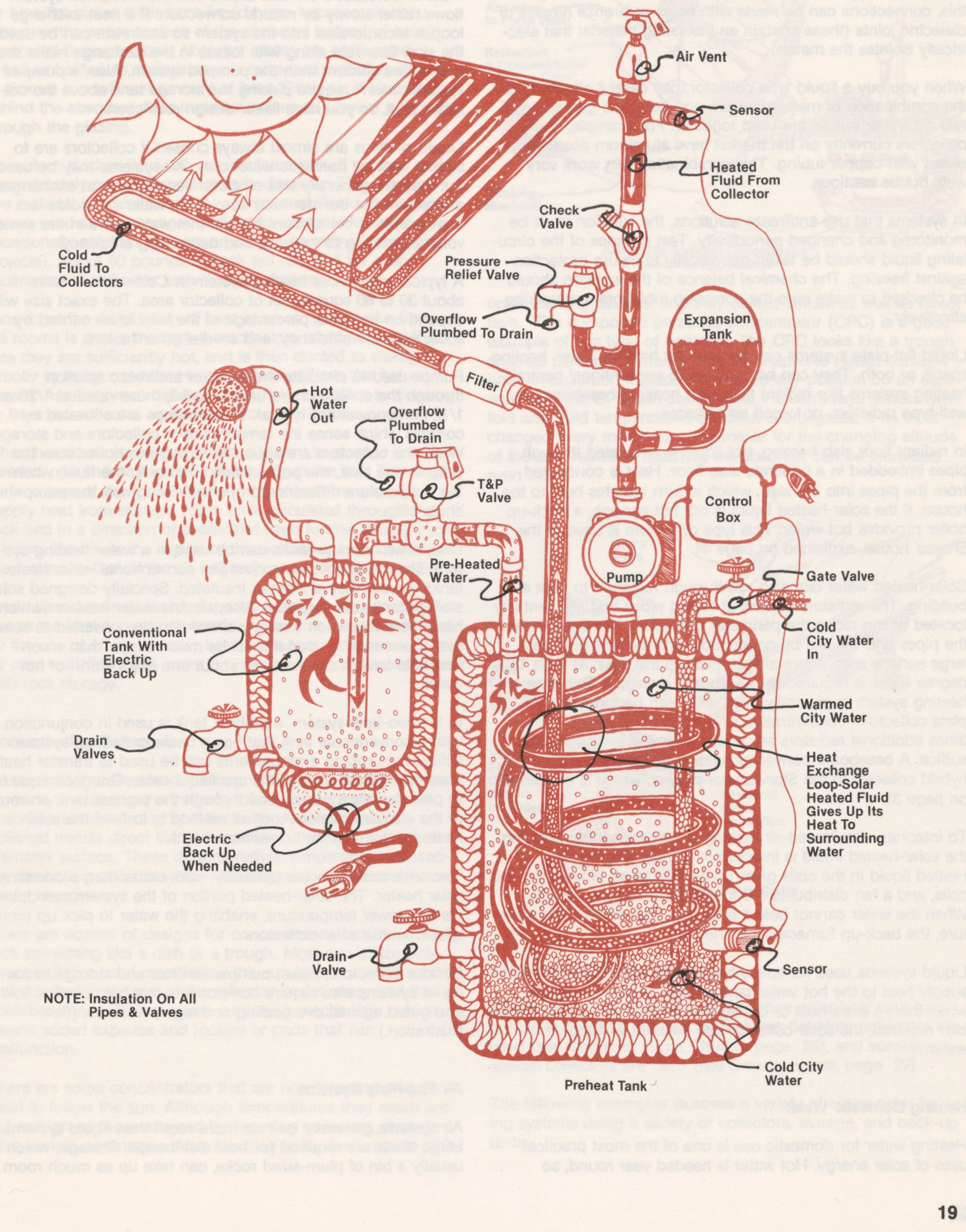
When antifreeze is used, it must be kept totally separate from the water supply as a safety precaution. (Who wants to drink antifreeze?) To achieve this separation, devices called heat exchangers are used. They keep the fluids from coming into contact with one another, but allow heat to be transferred. Heat exchangers of several different designs are available. In most designs, the heated solution travels through metal coils that are either submerged in the water or wrapped around a storage tank. A full surface heat exchanger, which is essentially a tank within a tank, can also be utilized. With toxic antifreeze solutions, double-wall heat exchangers are required (often by code) to prevent contamination in case of leaks.

Next to freezing, corrosion is the worst enemy of liquid systems. Metals like aluminum and untreated steel will corrode rapidly if exposed to water, so corrosion inhibitors are added to the circulating fluid to avoid problems. (Again, a heat exchanger must be used to prevent contamination of the water supply.) Use of copper in the system also helps. Copper is corrosion resistant, as well as one of the best heat conductors. Unfortunately, it is much more expensive than the other metals.

In addition to the corrosion caused by the chemical reaction between water and metal, galvanic corrosion can also take

Figure 9
Closed-Loop, 2-Tank Domestic Hot Water System

Components drawn in order of logic, not necessarily an actual representation, as plumbing angles may differ in an actual installation.



place in a solar system. This occurs when two different metals come into contact with one another in the presence of water. For instance, if a copper fitting is directly connected to a steel storage tank, steel threads in the joints may be stripped by galvanic corrosion. This problem can be reduced by isolating metals like copper and steel from each other. To accomplish this, connections can be made with brass or bronze nipples or dielectric joints (these contain an insulating material that electrically isolates the metals).

When you buy a liquid type collector, pay careful attention to the combination of materials used, and get good guarantees if two dissimilar metals are used together. For example, many collectors currently on the market have aluminum absorber plates with copper tubing. This combination can work very well, but be cautious.

In systems that use antifreeze solutions, the solution must be monitored and changed periodically. Test samples of the circulating liquid should be taken periodically to insure protection against freezing. The chemical balance of the solution should be checked to make sure the corrosion inhibitors are working effectively.

Liquid flat-plate systems can be used for heating water, heating space, or both. They can be tied in with conventional central heating systems like radiant floor slab heating, baseboard or wall-type radiators, or forced air furnaces.

In radiant floor slab heating, hot liquid is circulated through pipes imbedded in a concrete slab floor. Heat is conducted from the pipes into the slab, which in turn radiates heat to the house. If the solar-heated liquid is not hot enough, a back-up boiler provides hot water. This type of system is used in the Shores' house, explained on page 41.

Solar-heated water can also run through radiators to heat a building. The radiators consist of finned pipes that are centrally located or run along the perimeter of a room. Hot liquid heats the pipes and the fins by conduction, and the fins provide a large surface area where air can pick up the heat. At least 150-degree water is required for baseboard radiators. This type of heating system is generally used with high performance flat-plate collectors, concentrators or a hybrid of the two. Sometimes additional radiators are added so lower temperatures suffice. A baseboard convector heating system is used with a hybrid collector in the Stonebraker project, which is explained on page 33.

To integrate with forced-air heating a heat exchanger carrying the solar-heated liquid is installed in or near the furnace. Heated liquid in the coils gives up its heat to air blowing by the coils, and a fan distributes it through ducts to your rooms. When the water cannot heat the air to a high enough temperature, the back-up furnace heats the air.

Liquid systems used for space heating generally have a loop to supply heat to the hot water tank as well. In sunny periods when there's extra heat or during the summer when space heat isn't required, the solar collector can be used to supply hot water.

Heating Domestic Water

Heating water for domestic use is one of the most practical uses of solar energy. Hot water is needed year round, so equipment never sits idle and can usually pay for itself in fuel savings faster than a space heating system.

Of the two types of solar water heaters generally used—the thermosiphon and the pumped system—the latter is utilized most in Colorado's climate. Liquid in a thermosiphon system flows rather slowly by natural convection. If a heat exchange loop is incorporated into the system so antifreeze can be used, the slow flow rate along with losses in the exchange make the heater less efficient than the pumped system. Also, a pumped system doesn't require placing the storage tank above the collector area, so you have fewer design restrictions.

Liquid systems are almost always chosen if collectors are to supply heat for domestic water only. Air systems may be used, but they are generally less efficient. Very large heat exchangers are required to transfer heat from air to water (air holds less than one-third the amount of heat that water does in the same volume), adding to expense and decreasing efficiency.

A typical solar water heating system in Colorado will have about 30 to 80 square feet of collector area. The exact size will depend on demand, percentage of the load to be carried by solar, collector efficiency, and several other factors.

Pumps used to circulate the water or antifreeze solution through the collectors are usually small; those rated at 1/20 or 1/12 horsepower are typical. These pumps are activated by controls which sense the temperature in collectors and storage. When the collectors are about 10-12 degrees hotter than the water in the tank, the pump starts circulating the fluid; when the temperature difference drops to 3-5 degrees, the pump shuts off.

One or two storage tanks can be used in a water heating system. The storage tanks are just like conventional water heater tanks, except they are better insulated. Specially-designed solar storage tanks are available. Also, electric water heaters (which have more insulation than gas units) can be converted to solar use. If one tank is used it must be much bigger than a conventional tank; it should store about one day's worth of hot water.

In the two-tank system, a preheat tank is used in conjunction with a conventional tank that has a back-up heating system. Different plumbing arrangements can be used to transfer heat from the preheat tank to the auxiliary heater. One technique is to pass the water supply line through the preheat tank en route to the auxiliary heater. Another method is to feed the solar-heated water into the conventional tank.

Two-tank arrangements generally work better than a one-tank solar heater. The solar-heated portion of the system can operate at a lower temperature, enabling the water to pick up more heat from the solar collectors.

Besides collectors, pipes, pumps, controls and storage tanks, liquid systems also require components that help control flow and guard against overheating and high pressures. (See illustration.)

Air Flat-Plate Systems

Air systems generally take up more room than liquid systems. Large ducts are required for heat distribution. Storage, which is usually a bin of plum-sized rocks, can take up as much room as a Volkswagen van in a home-heating application. On the other hand, they don't need to be protected from freezing or corrosion. Air systems do not have to be leak-proof to work. They are very popular in Colorado for heating homes or small buildings.

Air type flat-plates differ from liquid types because air circulates over the entire surface of the absorber instead of being channeled through tubes. Absorber plates are corrugated, finned or baffled so surface area is increased, enabling the air to pick up a maximum amount of heat. Often air is circulated behind the absorber plate in an air system to prevent heat loss through the glazing.

Air system storage is usually an insulated box of washed rocks approximately two or three inches in diameter. This inexpensive material is available almost everywhere. Rocks are almost always used as the storage medium for air systems, although occasionally eutectic salts are employed (mostly in research projects). About 50 pounds of rock are required for every square foot of collector area in an air system.

Fans force the distribution of heat in an air system. Air from the rooms is drawn through the collectors when sensors indicate they are sufficiently hot, and is then ducted to storage or directly to living quarters. Heat is extracted from the hot air stream. Auxiliary heat can be used in an air system by passing air from the collector or storage through a furnace.

When heated air from the collectors is sent to storage it is delivered at one end of the rock bin, usually at the top. The large surface area of the rocks results in rapid heat transfer. To supply heat from storage, room air is circulated through the rock bed in a direction opposite that used for the storing cycle. It leaves the bin in the region of the hottest rocks, at a temperature close to that of the air originally used to heat the mass.

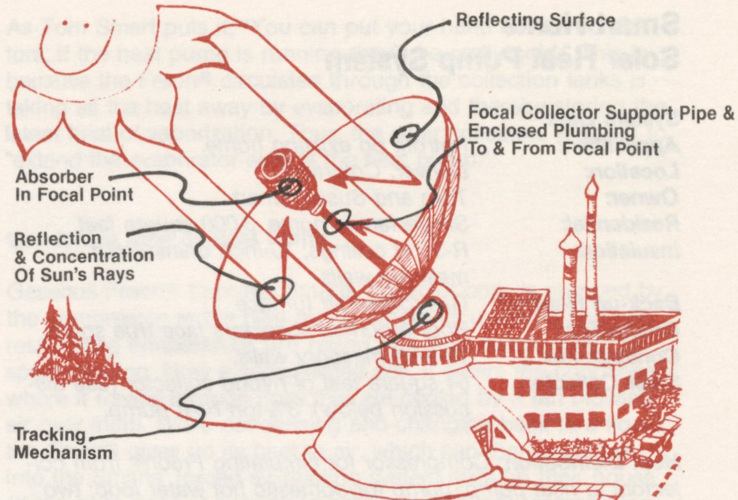
If you have an air system for space heating, it is also possible to use the heat for your domestic water. This can be achieved by the use of an air-to-water heat exchanger. You can run hot air over coils filled with water or you can surround a water tank with rock storage.

Concentrating Collectors

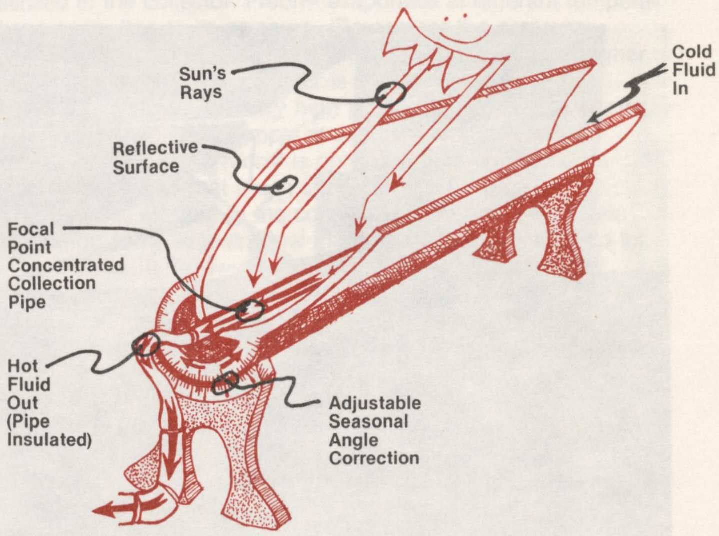
Concentrating collectors are designed to produce high temperatures by increasing the intensity of the sunlight striking the absorber. Lenses or highly reflective surfaces like mirrors or polished metals direct the solar radiation that strikes them onto a smaller surface. These devices deliver temperatures exceeding the boiling point of water (212 degrees), and hence more useful energy.

There are dozens of designs for concentrators, but they usually look something like a dish or a trough. Most can utilize only direct radiation, and must follow the sun to operate. Either the entire collector swivels, or the reflector is stationary and the absorber moves. This requires a tracking mechanism, which means added expense and motors or parts that can malfunction.

There are some concentrators that are non-focusing and don't need to follow the sun. Although temperatures they reach are not as high as those attained by focusing collectors, they do have certain advantages. Non-focusing units don't require elaborate tracking devices, and they collect diffuse as well as direct rays. The compound parabolic concentrator (CPC) is a good example of this type of collector. The CPC looks like a trough and has parabolic surfaces that are shaped to reflect sunlight onto an absorber. If placed in a stationary position on an east-west axis, the CPC can concentrate the sun's rays almost two-fold and yield temperatures of about 250 degrees. If its tilt is changed every month to compensate for the changing altitude of the sun, radiation reaching the absorber can be increased even more.



Automatic Tracking Concentrator Industrial Application



Trough Concentrator

Solar-Assisted Heat Pumps

It's possible to combine low temperature solar heat with heat pumps in a variety of ways. Sometimes flat-plate collectors are used (see Center of Hope Church, page 25), and sometimes special collectors are used (see Smarts' house, page 22).

The following examples illustrate a variety of active solar heating systems using a variety of collectors, storage, and back-up units.

Smart Home
Solar Heat Pump System

System Data:

Application:	*Retrofit on existing home.*
Location:	*Denver, Colorado.*
Owner:	*Tom and Susan Smart.*
Residential:	*Single-family home, 3,000 square feet.*
Insulation:	*R-30 in ceilings; 10-inch uninsulated masonry walls.*
Back-up Heating:	*Gas forced air furnace.*
Orientation:	*Roof-mounted collectors face true south.*
Construction:	*10-inch masonry walls.*
Solar Collector:	*64 square feet of hybrid collector (see discussion below); 3½-ton heat pump.*

Heat Distribution: *Compressor for circulating Freon® from collectors to heat pump; pump for domestic hot water loop; two fans for inside and outside coils of air-to-air heat pump.*

Storage: *No inside storage, although there are 40 gallons of water in each hybrid collector (see discussion below).*

Heat Exchangers: *30 feet of ⅝-inch copper coil in each collector panel to exchange heat from water (in collector) to Freon® (in coil); condenser evaporator in heat pump to exchange heat from Freon® to air; single-wall exchanger tank for domestic hot water (Freon®-to-water).*

Controls: *Standard heat pump controls with indoor thermostat.*

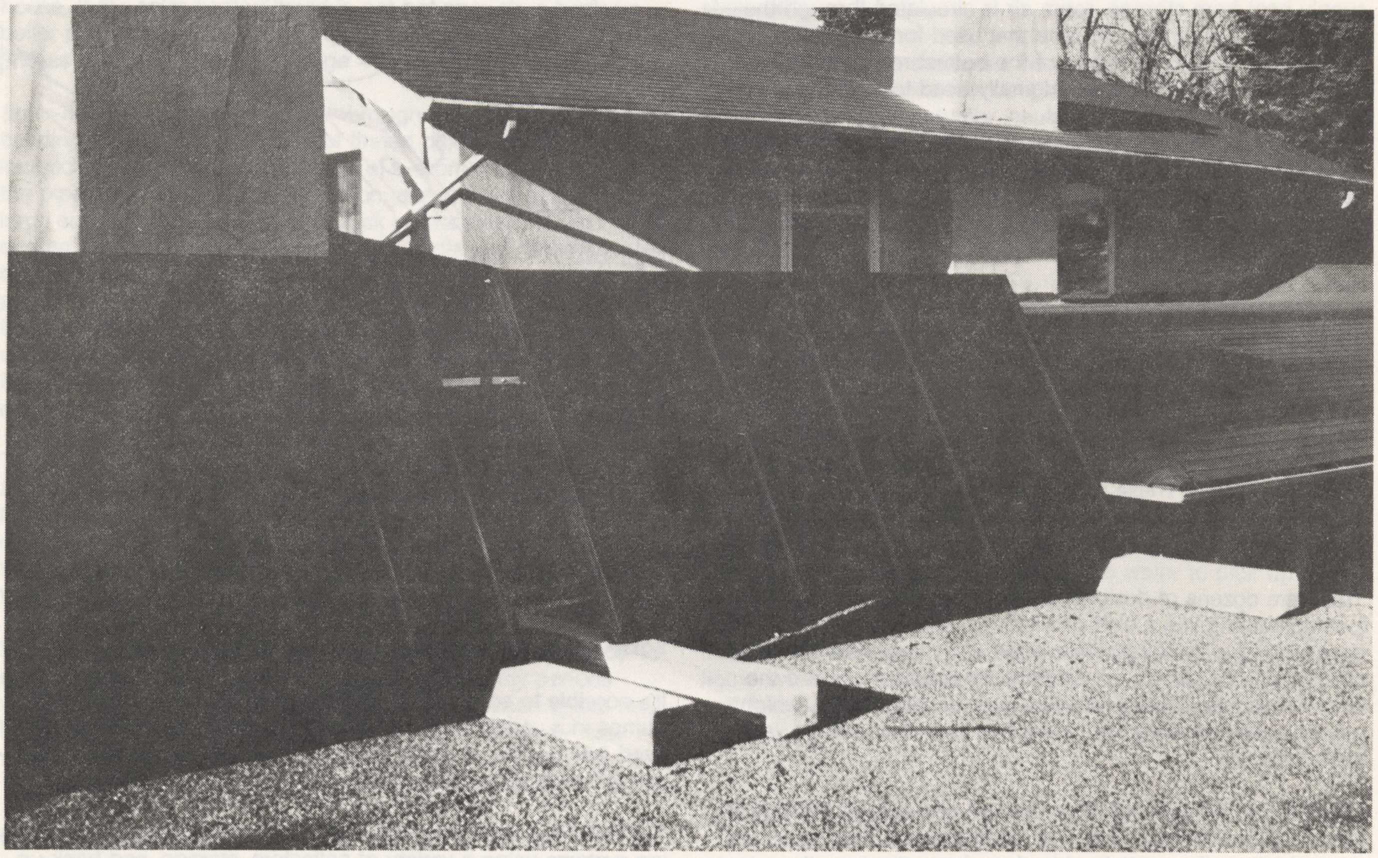
Solar Cost: *$8,000, including complete retrofit; tearing out existing radiator heating and installing new forced-air ducting and gas-fired duct heater; all equipment and installation included.*

"We were in a perfect situation to go solar," Tom Smart explains. "We had to replace our heating system anyway because the steam boiler was in bad shape and we wanted forced-air heat. I was professionally involved with the company, so we decided to go solar. We've been interested in it for a long time."

The commercially available system that Tom and Susan Smart decided on uses a relatively new concept in active solar energy collection. "Part of the concept is sort of experimental," says Tom. "A retrofit did not require any changes to the structure of the house."

The two 4 x 8-foot collectors in the Smarts' system look like conventional flat-plate collectors without any glazing, but they are actually "flat" (about 4 inches deep) black, galvanized steel tanks, each partially filled with 40 gallons of water and tilted toward the sun. A space at the top of the collector tanks allows for expansion when the water freezes. Thirty feet of ⅝-inch copper tubing filled with Freon® is coiled through each of the closed tank collectors of water in a closed loop from the collectors to the heat pump mounted on the Smarts' roof.

Because the Freon® in the coils is much cooler than the water in the tanks (even when the water is frozen), the Freon® picks



The home of Tom and Susan Smart in Denver, Colorado, needed a new heating system, so they decided to experiment with a commercially available solar system using a heat pump.

up heat from that water. This means that the **entire** surface of the collector tanks can conduct heat from the surrounding environment (called "ambient" heat) through the water into the Freon® coils. Although the north sides of the collectors are generally cooler than the south sides (at least when the sun is shining), they can still collect whatever heat is in the air. The collectors transfer heat to the water and to the Freon® coils inside.

Having picked up heat from all directions through the water, the Freon® fluid then goes into the Smarts' heat pump, where the heat is exchanged and delivered into the house through a forced-air ducting system.

Heat Pump — A Reverse Refrigerator

A heat pump uses electricity to compress Freon® (or other refrigerant fluid) that has picked up low-grade heat energy from surrounding air, ground or water. It is often described as a "refrigerator in reverse." A refrigerator uses Freon® to pick up low-grade heat from inside the box where the food is stored and transfer the heat outside through a heat exchange coil on the back of the refrigerator. (You may have noticed this heat being exhausted from the bottom of your refrigerator when the fan is blowing air over the coils.) The Freon® vaporizes (turns from liquid to vapor) when it picks up heat inside the refrigerator, and condenses (turns from vapor to liquid) when it gives off heat outside the refrigerator. An electric compressor raises the pressure of the evaporated Freon® and consequently raises the temperature so it will give up its heat to the air around the refrigerator.

A heat pump, in the winter mode, does exactly the reverse. Instead of taking heat from inside a box and dumping it outside the box, the heat-pump takes heat from outside a building and dumps it into the building at temperatures appropriate for human comfort.

Latent Heat of Vaporization

Just as water changes phase from liquid to vapor when it boils at 212 degrees at a pressure of one atmosphere, Freon® changes phase from liquid to vapor at much lower temperatures (depending on the pressure it is under). You can apply heat to a pot of water without boiling it away (evaporating it) because a lot of energy is taken up by the water as it changes phase. This is the latent heat of vaporization, and it will be given off when the vapor cools and turns back into liquid (condenses). If you raise the pressure of the water as it evaporates (as in a pressure cooker), you will raise its temperature (the reason food cooks quicker in a pressure cooker). If you lower the pressure of the water (there is less atmospheric pressure at high altitudes above sea level), you will lower its temperature (the reason food takes longer to cook at high altitudes). The compressor in a heat pump raises the pressure and thus the temperature of the evaporated Freon® so it will give off the total energy it picked up outside when it condenses.

Evaporator Side of Heat Pump

The evaporator side of the heat pump collects energy from the atmosphere and the sun. The Smarts' system uses the panels as the evaporator of the heat pump thereby collecting energy more efficiently.

As Tom Smart puts it, "You can put your hand on the collectors; if the heat pump is running they'll be really cold." This is because the Freon® circulated through the collection tanks is taking all the heat away by evaporating and thereby storing the latent heat of vaporization. Thus, the solar collectors are said to "extend the evaporator side of the heat pump."

Condenser Side of Heat Pump

Gaseous Freon® from the Smarts' collector coils is pumped by the compressor in the heat pump, where its pressure and corresponding temperature are raised to a level that is useful for space heating. Now a superheated gas, it enters the condenser, where it travels through coils that are cooled by a fan blowing air over them. While condensing and changing back to a liquid, the Freon® gives up its heat to air, which can then be blown into the Smarts' forced air ducting system through their house. (If the air is not hot enough to satisfy the house's demand for heat, the thermostat kicks on a gas-fired back-up forced-air furnace).

Thermostatic Expansion Value

After the Freon® has condensed and given all of its heat to the house, it goes through a thermostatic expansion valve, before going back to the outdoor coil and solar collectors to be evaporated again. This valve allows the Freon® to expand, thus cooling it. The Freon® expands to the appropriate temperature and pressure so that it will evaporate at the temperature being sensed in the collector. Freon® evaporates at different temperatures according to its pressure. (Remember the pressure cooker!) At higher temperatures, it will evaporate under higher pressure, so when the collector is very hot, the Freon® is allowed to expand to a very high pressure. When the collector is relatively cool, for example at night or during freezing, cloudy weather, the Freon® is only allowed to expand to a lower pressure so that it can still evaporate at the lower temperatures existing in the collector coils. The thermostatic expansion valve "knows" how much mass of the Freon® to let flow, because it "knows" the temperature at the collectors.

No Indoor Storage

Because the compressor enables the Freon® to pick up heat (or evaporate) even at very low temperatures (as low as 10 degrees below zero), no storage is required to carry the heating system through cloudy weather periods or nighttime laws. The Freon® can pick up energy at a low level, and the compressor will raise its temperature to a useful level. Even if the water in the collectors freezes solid, the Freon® can pick up some energy because it is cooler than the ice, and therefore can pick up "heat" from the ice. (Also see latent heat of fusion, below.) In many applications storage can be added to take advantage of off-peak electrical rates.

Because of the extra evaporating surface added by the solar collectors, the conventional defrost cycle on the air-to-air heat pump is simply disconnected on the Smarts' system and replaced by a less energy-consumptive defrost cycle. The purpose of the defrost cycle (which consumes a lot of electricity in a regular air-to-air heat pump) is to remove frost. Frost makes the heat pump less efficient. In the Smarts' system, the evaporator surface area (or heat pick-up area) is enlarged by the copper tubing coiled in the collectors leaving enough energy available to evaporate Freon® even when the pipes frost up. If the copper line to the collectors were buried underground, it would work even better because the ground is always around 45 degrees no matter how cold the outdoor air temperature, due to the thermal storage of the earth's mass. In the Smarts' particular case, it was impractical to bury the lines because the entire installation is mounted on their roof.

Latent Heat of Fusion

In addition to using the latent heat of vaporization, as all heat pumps do, the Smarts' system picks up some efficiency benefits from the latent heat of fusion. In the same way that water takes energy to evaporate and gives off energy when it condenses, water takes energy to melt and gives off energy when it freezes. (Remember the heat energy your freezer must remove as it freezes water into ice.) The Freon® coils in the collectors can actually pick up this heat of fusion as the water inside the collectors freezes solid! In fact, as Tom says, "We want the water to freeze up at night because ice conducts heat three to four times better than water."

Domestic Hot Water

The Smarts also can get a good deal of their hot water from the solar energy collected by the system. Because people use hot water year around, and only use space heat during the winter months, the first priority for the solar heat is hot water. Therefore, the super-heated Freon® coming from the compressor goes first to the heat exchanger for the domestic hot water. The heat exchanger is a tank filled with water which has Freon® coils running through it. The Freon® gives up heat to the water, and the water is then allowed to flow from the exchanger into the regular gas water heater. If the water is already the desired temperature when it comes in, the gas will never come on. If it is not hot enough, the gas will come on to heat it to the desired temperature.

Reversible Heat Pump for Cooling

The Smarts' heat pump system is also capable of cooling their house in the summer. The system can be reversed from a heating mode to a cooling mode by reversing a four-way valve and making the indoor heat exchange coil the evaporator side of the cycle and the outdoor air coil the condenser side. In the space cooling mode, the solar collectors are being used to extend the surface area where condensation dumps indoor heat outdoors. This rejected heat, along with heat from the collectors, is used to heat domestic hot water. The cooling mode of the space-conditioning systems is not solar-assisted. It is simply assisted by the added surface area the collectors provide for condensation of the Freon®.

Tom Smart is very excited about his solar system, and points out its advantages with pride. For example, he says, "The collector is not subject to vandalism because there's no glass; about the only thing you can do to it is shoot a bullet through it. Storage and exaggerated roof lines are also required."

Since they never had forced-air heat before they had the collector and heat pump system, the Smarts do not know exactly how much energy they will save by using solar energy. Since gas (to run a forced-air furnace) is cheaper per unit than electricity (to run a heat pump), Tom says the payback "doesn't look as good as if you were competing with electric resistance heat." But he feels he made a good investment, and estimates that he will save "at least two-thirds" of the energy that would have been required if they had switched to a conventional gas forced-air system instead of the solar-assisted heat pump system.

"Not only can they pick up heat in cloudy weather and at night, but they actually work better in the wind than in still air, because there is more energy blowing by them," Tom explains, pointing to the collectors. "And it's easier to retrofit because you only need two collector panels." Tom guesses that his house and hot water are about 70 percent solar-heated, and the other 30 percent is electricity consumed. "Of course, the electrical consumption goes up, but unlike many solar products the demand is fairly flat." Many solar heating systems tend to require peak energy use for back-up heating just when the demand of non-solar customers is greatest—during cold snaps and in the evenings when people come home and turn their thermostats up and all their appliances on.

Although he says the system is "confusing to most people," Tom is glad he is experimenting with a system he believes is a better use of solar energy for home heating than conventional flat-plate collectors.

Center of Hope Church
Drain-Down Water with Heat Pump

System Data:	
Application:	*Westminster, Colorado.*
Owners:	*Center of Hope Church.*
Church and Parsonage:	*Two buildings totaling 20,000 square feet.*
Insulation:	*R-24 in walls; R-30 in ceilings.*
Back-up Heating:	*No conventional back-up; solar system integrated with 25 horsepower chiller which works like a heat pump.*
Orientation:	*Collectors face due south.*
Solar System:	*3,100 square feet of water collector on church (2,728 square feet net) for space heat; 100 square feet of water collector on parsonage for domestic hot water.*

Heat Distribution: *Pumps for distribution from collector to storage tanks; blower (in air handler) for forced air interior heat distribution.*

Storage: *Two tanks of water (6,000 gallons and 8,000 gallons) totaling 14,000 gallons storage for large church collectors; domestic-size preheat tank for parsonage hot water collectors.*

Heat Exchangers: *Heat exchanger in heat pump to exchange heat from water to refrigerant fluid; liquid-to-air heat exchange coil in air handler.*

Controls: *Custom control package; all automatic, pneumatic, electric, and electronic.*

Solar Cost: *$80,000 completely installed.*

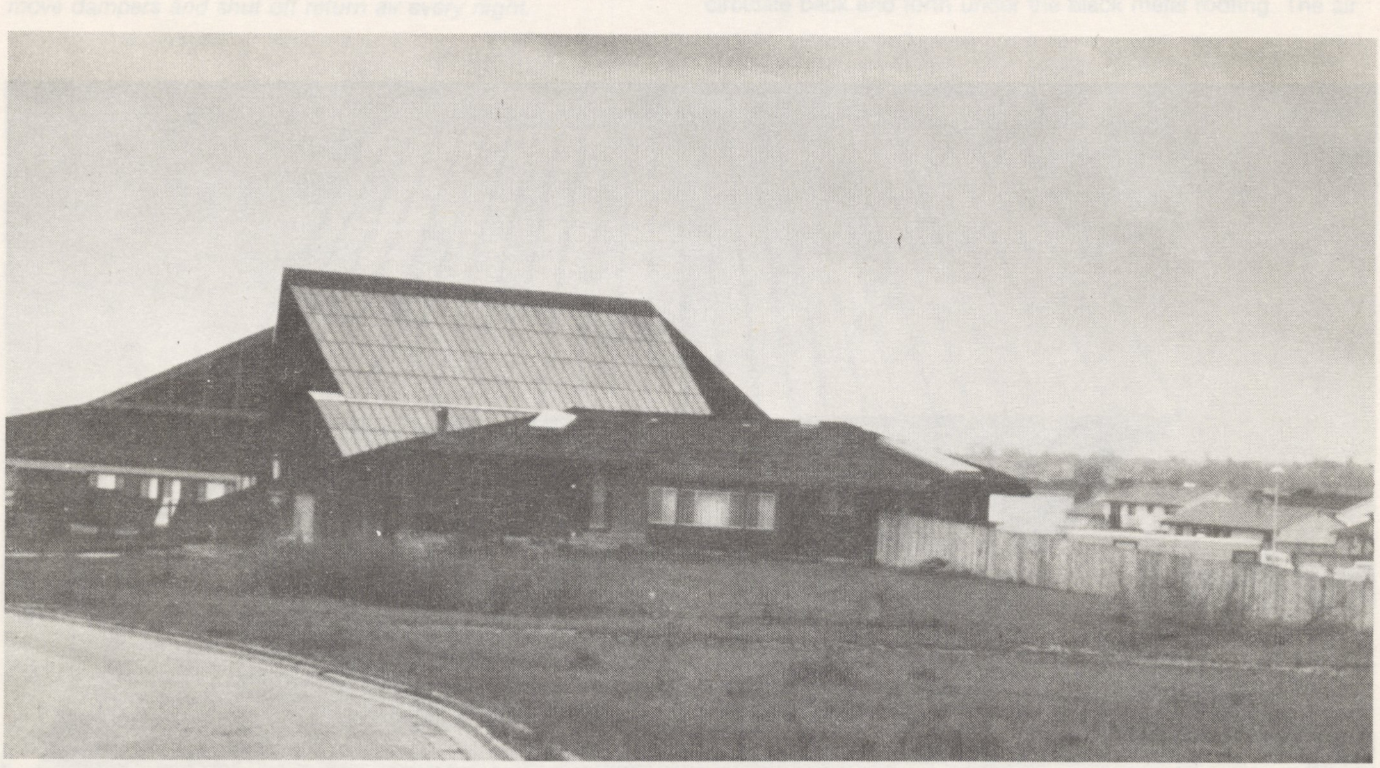
"The main reason we went solar was because we thought the church should be a leader in things like this," says Pastor Peter Haan about the first solar-heated church in the nation, completed in September, 1976. The system was manufactured and installed by a local solar company owned by a previous church board member. Haan says "86.5 percent of the energy requirements (for both the church and parsonage) are directly from solar; 12.4 percent from the electric, solar-assisted heat pump; and about 1 percent from wearing sweaters and warm clothing.

"It couldn't be any better. The most we ever pay, for an all-electric, demand-meter utility bill, is the cost of heating five all-electric homes. We have a half acre of heated floor space. Both buildings are used six or seven days a week. The system does way more than we expected."

The day care center in the church serves 180 preschool children, 12 hours a day, six days a week. A commercial kitchen is used to provide hot meals. The kitchen has the only vent allowing warm air to escape. All other warm exiting air is ducted through an air blender where it preheats incoming outside air. The pastor says, "The unusually good system of moving air really helps. Even the bathroom air has heat taken out before it leaves the building."

Air Blender for Waste Heat Recovery

Sixty-five percent of the heat in the exhausted air is transferred to incoming fresh air. The building is supplied with fresh air, required by code, but saves a significant amount of heat. The waste heat recovery occurs in the air blender. It has no moving parts, but consists of many sheet metal fins that help mix warm, exiting air with cool, incoming air to recapture heat



The Center of Hope Church and day care center in Westminster, Colorado, uses active, drain-down water collectors in combination with heat pump devices to supply 98 percent of the church's space and water heating needs, as well as 60 percent of parsonage needs. Courtesy R.M. Products.

before it leaves the building. The waste heat recovery system, combined with night set-back thermostats, reduces the total heat load of the church from 300,000 Btu's per hour to 144,000 Btu's per hour.

Solar System/Heat Pump

The Center of Hope solar collectors are made with copper plates which select various wavelengths of the sun, and tubing in an insulated aluminum box covered with single-pane tempered glass. Mounted during construction between the rafters, the collectors saved money by serving as the roof surface. Because of the integral mounting, they are easily accessible for maintenance.

Heat is stored in 14,000 gallons of water in two tanks. The main 6,000-gallon tank and the collector surfaces are monitored for temperature changes. When the collector becomes 20 degrees hotter than the storage, a pump circulates water through the collector until its temperature is within 3 degrees of storage temperature. The collectors drain into the storage tanks whenever the pump is off, eliminating the dangers of freezing or overheating. When the pump is on, 95-to-185-degree water is pumped directly to the air-handler heat exchange coil, where forced air picks up the heat and delivers it to the buildings.

If the water storage temperature drops to 95 degrees, the water is mixed with chilled water and sent to the heat pump at 55 degrees. The heat pump channels heat into the building through the coil in the air handler. After releasing its heat, the air is returned either to the collectors or to one of the storage tanks.

"Either of the two storage tanks would adequately take care of the [church] building," according to Pastor Haan, who described plans to add 15,000 square feet of heated space using the same solar system. The new building will receive 75 percent of its heat from a passive solar system, including a greenhouse. The remaining 25 percent will be provided by the original active system, with the addition of a swimming pool for storage.

Fuel Bills

The highest monthly fuel bill at the Center of Hope was $1,250 in December of 1978, although the amount of electricity used was less than in December of 1977. The summer bill usually is around $300. According to a computer study, an 8 percent annual increase in the price of electricity over a 20-year period, will yield the church a fuel bill savings of $180,000. "That's double the return predicted by the people who put it in," said Pastor Haan. "It will be paid for in 12 years, according to the computer."

He added, "It's amazing how much pride the congregation has in the solar system now, much more than when we first built it. For one thing, the system has proved itself, but for another, people are finally starting to talk about solar. I would try to convince anybody anytime that if they didn't add 10 percent or even 20 percent to the cost of their house for solar, they'd be crazy. So it costs $10,000. It's the best $10,000 you'll ever spend. It's just a shame that more people aren't doing it. When people say solar won't be economic till the year 2000, it's ridiculous. Ten years from now, anybody who doesn't consider solar as an option will be considered backwards."

Pagosa Springs Fire Station
Air Collectors Built into Roof

System Data:

Application:	*New building designed for solar.*
Location:	*West of Pagosa Springs, Colorado.*
Owners:	*Pagosa Fire Protection District.*
Fire Station:	*Office and truck garage; 2,700 square feet with loft.*
Insulation:	*R-19 in walls; R-30 on north roof (south roof constitutes collector); slab perimeter insulated.*
Back-up Heating:	*Propane forced-air furnace (170,000 Btu/hr).*
Orientation:	*Collector face of gable roof faces true south.*
Construction:	*2 x 6 inch frame construction; 2 x 12 inch rafters.*
Solar System:	*714 square feet of roof collector.*

Heat Distribution: *Furnace fan in back-up forced-air furnace for distribution to building; blower fan for circulating air through collector to storage.*

Storage: *6-foot x 6-foot x 16-foot rock box containing 576 cubic feet of "golfball to baseball sized" rock; also passive storage of 6 inch concrete floor slab (perimeter insulated) and 500 gallons of water on each of the two fire trucks.*

Heat Exchangers: *None.*

Controls: *Fan blower to collector automatically on when collector reaches 90 degrees; off when collector is below 90 degrees; thermostat on furnace for heat distribution; manually move dampers and shut off return air every night.*

Solar Cost: *$5,000, including cost of roof, all roofing materials and labor.*

"We calculated that this building would cost about $98 per month to heat with just propane. With solar, our heating bills have averaged $34 per month over the last two years," according to Danny Armijo, who helped foster and design the solar-heated Pagosa Springs Fire Station.

Danny works at Eaton International Construction. His company donated the construction of the building to the Pagosa Springs Fire Protection District. The building has been operating since January, 1976, and Danny said the furnace rarely runs in the daytime. The thermostat in the building is set at 40 degrees, "just to keep it from freezing." The only occupants, except for one day a week when meetings are held, are two large fire trucks each holding 500 gallons of water. Much as people give off their body heat to a building, these trucks supply thermal mass that helps the temperature of the building at night.

The lowest temperature ever recorded in the fire station during the first two winters of use was 46 degrees—this in a high alpine climate where sub-zero temperatures are not uncommon. The south roof of the building is constructed so that its 2 x 12-inch rafters and black metal roofing form a solar air collector which takes care of 70 percent of the building's heat requirements.

Solar Collector Integral with Roof

Danny cut notches into the rafters, roofed the building with black metal and covered the south roof with two layers of fiberglass glazing. The notches in the rafters allow hot air to circulate back and forth under the black metal roofing. The air

The fire station in Pagosa Springs is about 70 percent solar-heated by a fan-powered air collector built into the roof.

is forced by a blower from the bottom of one rafter through the notch in the top of the next, to a notch in the bottom of the next rafter, and so on, in a serpentine pattern. Rafters are isolated from the building interior by a plywood ceiling, 6 inches of fiberglass insulation, 2 inches of foam board insulation and a vapor barrier. The rafters form baffles that create turbulence and enhance heat exchange from the black absorber plate (metal roofing) to the air circulating behind it.

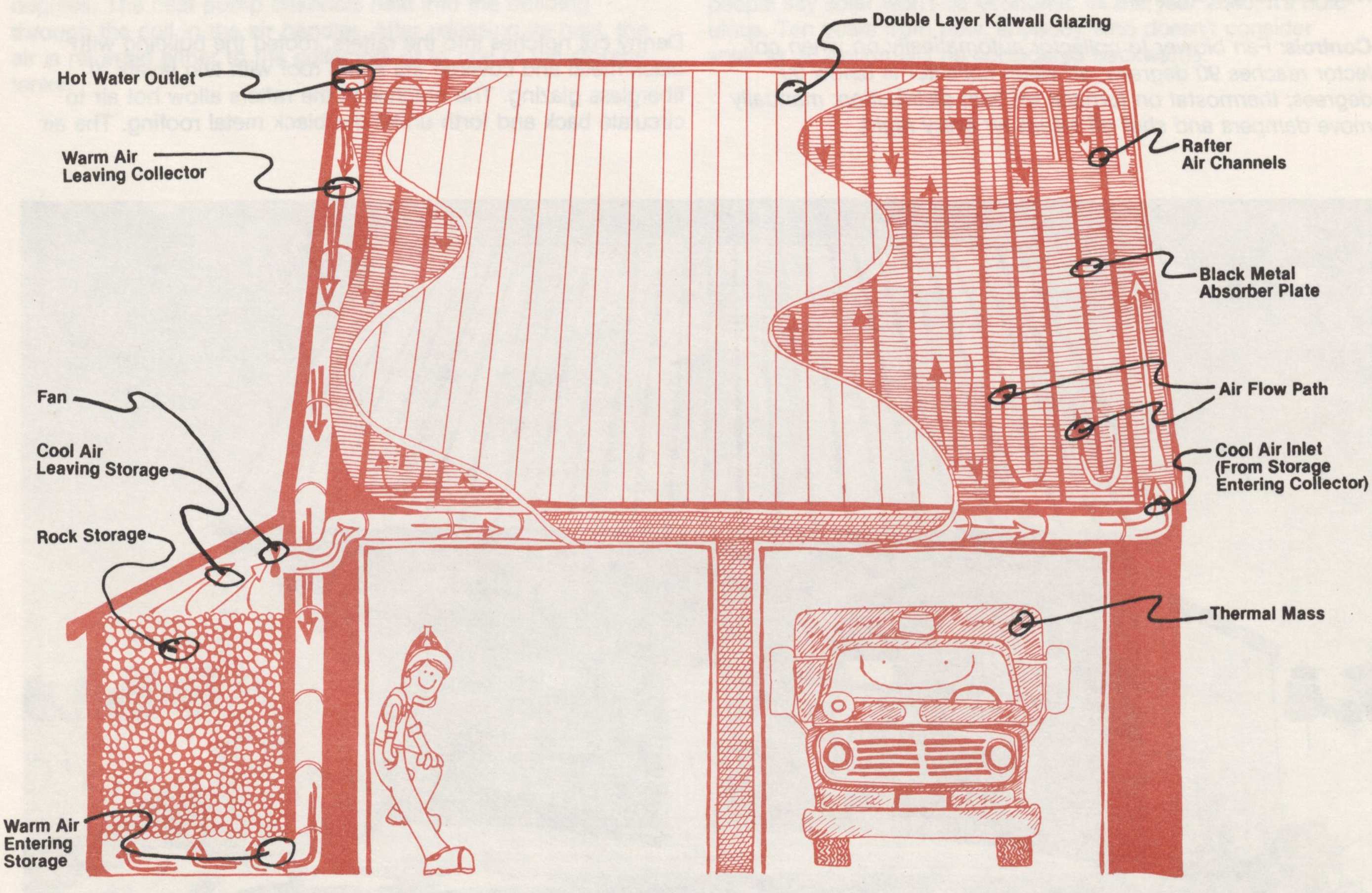
If he built the collector again, Danny said he would change the air flow pattern. Instead of using a serpentine air flow, he would modify the design to create a vertical air flow by putting manifold ducts along the top and bottom of the rafters. This would supply a more even air flow across the whole surface of the collector, he concluded.

Rock Bin Storage

There are a few other modifications planned by Danny to improve the system, including moving the hot air inlet from the bottom of the storage bin to the top. It is logical to think that since heat rises, the best way to get the air through the rock would be to let it in at the bottom and allow it to rise up naturally through the rocks. But if you let the hot air in at the top, the hot air will cool as it loses its heat to the rocks, and sink through the rock bin to the bottom. The principles of air flow through various types of rocks are complex. Theories differ about how hot air behaves while moving through rocks, but all agree that the objective is to get maximum rock surface exposure to the air.

If he did it again, Danny said he would locate the rock bin either inside the building or underground. That would eliminate much of the heat loss from the storage bin, which is now in a shed attached to the west wall of the building. He would insulate both the rock box and the building more heavily. Also, he would omit the north windows, and try to eliminate some of the heat loss from the large garage doors.

If you decide to build an integral roof collector, one last caution from Danny Armijo. "Have the fan system on line before you put the last panel of glazing on the collector! While building the collector, we completed it and sealed it off, and the stagnating air developed temperatures of 290 degrees. We were fearful that it would cause fire. It probably would have caught fire, but we removed some of the panels immediately. The spontaneous combustion temperature of wood around here is about 350 degrees," he said.



Day Time Heat Collecting Mode
Pagosa Springs Fire Station

Foulk Residence
Air with Eutectic Salt Storage

System Data:

Application:	*New home designed for solar.*
Location:	*Hotchkiss, Colorado.*
Owners:	*Mr. and Mrs. Beau Foulk.*
Residential:	*Single-family home, 2,300 square feet.*
Insulation:	*R-40 in ceilings; R-22 in walls; double glazing.*
Back-up Heating:	*Electric resistance duct heater, separately metered to monitor energy use.*
Orientation:	*Roof-mounted collector races true south.*
Construction:	*2-inch by 6-inch frame walls; 2-inch by 12-inch roof rafters.*
Solar Collectors:	*400-square-foot roof-mounted air collector.*

Heat Distribution: *Collector-to-storage circulation fan; duct fan on duct heater for interior heat distribution.*

Storage: *2,500 eutectic salt trays in insulated sheetrock box in southwest corner of walk-in basement.*

Heat Exchangers: *Air-to-liquid heat exchanger mounted in duct between collector and storage for domestic hot water preheat.*

Controls: *Differential thermostat, with digital readout for collector and storage temperatures.*

Solar Cost: *$11,500 including all ductwork, back-up heater, and roof-mounted swamp cooler.*

Beau Foulk says, "I decided to go solar because there were no alternatives except electricity or propane. I knew ten years from now an all-electric system would cost at least $300 per month, while the solar will pay off in less than ten years, and then the energy will be free."

Active Air Collector

The system the Foulks decided on is a commercially-available air collector with eutectic salt storage trays. The 400-square-foot roof-mounted collector uses an aluminum absorber plate with small triangular spines protruding from it. These protrusions increase the surface, heat collecting area of the absorber plate, and increase the turbulence of the air as it flows through the collector, causing it to give up its heat to the absorber more readily. Most of the air flows from the bottom to the top of the collector **behind** the absorber plate so that the hottest air is exposed to the insulated back of the collector instead of to the glass top where it could be lost.

Hot Water Preheat: Air-to-Water Heat Exchanger

The hot air collected in the manifold along the top of the collector is forced down a duct to a storage box in the basement.

The home of Mr. and Mrs. Beau Foulk in Hotchkiss is heated by a commercially available active air collector system with eutectic salt trays for heat storage.

On its journey, the hot air surrounds loops of copper pipe in the duct, giving up some of its heat to the pipes and water in them. This copper piping forms a "closed loop" running to the duct from the electric hot water heater. It is designed to pre-heat the water in the electric hot water tank and reduce the amount of heat required to get the water up to use temperature. Water from city water mains or wells normally is about 35-45 degrees. The Foulk's solar system pre-heats the water in the tank to 50-100 degrees in the winter, and even hotter in the summer (because there's no space heating requirement in the summer and all of the solar heat can be applied to hot water heating).

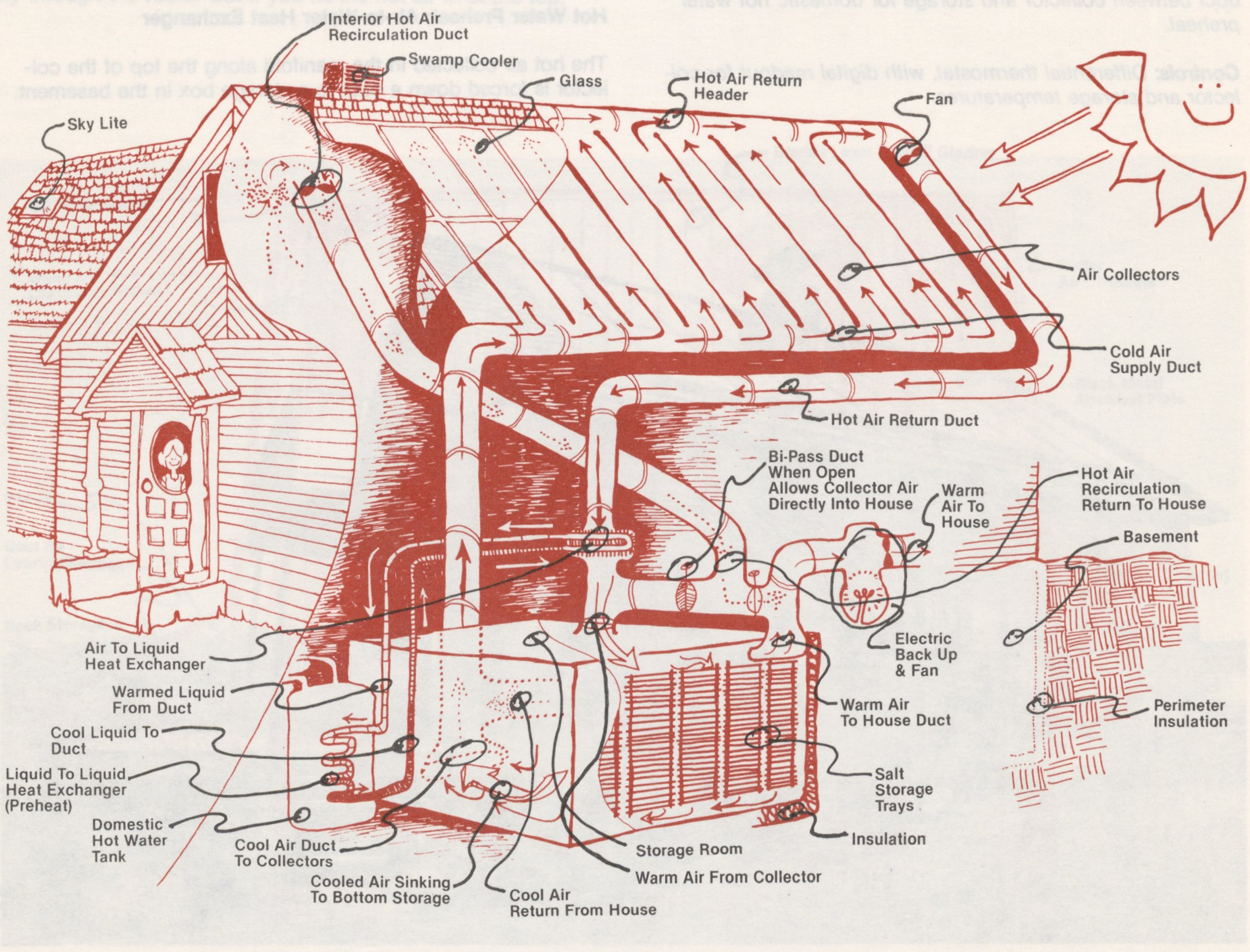
Eutectic Salt Heat Storage

The Foulk's solar storage medium is eutectic salt, also called Glauber's salt, which melts at 90 degrees. Salts can store more heat in a smaller area than rocks, because salts can store latent heat while rocks store only sensible heat.

Latent heat is the heat stored by the salts at the point when they melt into liquid. (See the discussion of phase change materials on page 2.) Put simply, it takes much more energy to raise the salts' temperature the one degree between 90 and 91 degrees than it does to raise their temperature one degree at any other temperature. This is because a tremendous amount of energy is taken up by the salts as they melt; this energy is called latent heat.

The salts are in a solid form when they are installed in the storage box. When the collector delivers hot air to the storage box, the salts are heated. (It is common on a sunny day to get the storage temperature much hotter than 90 degrees.) Until they melt, the salts store sensible heat by conduction to their mass, just as rocks would. At their melting point, they store a much larger amount of heat in the process of melting (latent heat). Then they continue to store sensible heat as a liquid mass, just like water.

When the house thermostat calls for heat from storage (which happens at night or during cloudy periods when the collectors are not circulating), hot air is pulled out of storage and the salts begin to cool. When the hot liquid salts are cooled down to 90 degrees, they change back to solid form and release the latent heat stored in their melting transition. If and when the



Foulk Residence
Heat Collection Mode
Hotchkiss, CO

salts are solid again, and the thermostat is still calling for heat, the storage is cooler than the house, the thermostatic controls tell the electric resistance duct heater to come on.

Then when the sun comes and the collectors turn on, the salts are ready to melt again. Theoretically, the salts can change phase from solid to liquid and back again an infinite number of times. (They are guaranteed by the manufacturer for ten years). The system (collectors and storage) can be sized to store heat for one day or for many days; the longer you want to be able to store heat, the bigger the system, and the higher the cost.

The eutectic salts in the Foulks' storage box are sealed in plastic trays about one foot square and several inches high. The trays are plastic because liquid salts can cause corrosion when in contact with metal surfaces. The trays are designed with legs self-stacking with an air space between. They are formed in plastic molds in such a way that the air flow between them is forced to zig-zag under each tray instead of rising quickly between trays. Every 18 inches or so the trays are supported by plywood to prevent the plastic from sagging as it heats up.

Interior Hot Air Recirculation

Another feature of the Foulks' system, common in many energy-conserving buildings, is recirculation of hot air within the interior of the home. Because warm air rises, it will always find its way to the peak of the ceiling or roof. Here it can be collected by a fan and returned to the lower levels of the house for recirculation through a ducting system.

By recirculating the hot air that collects at the top of the house, you can keep the thermostat which is located at lower, cooler levels, reading warm temperatures, just for the cost of running a fan. Usually, as in Foulks' case, this fan can be the same one that already exists to force air through the ducting system. (In a boiler-fired, radiator system, a fan will have to be added because the existing heat distribution is powered by a pump instead of a fan.).

This type of recirculation device is very simple and inexpensive to add to any existing building, and will pay for itself very quickly in fuel-bill savings.

The Foulks are pleased with the performance of their solar system. "The beauty of the system," says Beau, "is that there's very little maintenance; if something does go out, it will be a little 1/2 horsepower motor; and the collectors will be there delivering heat for a long, long time."

Stonebraker 19th Street Solar Housing Liquid Collectors with Baseboard Heat

System Data:

Application:	*New building designed for solar.*
Location:	*1841 19th Street, Boulder, Colorado.*
Owners:	*Dorothy and Donald Stonebraker.*
Apartment Building:	*8,600 square feet.*
Insulation:	*R-19 batt insulation on exterior walls with 6 mil polyethylene vapor barrier stapled directly to interior surface of wood framing; R-38 fibrous batt insulation for roof with 6 mil polyethylene vapor barrier stapled directly to interior surface of wood joists and composite built-up roofing; double glazed windows.*
Back-up Heating:	*Gas-fired hot water boiler.*
Orientation:	*East-west axis.*
Construction:	*Three-story wood frame.*
Solar Collector:	*860 square feet of hybrid, glass tube concentrating collectors.*

Heat Distribution: *Pump for distribution from collector to storage tanks and from storage to hot water baseboard convectors.*

Storage: *1,500-gallon steel water storage tank for space heating; 140-gallon insulated preheat tank for domestic water.*

Heat Exchangers: *Liquid-to-liquid heat exchange coil to transfer heat from antifreeze solution to water in space heating storage tank and domestic water preheat tank.*

Solar Cost: *$22,450.*

"When we wrote the proposal for HUD for the solar system grant we selected a concentrating collector that we discovered wasn't ready for production. Two years later, it still was not being produced," comments Roland Hower, one of the designers of the 19th Street Solar Housing in Boulder. "Then we were locked into a certain performance level. We had very few choices of other collectors."

Hybrid Collector

The collector that Joint Venture, Inc., Architects, chose for the project is a hybrid type that combines features of tubular and concentrating collectors. It consists of a series of parallel corkscrew copper tubes, coated with black copper oxide, that are enclosed within double glass tubes. The tubes are not evacuated, but one side of the outer tube is silvered with a

The solar system on the 19th Street Student Solar Housing in Boulder has high efficiency collectors which provide hot water for baseboard convector heating. The student apartment complex was built in 1976 with the assistance of the Department of Housing and Urban Renewal (HUD) Solar Demonstration Program.

thick film that magnifies the incoming solar rays onto the copper conduit and conveys a water-antifreeze solution. The collector tubing is built into an aluminum frame and covered with a layer of tempered glass to protect the tubes from snow build-up and vandalism. Because solar radiation is concentrated and heat loss is minimized by the double tubes, these collectors can deliver higher temperatures than a flat-plate collector, making them suitable for use with the baseboard convectors that distribute heat to eight apartment units. The ratio of collector area to living area is 1:10, smaller than usual for solar space heating applications. Eight-hundred-sixty square feet of collectors are used to heat 8,600 square feet of living space. According to Dorothy Stonebraker, co-owner of the building, 60 percent of the space heat and most of the heat needed for the hot water is provided by the system.

Donald Stonebraker says, "Our heating bills for the first ten months of operation averaged $11.50 per unit per month. That included space and water heating and some incidental lighting outside. Without the solar, that would probably have been 2-4 times higher."

Cost of Solar

The Stonebrakers didn't have to pay for the solar system; it was bought with a grant of $22,450 received from the Department of Housing and Urban Development (HUD) as part of the National Solar Heating and Cooling Demonstration Program. Authorized by Congress in 1974, this federal program was initiated to stimulate the widespread use of solar energy by subsidizing working solar demonstrations in buildings across the nation. The 19th Street project is one of the first of over 272 solar dwellings units constructed in Colorado with the assistance of that program.

"I don't know if I would have invested $22,000 extra for a solar system without the grant," relates Donald Stonebraker. "I never really worked out the economics, although my feeling is that I would still have come out ahead. I think it would pay for itself. I've never had a vacancy or any problems when we raised rents. Solar definitely has some market value. The problem would have been just coming up with the $22,000."

"When we went to get financing for the building we must have gone to every lending institution in Colorado," Mrs. Stonebraker recalls. "We had a terrible time. Everything was fine until we mentioned solar and students; then they changed their tune. Finally we met a young guy at one place who thought it was a good idea and pushed it through. Although even then we only got partial financing."

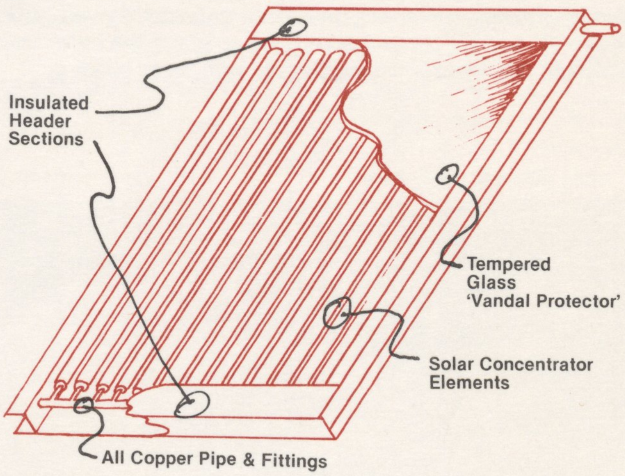
Dorothy said that the decision to go solar just sort of happened. "I ran into Joint Venture and thought it was a great idea when they mentioned it, and so did Donald. We didn't really start out with it in mind."

Joint Venture designs only energy-conscious buildings, most of them solar, and considers the Stonebrakers' apartment building important primarily from an aesthetic point of view. "I think it's better looking that most solar buildings, and that helps the whole realm of solar," comments Roland Hower with a touch of pride. "A lot of the early solar people were backyard throw-it-together types, and that became the image of solar energy. A lot of solar buildings have been second class from a design point, but that's really not necessary. There are more and more projects all the time that are sensitively done. Our philosophy is that you don't have to optimize one factor at the expense of another. Buildings do other things for people besides keeping them warm."

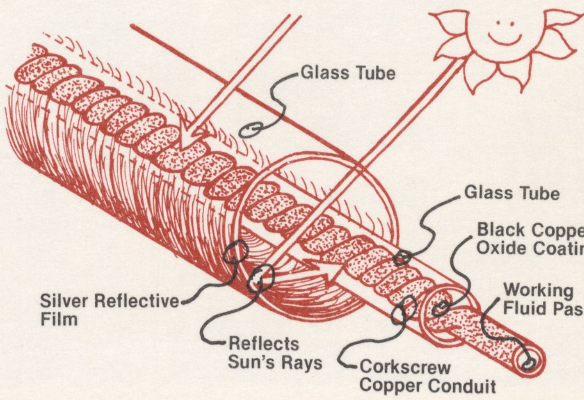
The solar system on the student housing complex has performed to the Stonebrakers' expectation. "There is a slight leak someplace we haven't found that loses two gallons a month, but it's hardly anything significant," says Donald Stonebraker. "But we did have horrible problems getting the collectors up and running."

The company that provided the collectors for the project was relatively new and has since been bought out by a bigger concern. They made a few mistakes that Donald believes no manufacturer would make today.

Alan Brown, another partner in Joint Venture, remembers the experience with some displeasure. "They were three months behind in shipping the collectors to us, and when they finally got here and were installed with all the piping connected, we discovered they had frozen in flight. Somebody had neglected to drain them before shipment." New collectors were sent to Boulder after attempts to repair the damaged ones failed. The



KTA Collector Detail
Stonebraker, Boulder, CO



Collector Element Detail

collectors were again installed, but after a period of time a film started to coat the inside. "They put this foam rubber, weather-stripping type stuff behind the glass tubes to prevent breakage in shipment. It outgased after a short period and the collectors had to be taken down again to remove the sponge rubber stuff and be cleaned."

The Stonebrakers have no regrets about their decision to use solar even though problems with the collectors were a "hurdle."

"I didn't have any idea that would happen, but it's been a rewarding experience," says Dorothy. "It's new, it's exciting, it works. The tenants like it, and it's just nice to have the sun instead of relying totally on Public Service."

Says Donald, "the real key is the way the whole building is designed, not so much the collectors. The main thing is not to need so much heat. We used heavy insulation, thermopane windows, doors on the south side—lots of energy-conserving features."

Integrated Systems

Solar systems using both active and passive features are often called "integrated" or "hybrid" systems. Almost infinite variations are possible, and active or passive collectors can be tailored to the needs of each particular application.

Integrated systems are generally designed to maximize the usefulness of available heat. For example, the hot water coil mounted on Paul Pixler's Trombe wall surface is an integrated solution because it uses heat collected in the passive space heating system (Trombe wall) for hot water as well. (See page 10). The hot water part of the system required a pump, so it is technically "active" even though it is using heat collected in a "passive" manner in the Trombe wall.

An integrated system is often the best solar solution for new construction. The extra design time required pays itself off quickly. Current trends in passive solar design indicate that a small pump or fan is often well worth the cost of energy to run it. Making use of active components to maximize the effectiveness of passive features is the challenge of integrated solar system designers.

Examples of integrated designs on the following pages should give some indication of the great variety of systems that can be produced with a little ingenuity and a perspective which treats the whole building as one system.

Rick's Cafe
Greenhouse Air Heater and Water Heater

System Data:

Application: Retrofitted and remodeled old gas station/garage.
Location: Denver, Colorado.
Owners: Rick's Corporation.
Commercial: Restaurant and bar, 4,000 square feet.
Insulation: Building is essentially uninsulated; owners sprayed urea-formaldehyde on ceiling.
Back-up Heating: Roof-mounted gas forced-air furnace; swamp cooler and electric resistance heater combination.
Orientation: Bayaud Street exposure, almost due south.
Solar System: 440 square feet of active, drain-down water collector; waste heat recovery tank that recycles heat from dishwasher to preheat collector water; 548 square foot passive greenhouse with integrated, transparent collector; integral transparent air collector; 16 passive turbine fans for ventilation and cooling.

Heat Distribution: *Fan on greenhouse collector; fan on back-up forced-air furnace system; pump and solenoid valves for water collector; also natural convection through open building.*

Storage: *180 cubic feet rock bin storage for air collector integrated in greenhouse, plus slate floor of greenhouse, 44-ton concrete bench along south interior wall of greenhouse; 1,200-gallon solar storage tank (water); 600-gallon waste heat recovery tank; 320 square feet of brick wall between greenhouse and building.*

Heat Exchangers: *Water-to-water heat exchanger in waste heat recovery tank (double coil, counter flow).*

Controls: *Differential thermostat for water collectors; two-point thermostat for air collector fan in greenhouse; three-way valve to mix water from waste heat recovery tank, solar, and city water to maintain use temperature (bi-metalic scalding valve); gravity-loaded one-way dampers (shutter dampers) in air ducts in active greenhouse system; centralized control panel reading out temperature at approximately 20 points in the system.*

Solar Cost: *Approximately $40,000.*

Peter Simonson, part owner of Rick's Cafe, says "we decided to go solar because we're energy-conscious people, and we try to be ahead of the times in our restaurants." He adds they try to conserve energy in other ways, like using only microwave ovens instead of gas or grill cooking. According to an employee at the Denver restaurant and bar, "The owners are not afraid to try something new, and we figure the more units are being used, the more progress will be made."

Rick's Cafe in Denver combines active and passive solar systems for heating, dishwashing and ventilation.

Also, according to the manager, "It's been a pretty effective image for the business, along with our policy of trying to use all natural, organic food ingredients and using recycled materials for the building itself." For example, the tables at Rick's are made of recycled wood, and the greenhouse floor is made of slate from old blackboards turned upside down.

Active Solar Water Heater

Peter Simonson says that Rick's gets about 1,500 gallons of free hot water from the solar collectors. (The restaurant uses 800 to 1,500 gallons of hot water per day.) The 440-square-foot collector on the kitchen roof, combined with a waste heat recovery tank that recycles heat from drain water, supply Rick's with 50-80 percent of its water heating needs.

The commercially available collector is made of copper pipe and a copper oxide absorber surface housed in insulated sheet metal boxes which are single glazed on the south side and tilted at about 45 degrees toward the sun. Water running through the copper pipes collects the sun's heat. Freeze protection is provided by solenoid valves that sense the temperature and allow the water to drain out of the collectors when they cool to 42 degrees. The water drains into a l,200-gallon, insulated storage tank under the kitchen floor.

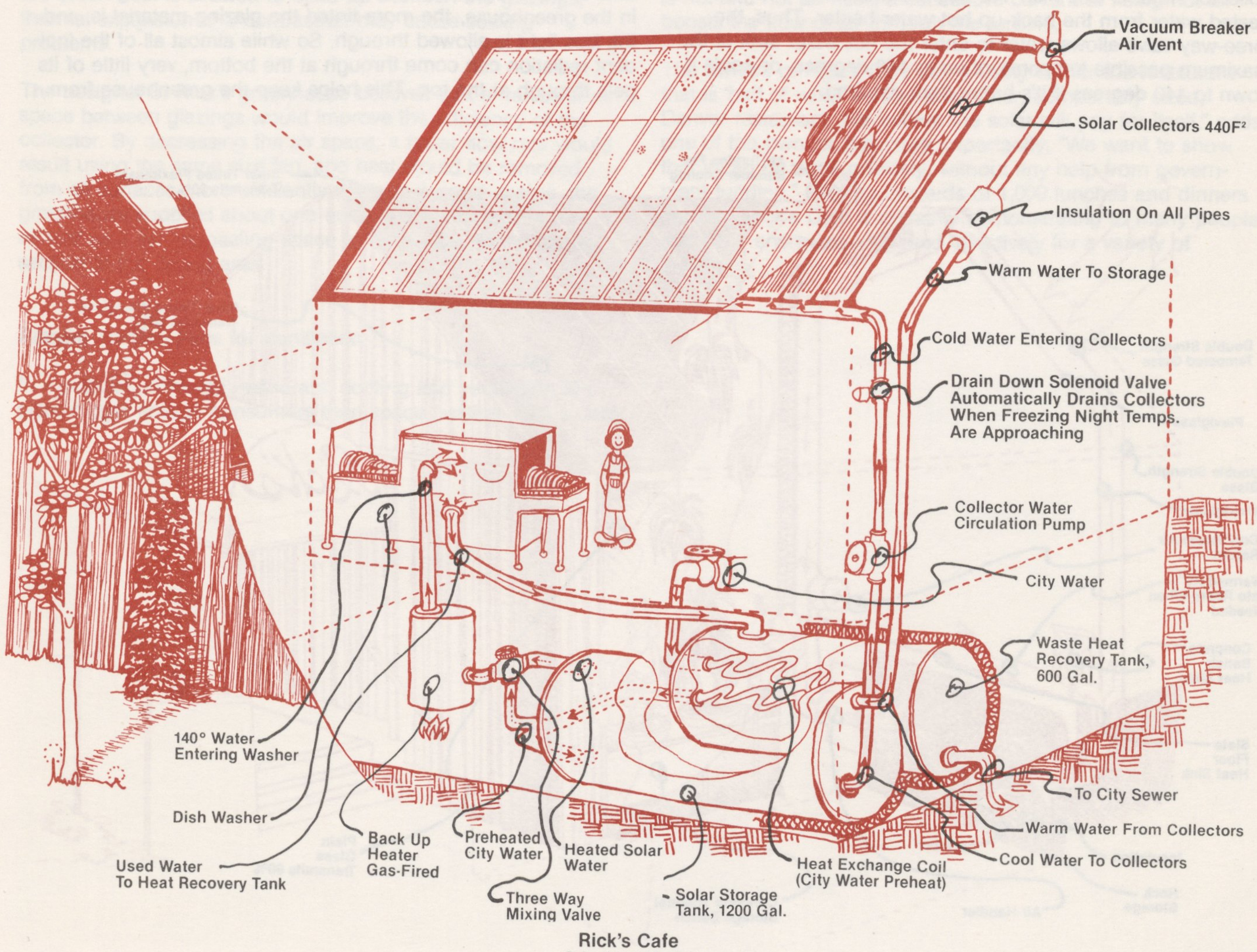
When the temperature in the collectors is above 88 degrees and the outdoor, ambient temperature is 4 degrees above the storage water temperature, a pump comes on and begins to circulate water from the storage tank through the collectors. This solar water heating system is integrated with a waste heat recovery system, and a gas-fired hot water heater that provides back-up heating to keep the dishwashing water at 140 degrees at all times.

The Health Department requires 160 degrees for dishwashing in restaurants. Rick's Cafe uses a special sterile dishwasher with a chemical wash so only 140 degrees is required. The solar collectors can easily achieve 140-degree temperatures on a sunny day.

When there is not enough sunshine to get 140-degree water, a boost is provided by a waste heat recovery system which captures some of the heat going down the dishwasher drains.

Waste Heat Recovery Tank

All the hot water from the dishwashers in Rick's Cafe drains into a waste heat recovery tank in the basement. Coiled through the waste water in this heavily insulated, 600-gallon tank is copper pipe through which cold (40-45 degrees) incom-



Rick's Cafe
Solar Water Heater
Heat Collection Mode

ing city water flows on its way to the bottom of the solar storage tank.

The waste water, still over 100-120 degrees when it drains out of the dishwashers, conducts heat through the copper coils into the fresh water, raising its temperature about 30 degrees. The preheated water then goes to the bottom of the solar storage tank, where it can be pumped to the collectors for additional heating, or to the hot water tank for additional heating or immediate use. Whether it goes into the solar system or into the hot water tank depends on its temperature, the temperature of water already in the hot water tank, and the temperature of water coming out of the solar collectors.

Three-way Mixing Valve

The pipes coming into the hot water heater from the waste heat recovery tank and the solar system all go through a three-way mixing valve, or "scalding valve." If the collector water is 140 degrees, the valve shuts off the other inputs and allows the 140-degree water to go into the hot water tank, where it's used immediately, or kept hot until needed. If the collector water is hotter than 140 degrees, the valve mixes it with cooler water from the city water supply until it's the right temperature. If the collector water is less than 140 degrees, it's mixed with preheated water from the back-up hot water heater. Thus, the three-way valve allows water to enter the hot water tank at the maximum possible temperature up to 140 degrees, or cools it down to 140 degrees if it's hotter than required.

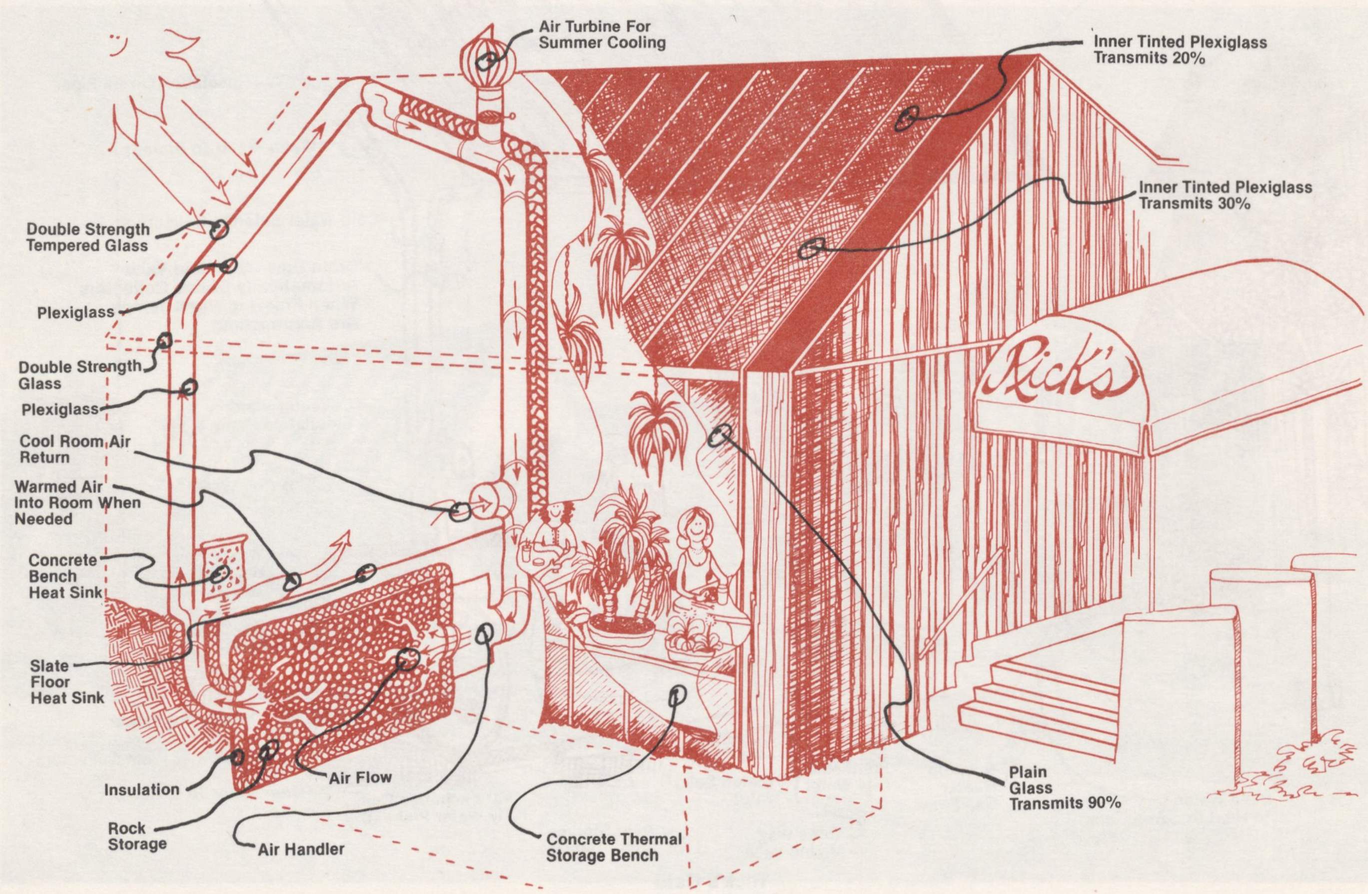
Greenhouse

In addition to the active water-heating system, Rick's Cafe has a solar greenhouse for direct-gain space heating to supplement the gas-fired, forced-air heating system. This greenhouse collects solar energy directly by trapping radiation that comes through the glazing and storing it in the mass of the slate floor, back brick wall, and a three-feet-high concrete bench that runs along the south wall of the greenhouse.

Because the greenhouse is used for dining space, it's constructed differently than most passive solar greenhouses. Since a greenhouse would normally be too hot for comfortable restaurant dining, much of the incoming radiation is captured in an air collector inside the glazing of the greenhouse, where it is blown by fan into rock bin storage located under the floor of the greenhouse. If the thermostat is calling for heat, the fan flows heat directly into the restaurant.

Integral Air Collector

The greenhouse frame is 2 x 4 inch redwood. It is glazed with double-strength, tempered glass on the outside. The inside glazing is made of various plexiglass materials with different tints to transmit different amounts of radiation. The higher up in the greenhouse, the more tinted the glazing material is, and the less light is allowed through. So while almost all of the incident radiation can come through at the bottom, very little of its gets through at the top. This helps keep the greenhouse from



Solar Greenhouse Heat Collection Mode
Rick's Cafe, Denver

overheating, and it also traps heat between the upper sections of double glazing.

The heat trapped between the greenhouse glazings is partially absorbed by the inner tinted glazings. So the upper, inside glazings of the greenhouse are effectively serving as absorber plates for an integrated air collector.

Neutral Density Glazing

All the glazings in the greenhouse are materials that transmit and absorb all wavelengths of light equally, so the designer calls them "neutral density" materials. In contrast, many conventional absorber plates are selectively coated to absorb more light of certain wavelengths. It is important to use neutral density materials in greenhouses because plants require a natural distribution of all wavelengths of light to stay healthy. People also generally prefer the same kind of light.

The heat trapped and absorbed by the collector integrated into the greenhouse glazing is removed from the collector by an electric fan sized to create an air flow of two cubic feet per minute across the whole surface. This is a relatively fast flow rate but is required in this type of collector to remove heat efficiently, since the absorbance of the collector is relatively low. If too much heat is allowed to build up between the glazings, thermal expansion and contraction may cause sealing problems.

The designer of Rick's greenhouse believes that a narrower air space between glazings would improve the efficiency of the collector. By decreasing the air space, a faster flow rate would result using the same size fan, and heat would be removed from all surfaces more efficiently. With its current design, the greenhouse supplies about one quarter of winter space heat, as well as a very appealing space to house the non-smoking section of the dining area.

Passive Turbine Fans for Ventilation

In a popular, crowded restaurant, cooling and ventilation are often bigger energy consumers than space heating. Rick's uses four operable skylight vents for ventilation, each equipped with a passive wind turbine fan. Combined with 12 other turbine fans, these supply 60 percent of the building's ventilation. Electric fans do the rest, while two swamp coolers provide back-up cooling. The draft created by the turbine fans helps cool the space, and provides a quick exit for cigarette smoke.

"Because of the wind turbines, it's almost never smoky in Rick's," according to Pete Simonson. "The turbines use the wind and sun to keep the air clear inside the restaurant." The action of the turbine fans is boosted by the fact that the greenhouse area acts as a positive pressure cell, or a sort of "header" for the building's ventilation. Because the greenhouse is always warmer than the rest of the building, a convective current is generated from the greenhouse into the building and out the turbine fan openings in the ceiling.

A turbine fan is a very common, inexpensive device shaped like a globe made of sheet metal fins that catch the wind from any direction and start the globe running. The fin structure is open, so as the globes spin, they pull air from below and exhaust it out through the spaces between the fins.

Because the turbines are made of sheet metal, they tend to heat up in the sunlight, and this increases the rate at which they remove air from the interior space. Since the sheet metal is hot and hot air rises, a convective current of rising hot air boosts the flow of air through the turbine.

The owners of Rick's Cafe pay a utility bill for the restaurant that is 'half of what we pay at another, comparably sized, Denver restaurant. We believe the solar will pay for itself," adds one of the owners, but more importantly, "We want to show that it can be done privately, without any help from government funding." Serving upwards of 1,000 lunches and dinners per day, Rick's Cafe is certainly demonstrating to many people that solar energy can be used effectively for a variety of purposes.

Shore House
Trickle Water Collector and Passive Features

System Data:
Application: *New home designed for solar.*
Location: *Old Snowmass, Colorado.*
Owners: *Ron and Jill Shore.*
Residential: *Single-family home, 1,450 square feet.*
Insulation: *R-42 in ceilings; R-42 in walls; Beadwall and Skylids for movable insulation on glazing.*
Back-up Heating: *None (fireplace sometimes used for pleasure).*
Orientation: *Long axis of house faces true south.*
Construction: *2-inch by 12-inch frame construction; heavy masonry floor and some masonry walls.*
Solar System: *564-square-foot active water, trickle-type collector with drain down for freeze protection; 90 square feet of vertical south-facing glass for passive direct gain, with Beadwalls; 48 square feet of south-facing skylight in roof, with skylids and reflectors to increase radiation in skylights about 25 percent.*

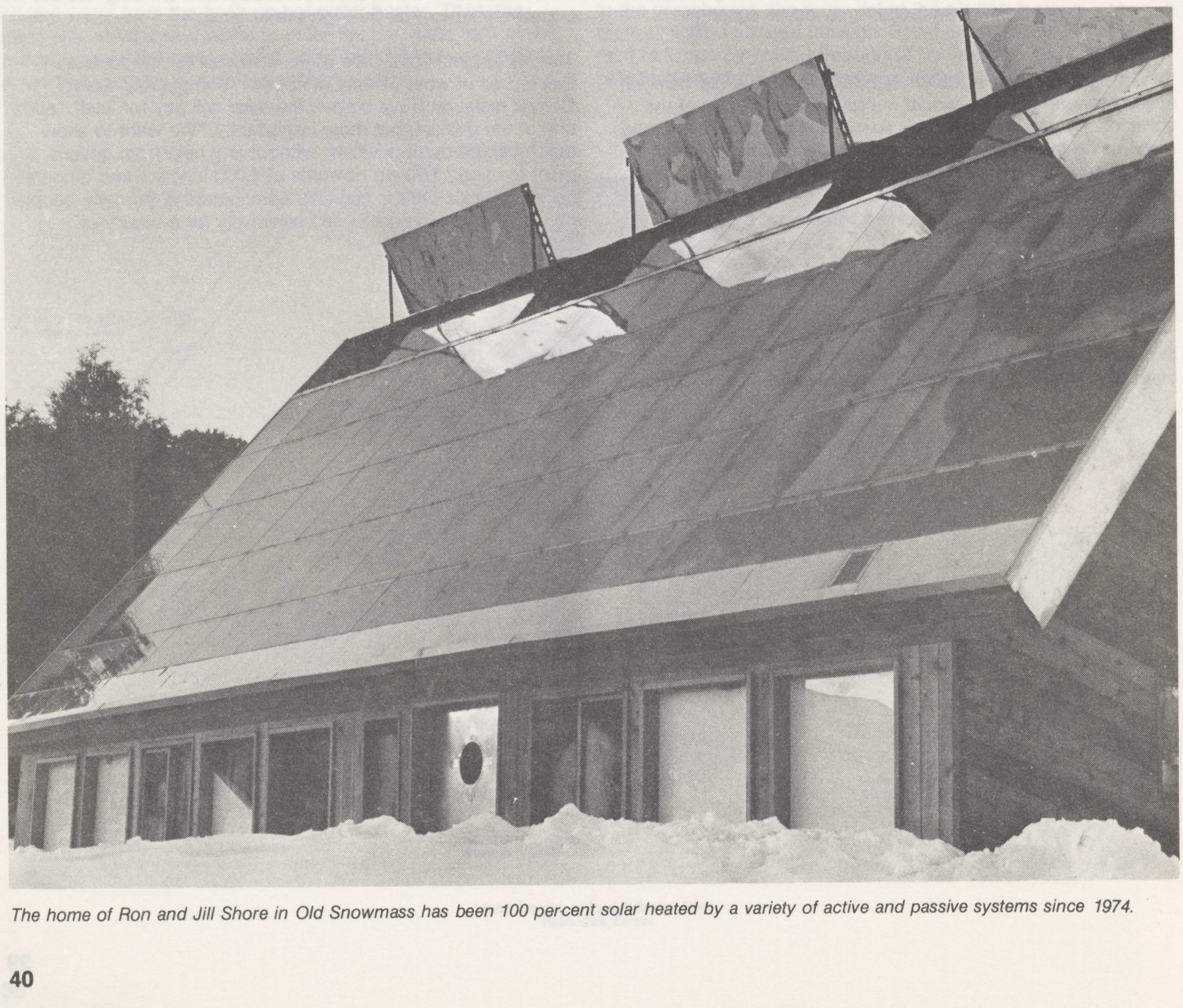
Heat Distribution: *Pump from storage to collector; pump to circulate hot storage water to radiant floor heating zones when thermosiphon is not adequate; thermosiphon from storage to domestic hot water tank; natural convective and conductive currents from buried storage tank to interior space; open circulation in interior space.*

Storage: *5,300 gallons of water in concrete tank (integral to foundation); massive masonry floors and wall sections capable of storing 18,000 BTUs; 52-gallon domestic hot water heater; north wall five feet below grade; south wall three feet below grade.*

Heat Exchangers: *3/4-inch diameter pipes (12 inches apart) of high-molecular weight polyethylene are embedded in upper 3 inches of concrete slab floor above underground storage tank to exchange heat from collector fluid to floor mass; 100 feet of similar pipe coiled in storage tank, thermosiphoning to domestic hot water tank.*

Controls: *Gravity drain-down freeze protection; differential thermostat; manual switches on Beadwalls; automatic Skylids.*

Solar Cost: *About $3,000 for materials (labor not included).*



The home of Ron and Jill Shore in Old Snowmass has been 100 percent solar heated by a variety of active and passive systems since 1974.

Ron Shore moved his family into their house in November, 1974 after five months intense construction. Ron recalls, "The first winter was an exciting experience for we had no auxiliary heat, not even a wood stove. I can always remember the eight straight days in January when the sun was obscured by snow storms and dense cloud cover. I felt like Dicken's Scrooge watching over the heat storage withdrawing BTUs from our bank and hoping to see the sun before we were out in the cold," he says. Shore has been involved with solar energy for most of the 1970s. Residing at an altitude of 7,200 feet in the cold climate (9,000 degree days) of Snowmass, Colorado, he and his wife, Jill, and their two young boys are living proof that solar energy works. Having experimented for five years in their daily lives with a wide variety of active and passive solar devices, Ron and Jill have a wealth of experience and knowledge that is rare.

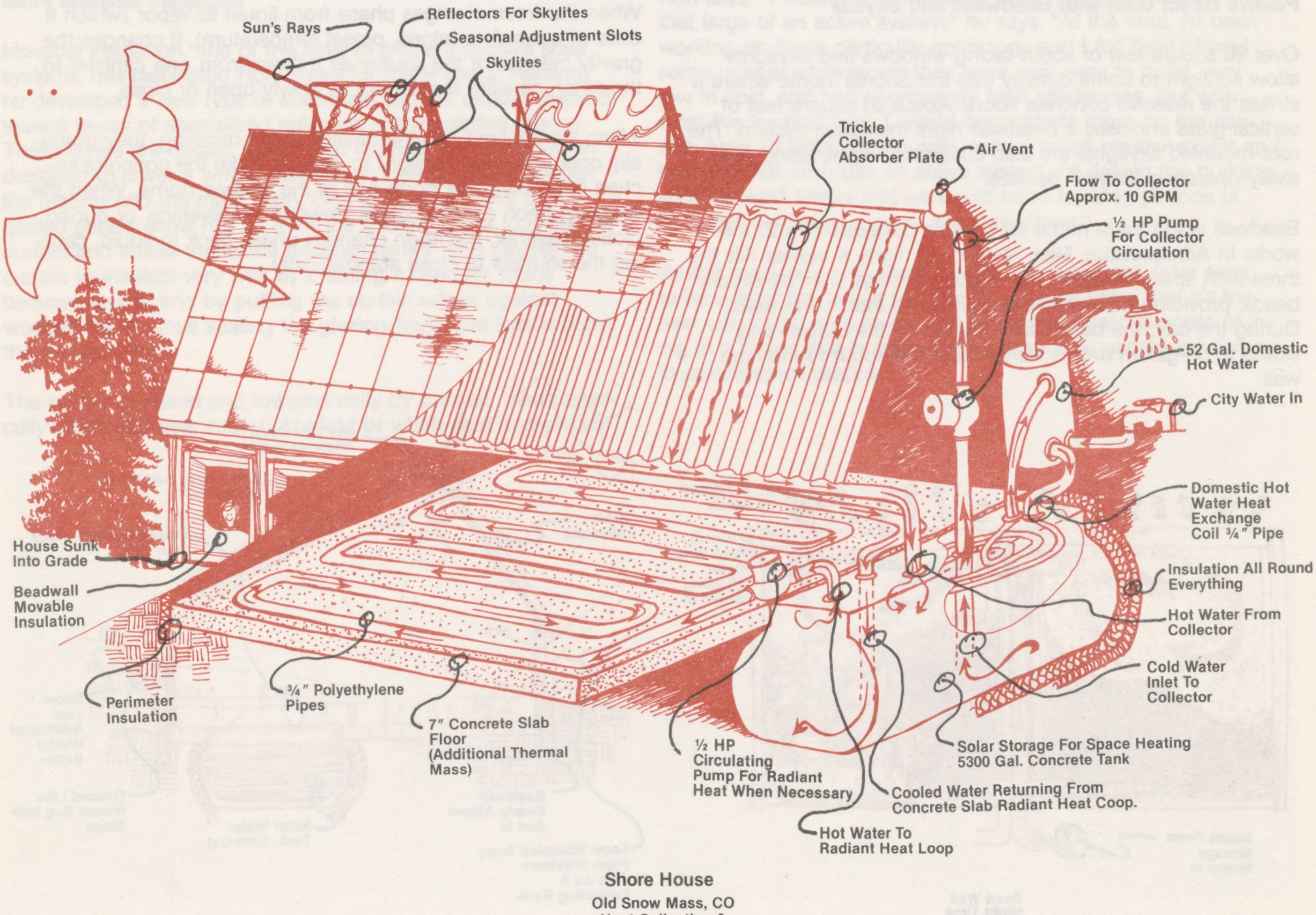
Trickle-type Active Water Collector with Drain-Down Freeze Protection

The Shores' active water collectors consist of 14 panels, each 2-1/2 feet wide by 14 feet long. They're homemade from two sheets of corrugated aluminum (common roofing material). These are spaced so close together that water flowing between them down the corrugations moistens most of the surface areas of each adjacent aluminum face, picking up heat from the upper sheet, which is in direct sunlight under two layers of glass. Water is pumped to the top of the panels from the bottom of a storage tank by a 1/2 horsepower centrifugal pump, at 10 gallons per minute. After trickling through the tiny space between the two aluminum sheets, the water is collected along the bottom of the panels by an outlet tube which flows down to the top of the storage tank which is buried under the 7-inch thick concrete floor of the house.

The pump, which delivers water to the collectors, is thermostatically controlled to come on when the collectors are hotter than the storage. When the collectors are too cool to deliver heat, in cloudy weather or at night, the water simply drains into the storage tank, so the collectors have no water in them to freeze. This type of drain-down freeze protection is a popular alternative to using an antifreeze solution in the collectors with a heat exchanger (which loses some of the energy as it transfers heat from one fluid to another).

Radiant Floor Heating

An interesting feature of the Shores' house is the manner in which heat is distributed from the storage tank to the house. Since the concrete storage tank is located under the concrete



Shore House
Old Snow Mass, CO
Heat Collection & Distribution Mode
Active Trickle Collection System

floor, some heat simply leaks up through the floor by conduction and convection. Additional heat is supplied by hot water from the top of the storage tank thermosiphoning up into pipes embedded in the concrete floor. If the Shores are feeling cold, they can turn on a small pump to circulate the water through the floors faster. There are three zones in this heating system, so hot water is only circulated through areas where heat is needed. Radiant floor heating has long been recognized in Europe as one of the most comfortable and even heat distribution systems. Conventional radiant floor heating systems use water heated by a gas or electric boiler.

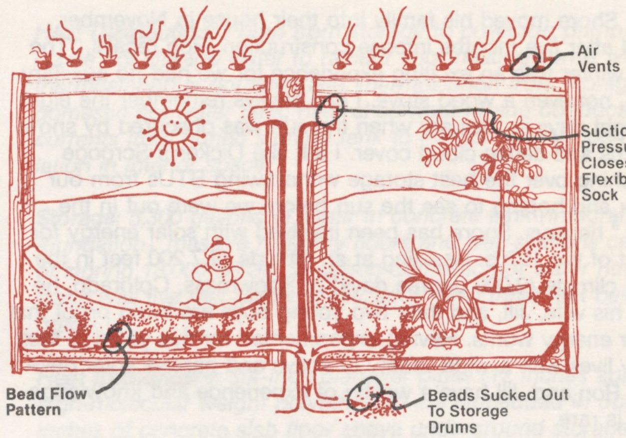
Domestic Hot Water

A loop consisting of 100 feet of 1-1/4 inch high-molecular-weight polyethylene pipe is zig-zagged through the top layer of hot water in the storage tank in a closed loop from the domestic hot water tank. The water flow between the water heater and the storage tank is strictly thermosiphon. Ron says they have been getting 100 percent of their winter-time hot water from this heat exchanger in the storage tank. The roof collector is shut off and vented open in the summer, so there's no solar hot water during the summer months, though Ron says he intends to build a separate thermosiphon water heater for summer-time.

Passive Direct Gain with Beadwalls and Skylids

Over 90 square feet of south-facing windows and skylights allow sunlight to come directly into the Shores' home where it strikes the massive concrete floors. About 60 square feet of vertical glass encloses a Beadwall night insulation system. The roof-mounted skylights are also covered at night, using passively operating "Skylid" devices.

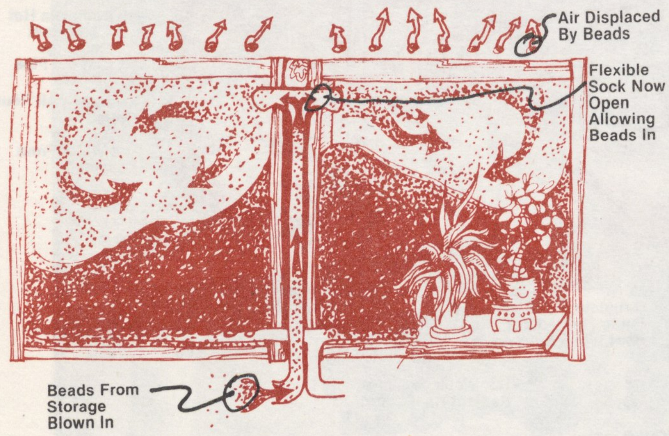
Beadwall is the trade name for an idea developed by Zomeworks in Albuquerque, New Mexico. At night, a blower fills the three-inch space between the double glazings with styrofoam beads, providing insulation comparable to that in the walls. During the day, the beads are emptied by the blower and stored in 55-gallon drums buried near the south foundation wall.



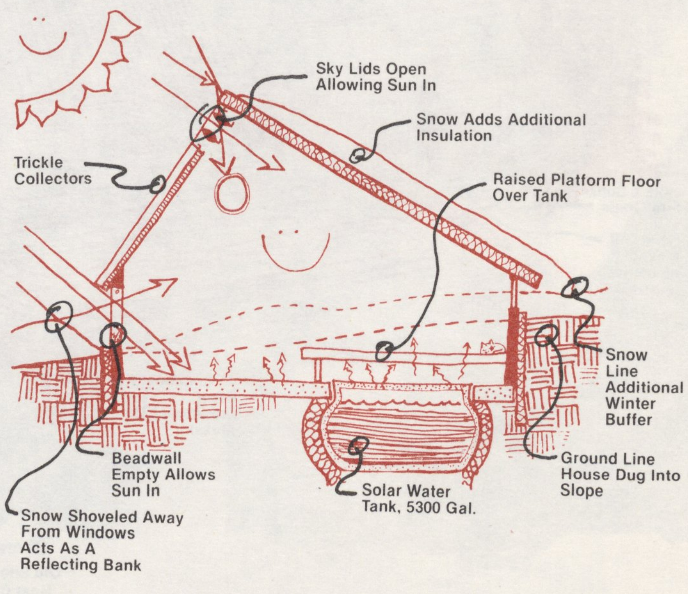
Beadwall Day Time Emptying Mode

Skylids are another type of movable insulation developed by Zomeworks. A Skylid is an insulating shutter mounted on a pivotal axis across the horizontal plane of the skylight. The shutter is mounted inside the glass. Two freon canisters, located at diagonally opposite corners of the shutter, cause it to open and close off the shutter, without using external power. When the freon changes phase from liquid to vapor (which it does at a pre-determined, preset temperature), it changes the gravity balance of the shutter as it flows from one canister to the other, causing the shutter to slowly open or close.

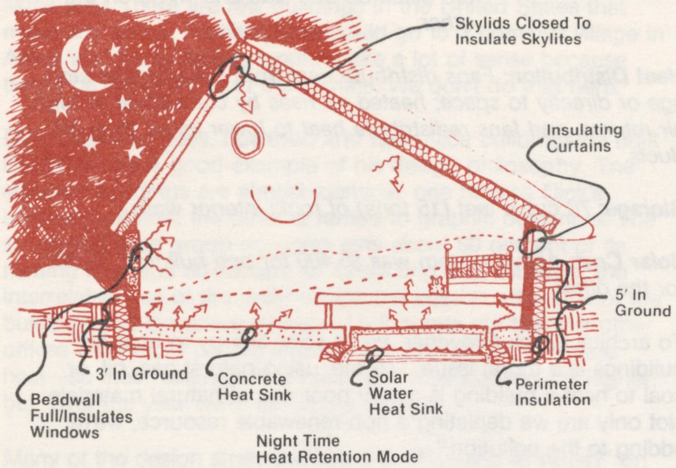
When the sunlight hits the Skylids in the morning, they gradually open, allowing sunlight to directly strike the concrete kitchen floor along the north half of the Shores' home. When the exposed freon canister cools down in the evening or during cloudy weather, the freon changes phase back to liquid, causing the shutters to close automatically.



Bead Wall Night Time Filling Mode



Day Time Passive Heat Collection



These movable insulation systems on the Shores' house are largely responsible for the success of the passive solar design features. By containing heat in the building at night, they help the whole mass of the house to retain its stored heat and keep the occupants warm.

More Movable Insulation

Movable insulation, one of the keys to efficient passive solar systems, has fascinated Ron Shore for many years. Recently, he developed a new type of automatic thermal curtain made of several layers of specialized reflective and insulating fabrics. These layers are quilted together at intervals across a curtain designed to cover a whole window or Trombe wall (between the glazing and the mass wall). Slits at the bottom of the quilted panels allow hot air from the interior space to enter the curtain and inflate the space between layers. This causes the curtain to insulate very well by creating a dead air space between layers, and by puffing the curtain edges against wooden tracks, thus sealing the glazing from heat loss around the curtain edges.

The curtain is raised and lowered daily by a small, thermostatically controlled gear motor. At night or when cold and cloudy conditions prevail, the curtain is slowly lowered filling with air as it descends. Los Alamos thermal tests show the curtain is nearly as effective as Beadwall, at less than half the price.

Solar Savings

During the winter of 1977-1978, the Shores did not turn on their active collector as an experiment to see how well the passive features of the house were performing. They were comfortable all winter (a fairly mild winter) with no active solar and very little auxiliary wood heat.

There have been some problems with the active collector system. There's been evidence of corrosion (Shore has replaced the collectors with copper tube and strip units) problems with the transition pipe connectors from the collector. Tygon tubing connectors failed after three years and caused flooding of the Shores' house; they've since been replaced with automobile radiator hose connectors. Also, some of the lower glazing on the collector broke because it was single-strength glass instead of double-strength, tempered glass like the upper glazing. As glass heats and cools, it expands and contracts slightly, and after many years of expanding and contracting, the single-strength glass finally cracked and broke. Ron recommends using tempered glass on both layers of glazing.

Ron says, "I wouldn't do the same system again. I wouldn't do that large of an active system," he says. "At the time, I'd been working on these particular collectors, and I felt they offered some unique advantages; they were very easy to build, very low in cost, and had enormously high efficiencies. But with what I've learned now, I would concentrate more on the passive. Now I'd optimize the passive to a much greater extent and probably not even use an active system. I'd design the building so it wouldn't freeze and we could leave for long periods of time and not have to worry about anything."

All the years of experimenting and learning about solar seem to have only confirmed the Shores' original belief that it's the best way to go. Ron says, "The value and consciousness of living in a house that is solar-heated cannot be expressed simply in performance graphs."

Cherry Creek Office Building Conservation Features with Active and Passive System

System Data:	
Application:	*New building designed for solar.*
Location:	*310 Steele Street, Denver, Colorado.*
Owner:	*Richard L. Crowther.*
Office Building:	*4,500 square feet each building.*
Insulation:	*16 inches of mineral wool fill in ceilings; 6-inch walls on east, west and south sides and 10-inch walls on north side are completely filled with mineral batt; fixed double pane windows in wooden frames.*
Back-up Heating:	*Two 3-ton high performance rotary heat pumps (not solar assisted).*
Orientation:	*East-west axis.*
Construction:	*Two stories wood frame walls on treated wooden foundations; stucco exterior.*
Solar Collector:	*130 square feet of air-type flat-plate collectors on one building; 160 square feet on the other; south-facing clerestory windows; south-facing glass with interior blinds that are black on one side and white on the other.*

Heat Distribution: *Fans distribute heat from collectors to storage or directly to space; heated air rises by convection to high air returns, and fans redistribute heat to lower levels through ducts.*

Storage: *70 cubic feet (15 tons) of rock; interior walls.*

Solar Cost: *Active system was $5,400 for one building; $6,000 for the other.*

To architect Dick Crowther, using solar energy to heat his buildings is a moral issue. "To me, using natural gas, oil, or coal to heat a building is a very poor use of natural materials. Not only are we depleting a non-renewable resource, we're adding to the pollution."

Dick feels that energy-wasteful buildings reflect much of what is wrong with present consumer society. "Sometimes I feel like we're living in a wild Disneyland. We throw away this, we throw away that; we eat junk food; and we have junk buildings the

By intelligent design which uses the energy of the sun, the wind and the earth, Dick Crowther has reduced the amount of electrical energy required to heat his Cherry Creek office building in Denver by 80 percent.

same way. There are few buildings in the United States that make any sense. Probably you could go to a primitive village in Africa and the buildings would make a lot of sense because they'd be designed to fit the climate. We don't do that here."

Dick Crowther does, however, and two office buildings he built in Denver are a good example of his design philosophy. The adjacent buildings are almost identical; one houses Dick's architectural firm, the other is rented to graphic designers. The structure Dick's group occupies gets about 80 percent of its heating load and 60 percent of its cooling load through "the interrelatedness of the architecture, the passive attributes of the building, and the active system." Dick points out that the other offices have more people and more lights—which generate heat—so their heating bill is lower and their cooling bill higher, but "over the year we're about the same."

Many of the design strategies listed in "Planning to Build?" on page 3 were used in the structure. Each building is recessed into the earth to take advantage of the ground insulating qualities; glass area represents only 10 percent of the total wall area (skylights on the north side of the building and "light scoops" on the roof above the entryways provide ample illumination); most of the glass and entryways face south and are protected from the high summer sun by overhangs; and earth along the perimeter of the site is bermed to deflect winds (as well as noise and exhaust fumes). In addition, Dick minimized the buildings' energy demand by using wood frame walls on a treated wooden foundation to allow for continuous insulation from the foundation plate to the roof parapet. Inductive ventilation and an air recirculation system are also keys to energy management.

Heating Mode

The most prominent feature of each building is a superstructure on the roof for the solar collectors and clerestory windows. In winter, the sunlight strikes the air-type flat-plate collectors, which are tilted at 45 degrees from horizontal, to provide approximately 20 percent of the heat for the building. The collectors are working "amazingly well," says Dick. " I think a lot of it has to do with the fact that our whole roof is a reflector. The entire roof is white marble chips, and we also have a reflector made of a mica-like material." The reflecting surfaces "push more energy onto the collectors than would normally get on them," Dick estimated that he has increased the effective collection area by 15-20 percent.

Clerestory windows mounted above the solar panels also serve as collectors. They admit direct sun in winter, which strikes a back north wall, adding to the heat gain in the building. They also admit diffuse light bounced from the reflecting surfaces, so they act as light catchers as well.

In the summer, the light roof materials reject the rays of the high summer sun, and the overhang shades the windows and collector panels. Light still enters the clerestory windows, but it is soft, diffuse light reflected from the white mica surface on the underside of the overhang. The skylight shaft and openings between floors give occupants a sense of openness, and play an integral role in the energy system. One of the two high air returns is located below the clerestory. Direct gain through the glass and heat that naturally rises from lower levels enters the return, is passed through filters for cleaning and reintroduced to the rooms. In this way, warm air stays at the people level, and the amount of energy required for heating spaces is reduced.

Passive features of the building provide about 25 percent of needed heat in the building. In addition to the gain through clerestory windows, south-facing glass with interior blinds that are black on one side and white on the other provide heat. The black side is turned toward the glass to absorb solar radiation; the white side is used to reflect it.

When solar heat from the passive system, directly from the flat-plate collectors, or from rock bin storage is not sufficient, heat pumps swing into action. If the heat pumps alone cannot supply enough heat, the electric resistance heaters come on.

Cooling Mode

Considerable thought went into how to cool the building as well as how to heat it. Inductive ventilation, mechanical cooling, or a combination of the two are used. Wind turbines on the roof induce air flow through the building, drawing in cool, outside air through low vents to replace warm air ducted outdoors through roof vents. The vents are gasketed so that when closed they do not allow heat to escape. When nights are cool and the days are hot, cool air is drawn in during the night and early morning. When the temperature outdoors rises, the vents are closed and the inside of the building stays comfortable long after outdoor air is too warm for cooling purposes.

Solar collectors are also used for cooling. Rather than exhausting warm air directly into the atmosphere, the air can be ducted through the collectors on its way to the roof vents. The collectors heat the air further increasing the pull on cooler air at lower levels. Ventilation is improved, and the solar collectors are cooled, which extends their life.

In one of the buildings, a west-facing plenum is also used to induce natural ventilation. During the afternoons the plenum heats up, creating a stack action that sucks in cool air. A gravel lining stores heat in the plenum to keep it working after the sun goes down.

If cooling by ventilation is insufficient, the heat pumps are used to dump heat out of the building, and as a last resort, a conventional mechanical air-conditioning system goes into action.

The air redistribution system is reversed for cooling, moving the low, cool air to higher levels, balancing temperatures and reducing energy demand.

Cost of Solar

The active systems for the Crowther offices cost $5,400 for one building and $6,000 for the other. The total energy system cost for each building was $10,400, including the passive system, the air distribution system, and the back-up heating. When originally built in 1976, Dick estimated that the solar systems would pay for themselves within 3.8 years. But it's been less than that because fuel prices have escalated.

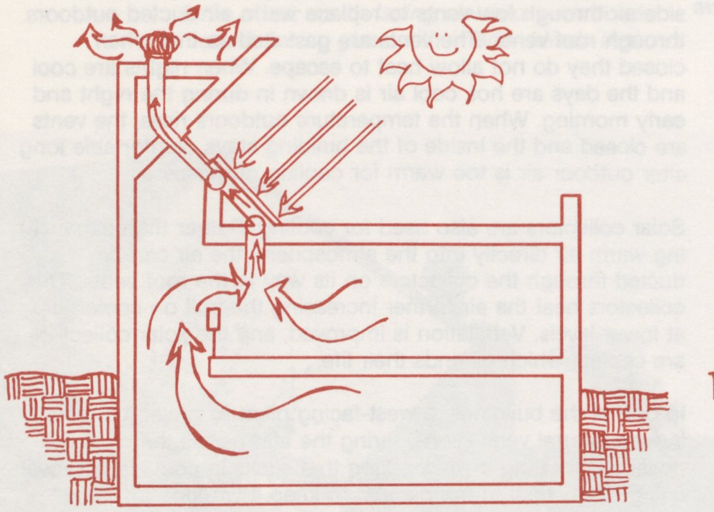
Utility Interface

When the offices were first constructed Dick and his colleagues had some doubts as to whether cost savings would match energy savings; Public Service Company of Colorado planned to levy a 50 percent penalty charge because the building was to use solar energy. Their rationale was that a solar building would draw on the utility primarily during peak demand times, forcing them to increase their stand-by generating capacity. Dick and his engineer, Don Frey, had designed the building to have an almost constant daily and year-round electricity demand, so they petitioned the utility to drop the penalty charge, explaining that their energy system would not make them stand-by customers.

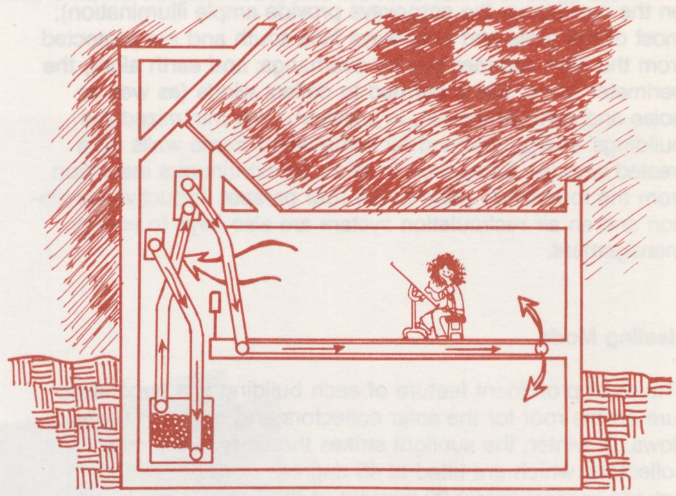
Don Frey wrote:"Our year-round demand is constant, our peak demand is low, and our 'auxiliary' equipment demands are met by switching off interruptable equipment.... This building will be using 80 percent less energy than a conventional building, but will have a utility bill which is only 10-15 percent less. This 10-15 percent savings is not sufficient to prompt many builders to incorporate energy conservation into their designs. We encourage the Public Service Company of Colorado to enjoy a fair profit, yet we also think that they have a socioeconomic responsibility to distribute the cost of benefits to all their customers, when all their customers are benefited, such as by energy conservation and solar buildings..."

Public Service Company of Colorado agreed, the penalty was dropped, and the Crowther firm was allowed to select the more favorable of the two electric rate structures for the buildings.

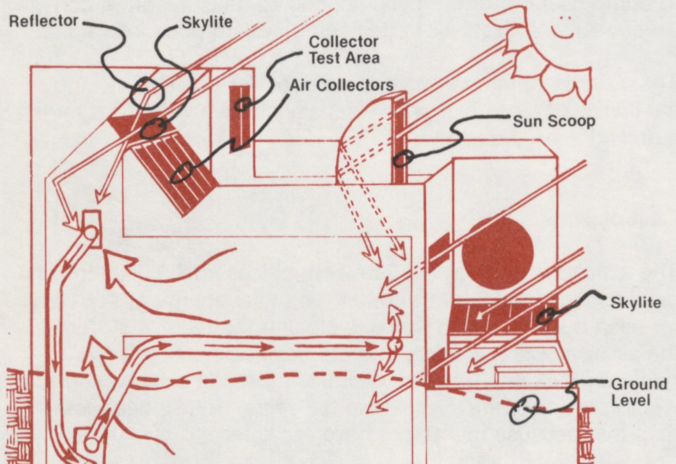
However, the question of how utilities will interface with solar buildings using electricity as a back-up heating has not been totally resolved. If solar buildings do not use load-leveling devices, the utilities must invest in stand-by generators to supply energy in periods of no sun or severe weather—the times when everyone else draws heavily on the system. Costs of this stand-by capacity will be passed on to solar customers, often making solar heating uneconomical. At the present time, this is not a problem because there are relatively few solar buildings, but utilities are concerned about what will happen as solar heating becomes more widespread. Homeowners are going to have to pay more unless they can keep the demand fairly constant, as Crowther has done.



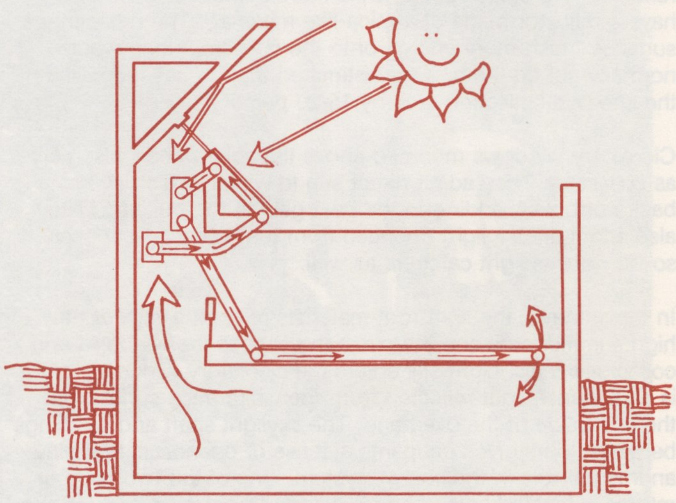
Inductive Ventilation



Heating From Storage



Direct Gain Heating &
Heating From High Air Return

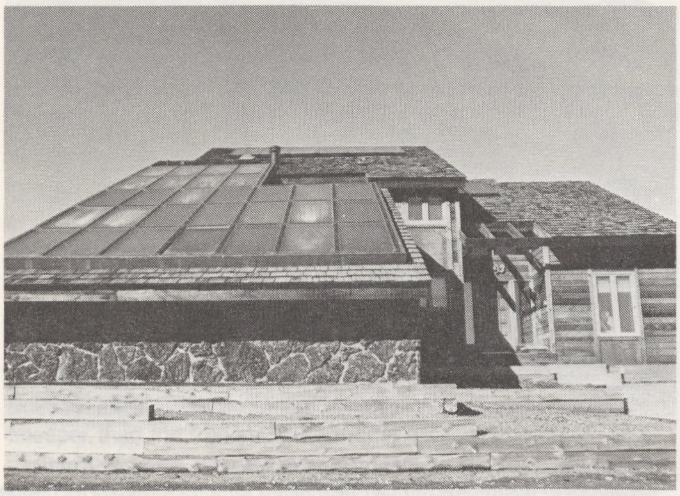


High Heat Return

Cherry Creek Office Bldg.
Denver, CO

More Integrated Solar Options

Kent Residence



Mr. and Mrs. Tom Kent's residence in Boulder, Colorado, uses a 580-square-foot active air system combined with passive features to supply about 65-70-percent of the space heat and over 90 percent of the domestic water heating. The passive skylight is designed to focus sunlight on a 40-ton lava rock wall, which is integrated with a heatalator fireplace. The controls and air-to-liquid heat exchange coil are incorporated into an air handler built by Tom's local solar control company.

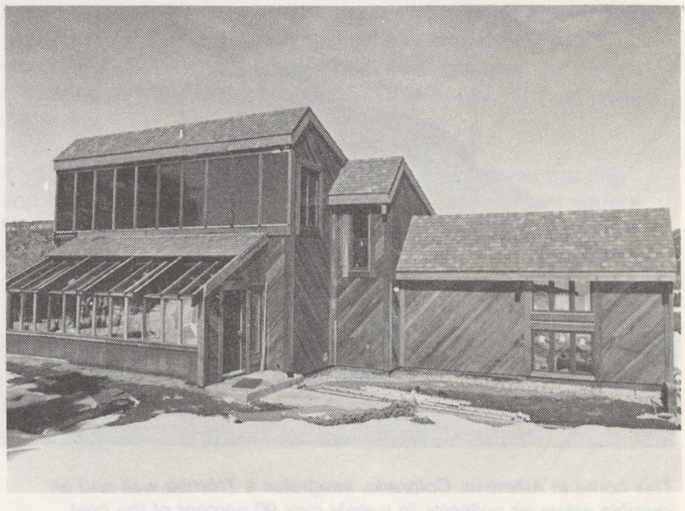
Kincaid Residence

The Kincaids' home east of Grand Junction, Colorado, uses an active air collector combined with passive direct gain and a greenhouse to supply almost all their heat. The air collector was very costly, since it was built by the owners using recycled aluminum newspaper printing plates for the absorber. Hot air is recirculated from the top of the ceiling down to the lowest level where the rock storage is housed.

Dobrovolny Residence

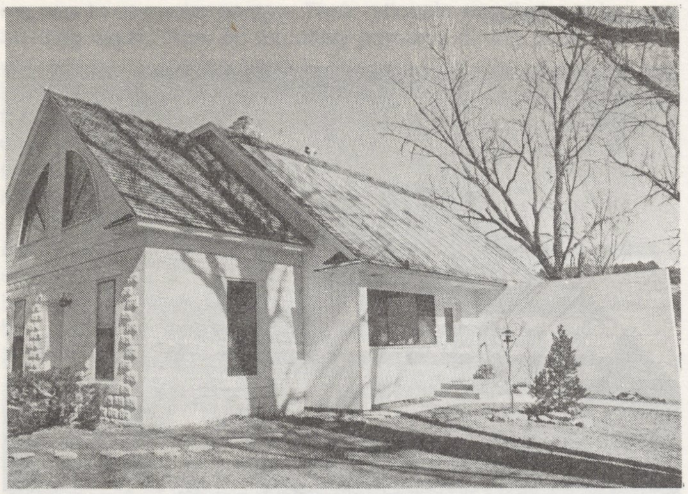
This integrated solar house in Snowmass, Colorado, completed by Mr. and Mrs. Peter Dobrovolny in 1976, uses an active air system and passive solar features to provide about 90 percent of the heat. Dobrovolny, who is a professional architect, says next time he will "concentrate more on the passive; it's so much simpler, and a lot cheaper." He says, "Passively, the house is doing great; we're getting about a 50/50 contribution from the passive and active systems."

Glennie Residence



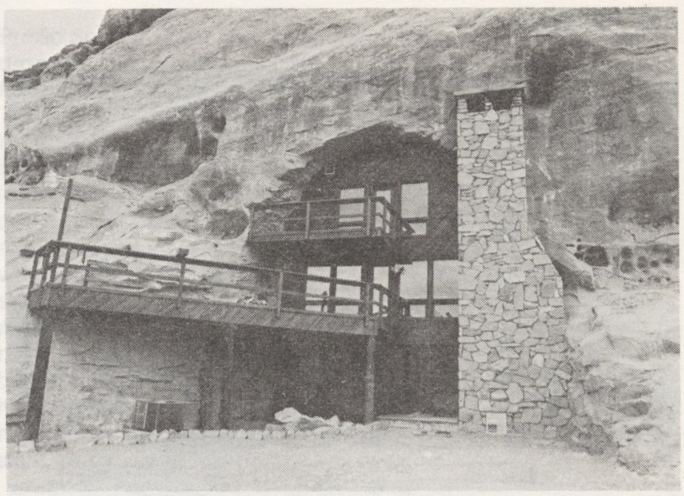
This suburban home near Durango, Colorado, integrates an active liquid system and a passive solar greenhouse. The liquid collectors also supply domestic hot water, and the water storage temperatures are augmented by a heat-recovery coil in the fireplace. Air from the rock box storage bin under the greenhouse floor heats the house at night, supplemented by an electric duct heater when necessary.

Vanarsdale Residence



This hundred-year-old home in Cedaridge, Colorado, was remodeled recently to incorporate passive and active solar features. The active air collector, with a forced-air furnace back-up, is supplemented by passive solar gain through south-facing windows. The rock box storage is passively augmented by the thermal mass of the masonry building. The concrete, stuccoed wall by the entrance helps direct winter winds away from the glass.

Nystrom Residence



This unique underground home was built for his family by Charles Nystrom in a south-facing cliff face near Loma, Colorado. The temperatures in the blasted-out rock cliff are so stable that Mr. Nystrom says the home requires only one quarter of the energy that a comparable, conventional, above-ground home would require. Most of their energy needs are supplied by sunlight that comes directly into the home through the south-facing, thermopane glass. A heat pump provides back-up heating when called for.

Ron Loser Residence

This home in Alamosa, Colorado, integrates a Trombe wall and an invisible active air collector to supply over 90 percent of the heat required. The conventional plywood-and-combination-shingle roof collects hot air between the insulated rafters. Hot air is blown by a fan under the foundation slab into perforated sewer pipes running through an insulated gravel bed. The Trombe wall which dominates the south wall also incorporates a sliding glass door airlock entry. A three-foot wide space between the glass and mass wall is also used to start plants and dry clothes.

Craven Residence

Built in Carbondale, Colorado, in 1976, this 2,800-square-foot home has a 100-square-foot greenhouse that combines passive and active features. A thermosiphon system is used for heating water. The house is designed to permit the addition of an active space heating system.

Solar Greenhouses

Do you sometimes long for a **real** tomato after looking over the tasteless orange blobs stocked at local supermarkets? If so, you might seriously consider combining food production with solar heat collection in a solar greenhouse.

Greenhouses all use solar energy by admitting through glass the sunlight plants use for photosynthesis. A "solar" greenhouse goes one step further; it traps and stores the sunlight to provide its own heat and even provide heat to an adjoining structure. While a conventional greenhouse is made almost entirely of glass or plastic, a solar greenhouse has a well-insulated solid north wall and at least partially insulated east and west walls. Glass or plastic takes up the south wall so maximum winter sun can enter.

A solar greenhouse can be free-standing or built as an addition. For almost all residental applications, the attached greenhouse makes the most sense. An adjoining greenhouse is cheaper than the free-standing model because the south wall of the house can serve as the north wall of the greenhouse. It permits easy access for gardening and creates a pleasant addition to the living space. But most important, it supplies supplementary heat and food for the building's occupants.

Heat collection and retention are achieved in much the same way as in any solar heating system. Solar radiation passes through the glazing, strikes interior surfaces, is changed to heat and stored for later use in some kind of thermal mass. Water, rock, and earth are often used; concrete, brick and other massive materials also work well. Water is usually tightly contained to prevent excess evaporation and high humidity. You may use a concrete slab floor, a row of 55-gallon drums of water or a masonry wall between the house and greenhouse. A storage compartment like a rock bin can be used too.

When temperatures in the greenhouse or in storage are sufficiently high, heat can be provided for the house. Air from adjacent rooms can be circulated through the greenhouse, where it's heated and returned. In this process the air is also humidified and charged with oxygen from plant respiration, adding to the comfort of the interior. In retrofit applications, windows and doors enclosed by the greenhouse can be opened so air can circulate, or vents can be cut into the common wall. If a separate storage compartment like a rock bin is used, air can be blown through the rocks and then ducted to the space to be heated.

Prevention of heat loss is critical. Double-glazing or movable insulation should always be used in Colorado. Heat that's trapped during the day must be retained at night and during very cold weather. Quality construction is also important so that air infiltration is minimized.

Solar greenhouses are net energy gainers over the winter season, but when temperatures drop very low it may be necessary to add heat to prevent plants from freezing. This can be accomplished by allowing warm air to flow from the house into the attached structure. A small back-up heater in the greenhouse is another option. Or you may prefer to close off the greenhouse during the coldest month in winter so you can take a break from gardening functions as an effective thermal buffer between your house and the cold outdoors.

People generally pay most attention to collecting and rètaining winter heat in a greenhouse, but summertime overheating is the problem most frequently encountered. This pitfall is easily avoided by intelligent placement of doors and windows, vents, small fans and shades. Vents placed low on one side and high on the other should be incorporated into the structure. This allows for natural convective currents to cool the greenhouse. The high vents should be about three times bigger than the bottom ones.

Vent placement will depend on the prevailing winds at your site. The high vent should be downwind of prevailing air currents. Vents may be opened and closed by hand, by thermostatically operated controls, or by heat-activated pistons. In many cases, a small fan is placed in the high vent so large quantities of heat can be exhausted when necessary. Doors and windows in the greenhouse can also serve as vents.

Shading can keep the greenhouse cool and shield plants from scorching summer rays. Movable insulation, special screens, deciduous trees to the south, vines or large plants like sunflowers, and overhangs in front of the south wall are all possibilities.

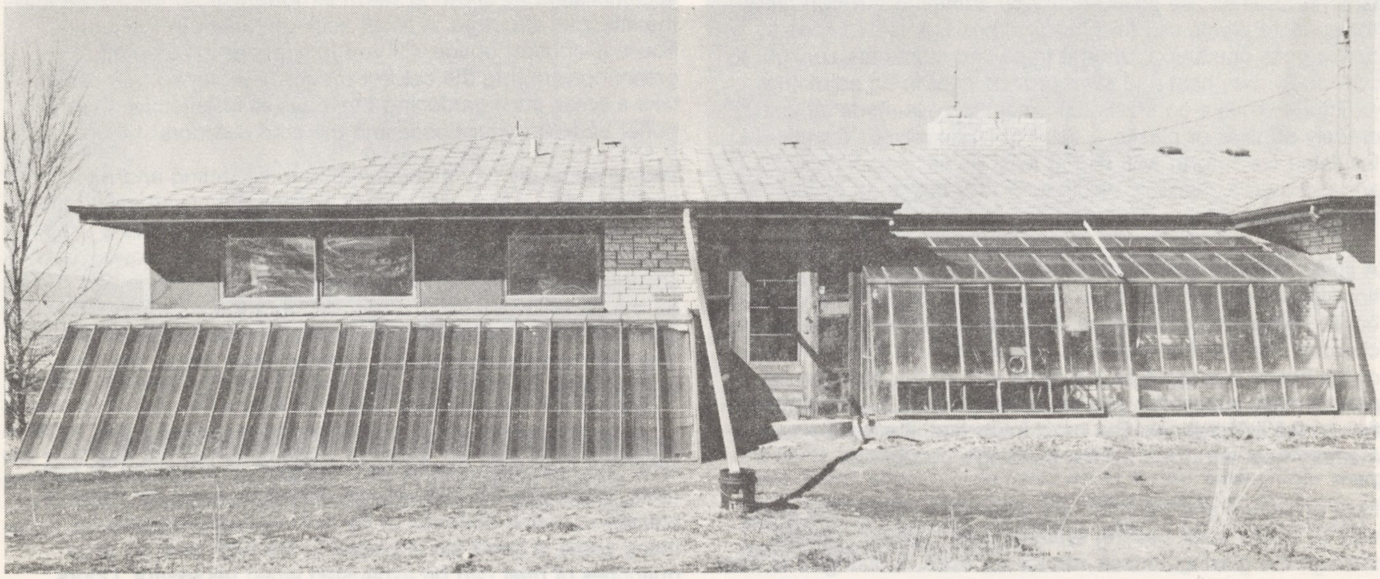
Solar greenhouses can be designed for both new construction and retrofit applications. The greenhouse can serve as a sun room and a vestibule that keeps cold air from escaping the house when doors are opened. You can integrate a solar water heating system with the greenhouse by using a flat-plate collector as an overhang; or, draw heat from between the layers of glazing as they've done at Rick's Cafe in Denver (see page 38).

If you build a greenhouse yourself with inexpensive framing and fiberglass glazing, it can cost as little as \$3.50 per square foot. Using moisture-resistant redwood and glass or a greenhouse kit will cost more. If you contract with a builder or solar greenhouse firm, it will cost \$20-\$35 per square foot.

VanWinkle Greenhouse Added on and Integrated with Collectors

During his spare time, Rip VanWinkle has spent the last six years constantly improving his home's thermal performance. He works full time as an electrical engineer for IBM in Boulder.

"When I moved into the house, I added insulation, then storm windows, then more storm windows. Then I added a greenhouse for passive heat. I added the collector, mainly to help the domestic hot water. The domestic hot water heating load was 36,000 cubic feet a year (of natural gas) or about 40 percent of our fuel bill. Now it's less than half that."



Rip and Ellie VanWinkle's home east of Boulder uses 20 percent less gas for space and water heating than before Rip added insulation, storm windows, a solar greenhouse and a homemade water collector.

Energy Conservation

Rip and Ellie are firm believers in insulation. Rip says, "If people are going to gain from solar, they have to first do everything they can to reduce the heat loss from the house. I definitely recommend triple-glazed windows on the north, east and west, and R-30 or R-40 or more in the ceiling. The first solar step I would recommend is a greenhouse. It gives you passive heat; when the sun comes up, you have instant heat. You don't have to wait for a collector to warm up and start circulating the heat around.

"When you can't store all the heat, then you put in an active collector. Between the two, a well-insulated house should never require more than about 300 square feet of collector, with a greenhouse, to get about 75 percent solar." The VanWinkles' greenhouse supplied them with an unexpected 30-40 percent of their space heating, not to mention a lot of vegetabes.

Greenhouse and Storage Tank

The VanWinkles' suburban home, of frame construction with masonry veneer, faces about 26 degrees east of south along the east/west axis. After adding insulation and triple-pane storm windows on the north, east and south, Rip and Ellie decided to build a passive solar greenhouse on the south side of their home in 1975. Rip built the greenhouse himself out of redwood and single-pane glass, using a large concrete septic tank filled with water for thermal storage.

When he built the greenhouse, Rip left the tank open with a plank floor resting on top of pipe supports. Because of excess humidity in the greenhouse, he added extruded polystyrene insulation floating loosely on top of the water.

The greenhouse has 260 square feet of southeast-facing glass on the roof and front face, which Rip says makes an aperture of 222 square feet accepting direct sunlight at a 45 degree angle. The back wall is masonry that conveniently existed as the veneer for the south wall of the house. A 2,400-gallon concrete septic tank serves as thermal storage under the greenhouse. Hot air from the greenhouse enters the house through two large existing, operable windows on either side of a large picture window.

"If I were going to build the greenhouse again, I'd probably go to thermopane glass to cut down heat loss," says Rip. "I wouldn't put in as many operable vents; we've got more than necessary," he adds, referring to the operable windows that occupy part of the greenhouse ceiling. "We added foam across the top of the ceiling because we didn't need that heat in the summertime, and we didn't get much heat from the ceiling in the wintertime; you really don't need a totally transparent roof."

Ellie says the only problem with the greenhouse has been burning of the plants. She says, "We need more shading," But they have had no problems with bugs or pests, which are often the nemesis of greenhouse operators. The VanWinkles credit their pest-free greenhouse to some garter snakes who volunteered to move in. 'One week I went out there about nine in the morning and found one snake spread out very happily, lying lengthwise along the pipe coming from the collector," says Rip. "It has about l00-degree water coming from it; he thought that was seventh heaven. The garter snakes must eat something because they stay there. We don't have any bug problem."

When Rip and Ellie decided to build a collector for domestic hot water, they realized that the one inch of foam around the storage tank would not be adequate for the higher temperatures generated by the collector. Rip went back and dug around the tank to reinsulate it. He drained the tank, insulated the inside, and constructed two partitions to create three sections, one "cool" 1,500-gallon section, and two smaller 350-gallon sections. Then he integrated the storage tank with a home-built copper water collector and a homemade "smart valve" to optimize the performance of the collector."

Solar Collector and "Smart Valve"

Rip built a 150-square foot collector designed to drain into the storage tank under the greenhouse during cold weather and at night. He made it from copper pipe continuously soldered to copper absorber plates, with fiberglass insulation behind the absorber. He made it lean against the house at a 51-degree angle, and used redwood trim between collector sections to match the greenhouse.

Using a small, 75-watt pump, water circulates through the collector and into the storage tank, where cool water from the bottom of the tank is recirculated through the collector. Rip has improved this operation by stratifying his storage tank (dividing it into sections of progressively higher temperatures), so hot collector water goes to the hottest tank and cool return water comes from the coolest tank. He further improved it by building what he calls a "smart valve," because the valve is smart enough to know where to put the warm water coming out of the collector.

The "smart valve," Rip's own invention, consists of a valve with a rotating disk mounted over four stationary pipes going to three different sections of the storage tank and to a hot water tank in the basement. Rip has installed temperature sensors on all these locations and on the collector surface. "The sensors are simply two diodes in series with a constant current going through them. You measure the voltage across the diodes to determine the temperature," Rip explains.

Wiring from the temperature sensors and the "smart valve" goes to a central control box which compares the different temperatures. In the morning when the collector temperature sensor tells the pump to start circulating water to the collector, the water in the collector is relatively cool. The "smart valve" compares its temperature to the temperatures in the tanks and "decides" to put the water in the coolest tank. Later in the day, when the collector water is hotter, the "smart valve" rotates its disk and puts the water in the next hottest, then the hottest section of storage. If the collector water is even hotter than the hottest tank, the valve puts it in a hot water tank in the basement. This tank also heats the basement by radiation.

Domestic Hot Water

Rip made a heat exchanger to feed the domestic hot water tank by running a continuous three-inch copper pipe from the main water inlet from the well to the house. The pipe goes to the coolest storage tank, where it's coiled through the upper section of water, then to the next tank, then the next, and finally to the gas water heater. The three-inch pipe running through the hot storage tank has about 11 feet of heat exchange surface. The heat exchange pipe goes to the existing hot water heater's supply inlet. In the summer, the water has been heated to 130-150 degrees before it gets to the water heater, because it's picked up heat while coiling through the storage tanks. Over the whole year, Rip figures his water is preheated to an average of 95 degrees, so the gas water heater uses 75 percent less gas than it did before.

Ellie says, "When you're using hot water from the collector, you don't wash three loads of laundry, take a shower and use the dishwasher; you wait for more heat to be collected in between. You just have to change your habits. As far as the greenhouse is concerned, you get in there and do you chores when it's not too hot, which is generally before nine in the morning."

Rip says the greenhouse has been operating three and one half years and the collector about two and one half years. "Before, we were using about 110-120 thousand cubic feet of gas a year. Now we're using about 40-50 thousand." He expects a pay-back period of about 10 years.

Gilmore Greenhouse Added onto Existing Building

"Last year we spent $350 on heating oil and propane," says Tom, "and this year, after adding the greenhouse, we spent less than $150 all winter." The greenhouse was supplemented all winter by a heatalator fireplace with glass doors and outside combustion air. Any additional requirements were met by oil-burning space heaters.

"By evening, on a sunny day, the whole house is up to 75 degrees," according to Gilmore. "All the interior doors are left open, providing completely open circulation of heat through the house."

The 60-year-old home has no central heating, which makes the Gilmores even more delighted with their solar greenhouse addition.

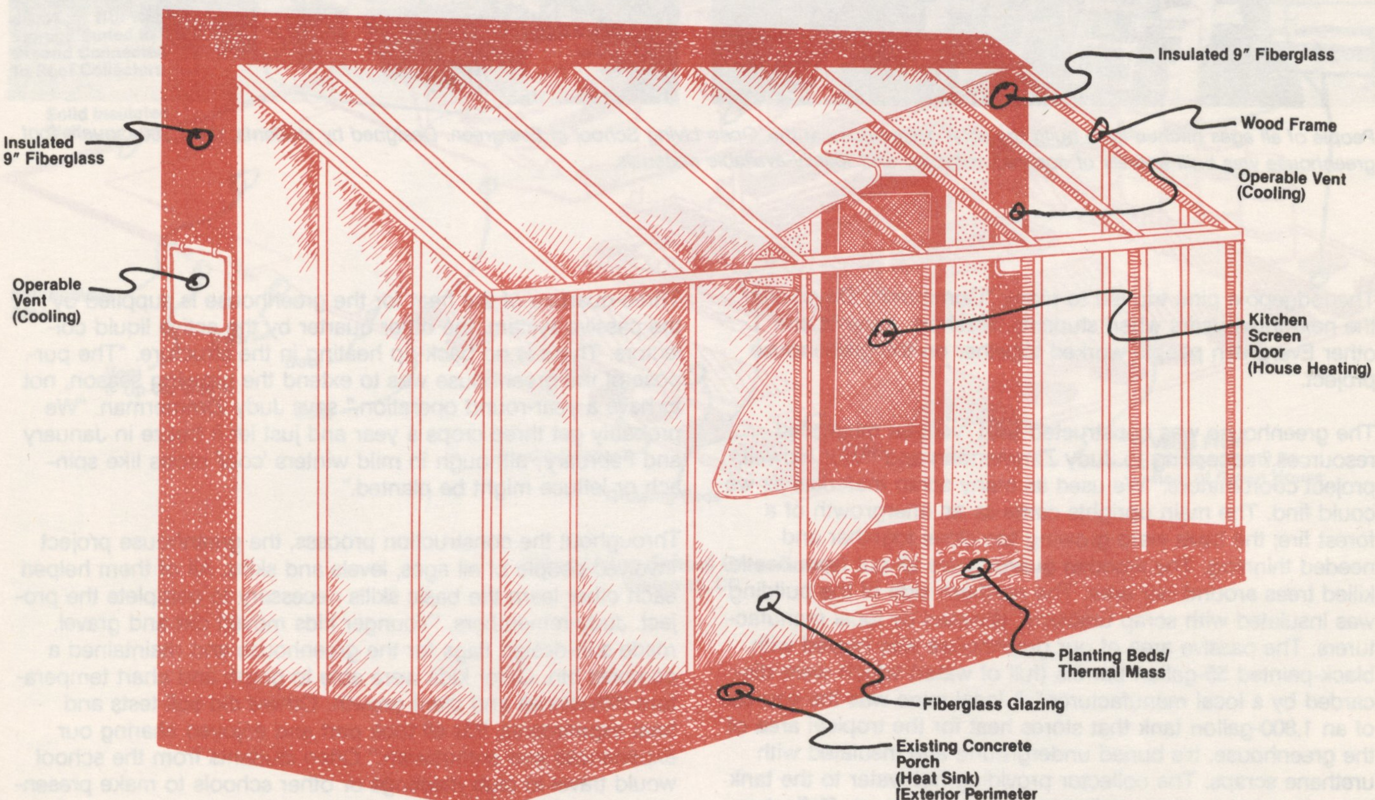
Built onto their existing south porch, the Gilmores' greenhouse uses the existing concrete slab porch foundation and the new planting beds as thermal storage mass. "It will hold heat overnight in October and November," says Tom. "That's when we noticed the biggest differences, and also in the spring months of March, April and May."

"We had fresh tomatoes all winter," adds Pat Gilmore. The greenhouse is located directly off the kitchen, so harvesting and washing of vegetables can be done as a routine part of food preparation. "We're garden nuts, and we originally put it in for that reason. We're amazed at how much heat it has generated."

The humidity has been much higher in the Gilmores' house since they added their greenhouse. Twenty-five average-sized plants provide about the equivalent of a small, commercial humidifier. In fact, the Gilmores "now leave the kitchen screen door open to the greenhouse, because the condensation was soaking the wood framing when we kept it closed off at night."

During construction, the Gilmores installed nine inches of fiberglass insulation in the end walls and upper ceiling of the greenhouse. They put large operable vents in the end walls to provide summer ventilation. They have insulated the 6-inch footer around the perimeter to increase heat storage in the concrete slab, and have added a heat exchanger in the fireplace with a water storage tank, combined with a small water collector. This has made us almost totally self-sufficient for space and water heating," says Tom.

Tom Gilmore, who is an economics professor at Adams State College in Alamosa, definitely believes solar energy pays off. He emphasizes the importance of energy conservation and insulation techniques, which are even more cost-effective than solar retrofits in most residential buildings.



Gilmore Residence — Greenhouse

Open Living School
Free Standing and Community Built

The environment is fragile in the mountain community of Evergreen, Colorado. The growing season is short; and just like everywhere else, fuel costs keep rising. In 1973, parents and teachers at the Open Living School decided they should do something about these problems and came up with Operation Sundance, a program designed to teach students and adults to use the sun for practical, domestic applications. With funding from the Department of Health, Education and Welfare, the program got underway in 1974. By the end of 1977, it had resulted in a 1,200-square-foot solar greenhouse behind the school, numerous student research projects on solar energy, many small greenhouses constructed by families in the Evergreen area, and a tremendous learning experience for students, teachers, parents and community members alike.

During the first year of Operation Sundance, the greenhouse was designed by junior high level students with the help of community volunteers. When designs for the greenhouse were complete, a camping trip was organized to cut lodgepole pine for the main uprights of the structure. Student Abby Ruskey recalls, "Eighty of us went up into the forest and cut down 750 lodgepole pines and stripped them in four days. It was a fantastic trip, very well organized. I liked concentrating on one thing with so many people. It's a good feeling to share with so many, all working for one purpose."

People of all ages pitched in to build the solar greenhouse at the Open Living School in Evergreen. Designed by students, the 1,200-square-foot greenhouse was built entirely of donated, recycled and locally-available materials.

The lodgepole pine trip led to many "Community Days" over the next three years when students, teachers, parents and other Evergreen people worked together on the greenhouse project.

The greenhouse was constructed with "various misplaced resources," according to Judy Zimmerman and Peter Howell, project coordinators. "We used as many scrap materials as we could find. The main uprights came as an aftergrowth of a forest fire; the trees were growing too close together and needed thinning. The wooden guards were all cut from beetle-killed trees around our area. The northern side of the building was insulated with scrap urethane, donated by local manufacturers. The passive area of our greenhouse was heated with black-painted 55-gallon barrels (full of water) which were discarded by a local manufacturer." A local mine was the source of an 1,800-gallon tank that stores heat for the tropical area of the greenhouse. It's buried underground and insulated with urethane scraps. The collector providing hot water to the tank is a converted coolant exchanger for an ice house. Reflectors made of scrap stainless steel were used to increase the amount of energy striking the collectors. All the lumber for the greenhouse is from beetle-killed trees, rough boards of "second cuts," cheaper than straight-edged lumber.

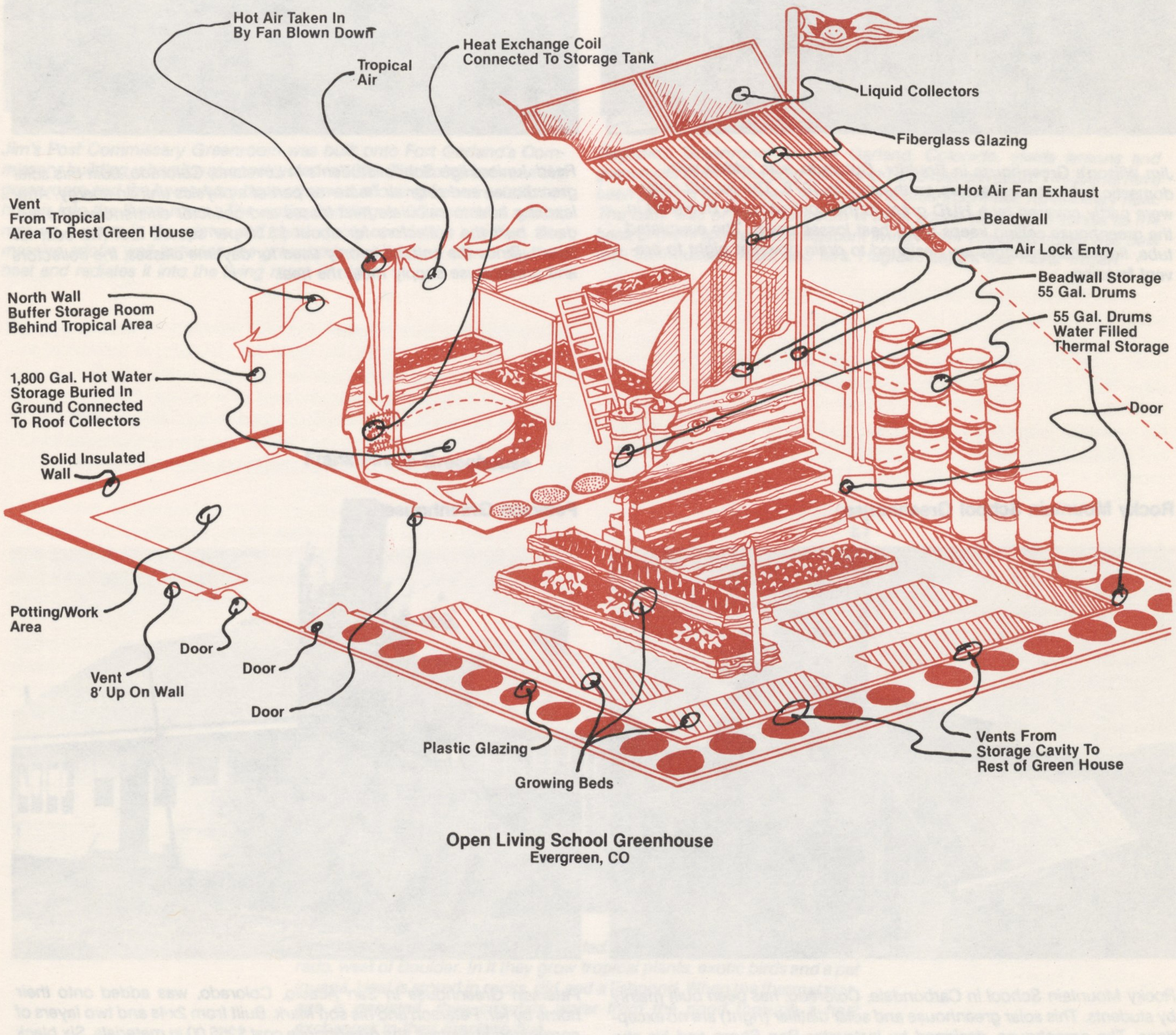
Three-quarters of the heat for the greenhouse is supplied by the passive system, the other quarter by the active liquid collectors. There is no back-up heating in the structure. "The purpose of the greenhouse was to extend the growing season, not to have a year-round operation," says Judy Zimmerman. "We probably get three crops a year and just let it freeze in January and February, although in mild winters 'cool' crops like spinach or lettuce might be planted."

Throughout the construction process, the greenhouse project involved people of all ages, levels and skills. All of them helped each other learn the basic skills necessary to complete the project. Judy remembers, "Younger kids moved dirt and gravel, made sun-design flags for the greenhouse and maintained a compost bin. Older kids were able to graph and chart temperature differences and plant growth. Others did soil tests and heat experiments. We all took part and enjoyed sharing our experiences and enthusiasm." Often students from the school would travel to club meetings or other schools to make presentations on the project. Other children were often amazed at how much their peers had accomplished, and faculty at several schools in the Evergreen and Denver area adopted parts of the Sundance program.

Operation Sundance is no longer funded, although the greenhouse remains as a place that students, teachers and the community use as a learning tool. If you go to their school, students can give you a tour of their indoor garden, explain how it works, tell you about the plants they are growing, and describe experiments that are underway.

Judy Zimmerman, who no longer teaches at the Open Living School says, "It's a great feeling to go back there and pretend you don't know what's going on and let the new students explain it to you. It means the program really worked; there's a continuation of the process and concepts we initiated."

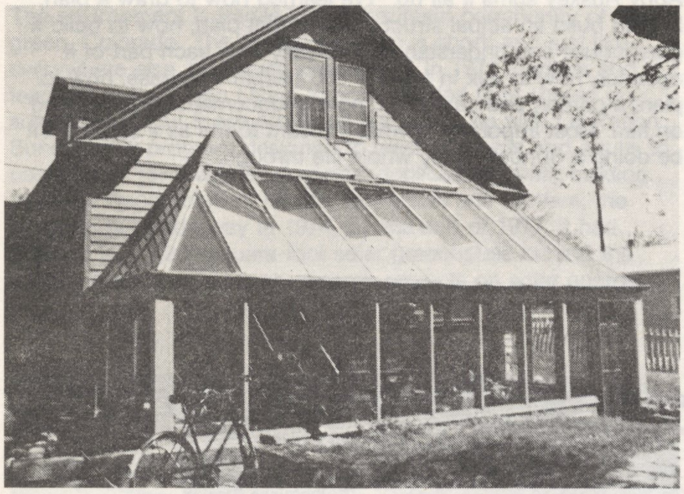
Abby Ruskey sums it all up: "I've learned how to draw a plan, how to build an actual structure from that plan, how to build a greenhouse and understand completely how each part of it operates, how to talk in front of 550 people with ease, how to plant a garden and care for it, how to document on paper and on film. Most important is what it meant to me as a student. I'll be doing a Sundance my whole life through."



Open Living School Greenhouse
Evergreen, CO

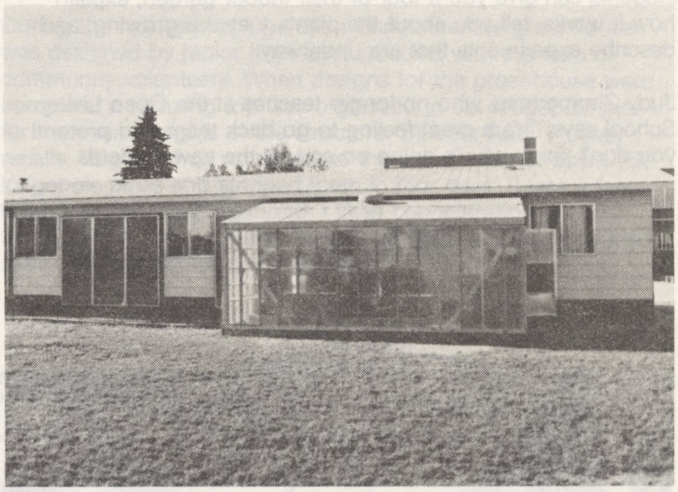
More Greenhouses

Jim Wilson's Greenhouse



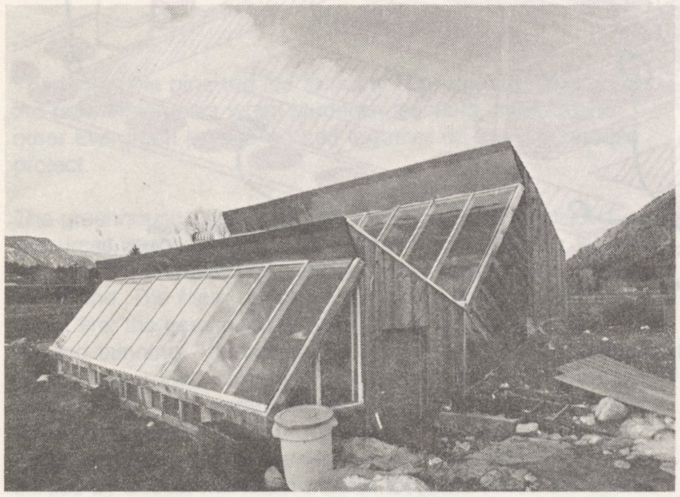
Jim Wilson's Greenhouse in Boulder, Colorado, was added with domestic hot water collectors on the roof in 1978. The retrofit costs were partly covered by a HUD grant to the contractor. A Beadwall in the greenhouse ceiling keeps night heat losses down. The evacuated tube, flat-plate collectors are designed to drain down at night to prevent freezing.

Reed Junior High School Greenhouse



Reed Junior High School students in Loveland, Colorado, built this solar greenhouse and solar air heater as part of a physics unit on energy. After learning how to calculate heat losses and collector efficiencies, the students built the collectors for about $3.50 per square foot (no cost for labor). Since the cottage is only used for daytime classes, the collectors and greenhouse supply most the heat.

Rocky Mountain School Greenhouse

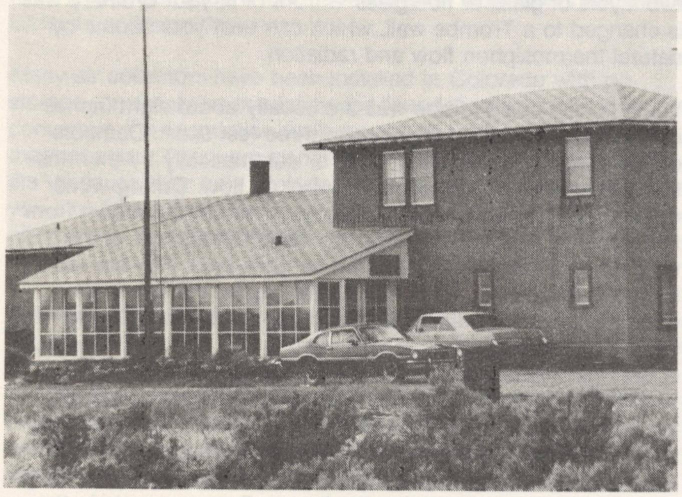


Rocky Mountain School in Carbondale, Colorado, has been built mainly by students. This solar greenhouse and solar distiller (right) are no exceptions. The greenhouse, designed by instructor Ron Shore and his students, operates all winter with no auxiliary heat at an altitude of nearly 8,000 feet. Rocks contained in chicken wire and black barrels of water store daytime solar heat for night use so the building remains warm enough for plants. A small fan captures heat from the ceiling and blows it into the lowest part of the rock storage.

Peterson Greenhouse

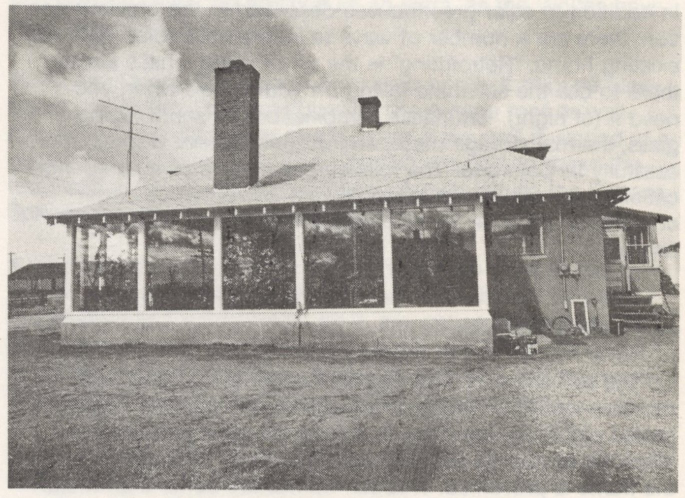
Peterson Greenhouse in San Acacio, Colorado, was added onto their home by Mr. Peterson and his son Mark. Built from 2x4s and two layers of corrugated fiberglass, the greenhouse cost $265.00 in materials. Six black drums of water and about 1,000 pounds of native basalt rock supply thermal storage. Heat enters the house through two existing operable windows which are closed at night. Peterson estimates they're getting about 25 percent of their heat for a 950-square-foot house plus lots of fresh vegetables.

Fort Garland Commissary Greenhouse



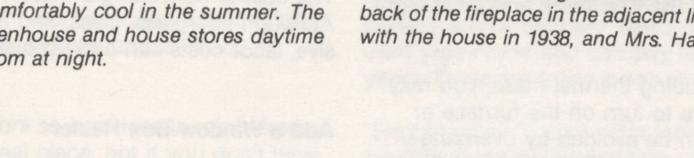
Jim's Post Commissary Greenroom was built onto Fort Garland's Commissary building when it was constructed in 1858. The doors between the greenroom and the home have been removed, allowing free circulation of hot air into the living room. The entire building is 20-inch thick adobe, making it warm in the winter and comfortably cool in the summer. The massive adobe wall between the greenhouse and house stores daytime heat and radiates it into the living room at night.

Hagland's Greenroom



Hagland's Greenroom in Fort Garland, Colorado, yields lemons and grapefruits even in the cold climate at 7,600 feet elevation. The plants have been bearing for 30 years, although the greenroom has no auxiliary heat. The back wall of the greenroom is thick adobe which also serves as the back of the fireplace in the adjacent living room. The greenroom was built with the house in 1938, and Mrs. Hagland says it has never frozen.

Frank Finn's Greenhouse



Finn Residence Greenhouse was added to their home in Gold Hill, Colorado, west of Boulder. In it they grow tropical plants, exotic birds and a pet iguana. Heat is stored in rocks, dirt and a fishpond. When the thermal storage is depleted, they circulate water from the pond through a heat exchanger in their fireplace flue.

Solar Retrofit Options

In addition to solar greenhouses described in the previous section, there are a number of ways to incorporate solar into your existing home. "Retrofitting" is the art of using what's already there to use the sunshine falling on your house when you need it (at night). Countless combinations of south-facing glass, thermal storage mass, and insulation have worked successfully in Colorado. The following examples give some indication of the enormous range of cost, performance and complexity available for refitting existing homes with solar energy.

Add South Windows

Let the sun shine in! Two layers of south-facing glass with movable insulation make an effective solar collector. Tightly sealed nighttime insulation is a must for good performance. Windows should be installed carefully so air infiltration around the frame is prevented. Wooden frames are better than metal because metal conducts heat from the house faster than wood.

Skylights on the south roof can be just as effective as windows, although extra care must be taken to prevent heat loss. Heat rises naturally, so a skylight will lose more energy at night than a window of the same size.

If you add south glass without adding thermal mass, you may sizzle during the day but still have to turn on the furnace at night. Overheating in summer can be avoided by overhangs, deciduous trees, or drapes. Extra heat gained during winter days can be stored in thermal mass for nighttime comfort.

Discounting labor costs, a double-pane window will cost $3-6 per square foot. Extra trim materials and weather-stripping are more.

Add Thermal Mass

If you already have rooms that overheat in the daytime, or plan on installing extra south windows or skylights, adding thermal mass to your floors or walls is a good idea. Any of the massive materials used with solar systems will work—water, concrete, brick, adobe, rock, etc. But remember, these materials are heavy. Make sure your floor can support their weight. Ten black barrels, each filled with 50 gallons of water, weigh almost 4,000 pounds. The mass should be placed in direct sunlight and preferably be painted black.

With restrictions of weight, space and placement, adding thermal mass to a home can be a challenge. Can you lay a brick floor? Put heavy tiles along the walls? Accumulate bottles for a water storage wall? Solutions are limited only by your time, imagination and pocketbook.

If you salvage materials like 55-gallon drums or bottles that are normally discarded, adding an absorber/storage component to your solar collection system will cost nothing. Other options will range in price.

Convert an Existing Wall to a Trombe Wall

If you have an uninsulated south-facing wall made out of stone, brick or concrete, you can transform it into a solar collection and storage system. By painting the wall a dark color, cutting out vents in the top and bottom of the wall, and putting two layers of glass or fiberglass in front of it, your ordinary wall is changed to a Trombe wall, which can heat your rooms by natural thermosiphon flow and radiation.

Vents placed in a Trombe wall are usually about eight inches in diameter and are spaced two to three feet apart. Dampers on the vents, controlled manually or automatically by thermostats, are opened and closed to control air flow. During winter days, all the vents are open so that cool air can be drawn from the house to heat and rise over the dark, hot surface of the wall. When it reaches the top, the air goes back into the room through high-placed vents. On winter nights, the vents are closed to prevent reverse thermosiphoning (warm air being sucked out through the top vents and losing its heat to the outdoors). An insulating curtain for winter nights can be an integral part of a Trombe wall system. The cold air stays outside, and the massive wall can radiate stored heat directly into the living space. (This is why the wall should not be insulated on the inside). In summer, the top vents in the wall are closed to keep unwanted heat from entering the house. Summer vents in the top part of the glazing, similar to the type used by the Pixlers (see page 10) will also help control summer overheating.

The cost of converting a masonry wall to a Trombe wall varies. Although fiberglass, glass, and framing are relatively inexpensive, labor costs can add up quickly.

Add a Window Box Heater

Window box heaters are popular do-it-yourself projects because they are easily constructed at low cost. (They are also available commercially.) In most cases, window box heaters will not contribute a significant portion of your heat, but they do help. These devices are especially appropriate for renters, since they can be moved easily.

Window box heaters usually operate by natural convection. The collector is located below the window level so air rises into the window, and air from the room is drawn in to the window box to be heated.

A guide to plans for window box heaters is provided in "Doing It Yourself" on page 70. For a working example, see Don Harvey's house, page 64. Building a window box heater from these plans will cost anywhere from $35 to $125 in materials; a prefabricated model can cost as much as $500.

Add an Air Collector for Daytime Heating

An air collector can be vertically mounted on a south wall for daytime solar heating. The units can draw air from the house by natural thermosiphoning using a small fan. Air heats as it circulates behind a black sheet metal absorber plate and then is ducted back to the house. Vertically mounted air collectors have been very popular in Colorado; hundreds have been installed throughout the state.

If you do not have space on a south wall to mount an air collector, placing one directly adjacent to your home as a freestanding structure may be feasible. You can use ducts to connect the collector to the house. The closer the collector can be to the house, the better. Ducting should be as short as possible to prevent heat loss (and reduce cost); it should also be well-insulated (an equivalent of six inches of fiberglass).

Air collectors can be built on existing walls for as little as $3 per square foot in materials. Installed commercial models range from $8-$20 per square foot depending on labor costs and variables in collector design.

Many air collectors have been installed in Colorado with no storage, or simply by insulating the foundation skirt, thereby converting the foundation walls and earth under the house to thermal mass. These are generally referred to as "daytime heaters" because they only provide heat when the sun is shining. If you can afford to add storage, the collector can provide heat at night when it's needed most.

Add Active Space Heating with Storage

In some cases, an active air or water system with storage can be installed on an existing structure. To provide a significant portion of home heating needs, a large area of collectors is needed, taking up most of a south-facing roof or wall or a section of your yard.

Sufficient room for storage is also required. Storage volume can be considerable—approximately two gallons of water or 50 pounds of rock for every square foot of collector. For example, 500 square feet of collectors would be needed for a 1,500-square-foot house. A liquid system would require about 1,000 gallons of water for storage; an air system, about 25,000 pounds of rock.

Storage should be installed indoors so heat loss is minimized. The basement is probably the ideal place, but if you don't have one, or if it's too small, there are lots of other possibilities. A garage might be suitable, or a nearby barn or shed. Use your imagination. In 1957 Dr. George Lof, one of Colorado's solar pioneers, retrofitted his home with an air system and put storage rocks in tall orange cylindrical tubes in the entryway.

If you have no indoor room for storage, you can build a special shed for it near the house, although this will add to system cost. Burying storage in the yard is another alternative. This will save you space, but fees for excavation and labor also make this choice expensive.

You'll also need room for pipes and ducts. Ducts running between collector and storage are typically a foot in diameter. Pipes are not nearly as large, but can still be obtrusive. In either case, the usual practice is to run them through hidden or infrequently used areas like closets, attics and workrooms. The Active Systems section describes various ways a solar system can tie in with a conventional heating system. Solar heat from either an air or a liquid system can often be channeled into the existing distribution network without any problem. (See page 18.)

Commercially available active space heating with storage is very expensive.

Incorporate a Solar System into an Addition to Your Home

Planning to make an addition to your home? If you can put it on the south side, you are in an excellent position to incorporate a solar system. The kind of system you select will depend largely on how you are planning to use the addition and how much money you have to spend, but the process of retrofitting with solar can be greatly simplified by putting a system on a new, attached structure.

Rather than changing an existing wall to a Trombe wall, you can design one into your new addition. This is a good option if you plan on using the addition as an extra, as the Wolfes have done (see page 69).

If you want to build a garage onto your home, it may be feasible to mount flat-plate collectors on the garage roof or wall. Installation of collectors is much easier if the roof is sloped at a good angle for solar collection. It's also possible to make the roof itself a solar collector, as Danny Armijo did on the Pagosa Springs Fire Station (see page 28).

If you're building an addition of any kind with a south-facing wall or roof, your solar possibilities are as unlimited as your imagination and pocketbook. As in any new construction, passive solar can be incorporated by simply designing the space to collect and store sunlight. It should cost only slightly more than it would cost to build an addition conventionally.

Add a Solar Water Heater

A typical family in Colorado uses 15 to 20 gallons of hot water per person every day. In a household's energy budget, this amounts to 15-30 percent of the annual heating bill. If electricity or propane is the regular heat source, adding solar water heating is economically viable now. The solar water heater is used year-round and can pay for itself over a period of a few years. There are many types of solar water heaters.

"Breadbox" or "batch" solar water heaters are the simplest and generally least expensive type. Although less efficient than off-the-shelf pumped systems, they are well-suited to the do-it-yourselfer with carpentry and plumbing skills.

A Breadbox solar water heater combines collector and storage. It consists of a well-insulated box, lined with a reflective material like aluminum foil, in which one or more water-filled black metal tanks (like 55-gallon drums or the inside tanks of conventional water heaters) are mounted horizontally. The south-facing top of the box is covered with two or three layers of glass fitted with insulating shutters which have a reflective inner surface. The shutters are opened during the day and closed at night.

Breadbox heaters are best suited for summer cabins or non-freezing climates because they're generally mounted outdoors. Although the heater can be built and installed for under $500, it's difficult to protect it from freezing even with a handy system for moving insulation over it.

Examples of Breadbox heaters are described on page 61.

Thermosiphon water collectors have separate collectors and storage, and operate by natural convective flow. Typically collector pipes slope upward to allow for natural thermosiphon flow. The collector is placed below an indoor storage tank. A pipe from the bottom of the tank carries the coldest water or antifreeze solution to the bottom of the collector, where it heats and rises through the panel and then up through a well-insulated pipe to the top of the storage tank. No pumps are necessary because of the natural flow of heat rising.

In Colorado, antifreeze is necessary or the collector must be drained in freezing temperatures. If an antifreeze is used, a double-wall heat exchanger in the storage tank is required.

Because drainage requires user vigilance and heat exchangers result in decreased system efficiency, the thermosiphon heater is not commonly used in cold climates. A thermosiphon water heater built by Arnie Valdez is described on page 16. It cost under $200 to build.

Active solar water heaters are the most common solar water heater in Colorado. They are usually liquid systems with about 60 square feet of flat-plate collector and a pump and storage tank. At an installed cost of $1,500-$2,500 these systems are practical for retrofit because they offer good performance and flexibility in system layout. These systems can be integrated with space-heating systems or installed independently (see pages ___ for complete discussion of operation).

Air collectors are sometimes used for water heating, usually in integrated systems designed also for space heating. The need for relatively inefficient air-to-liquid heat exchangers is a drawback, but air collectors eliminate the need for freeze protection.

Clearly each retrofit situation is unique to the structure and the needs and resources of its inhabitants. Some of the diverse possibilities and combinations are illustrated in the following examples.

Add A Solar Domestic Water Heater-Retrofit Option

"Breadbox" Water Heater

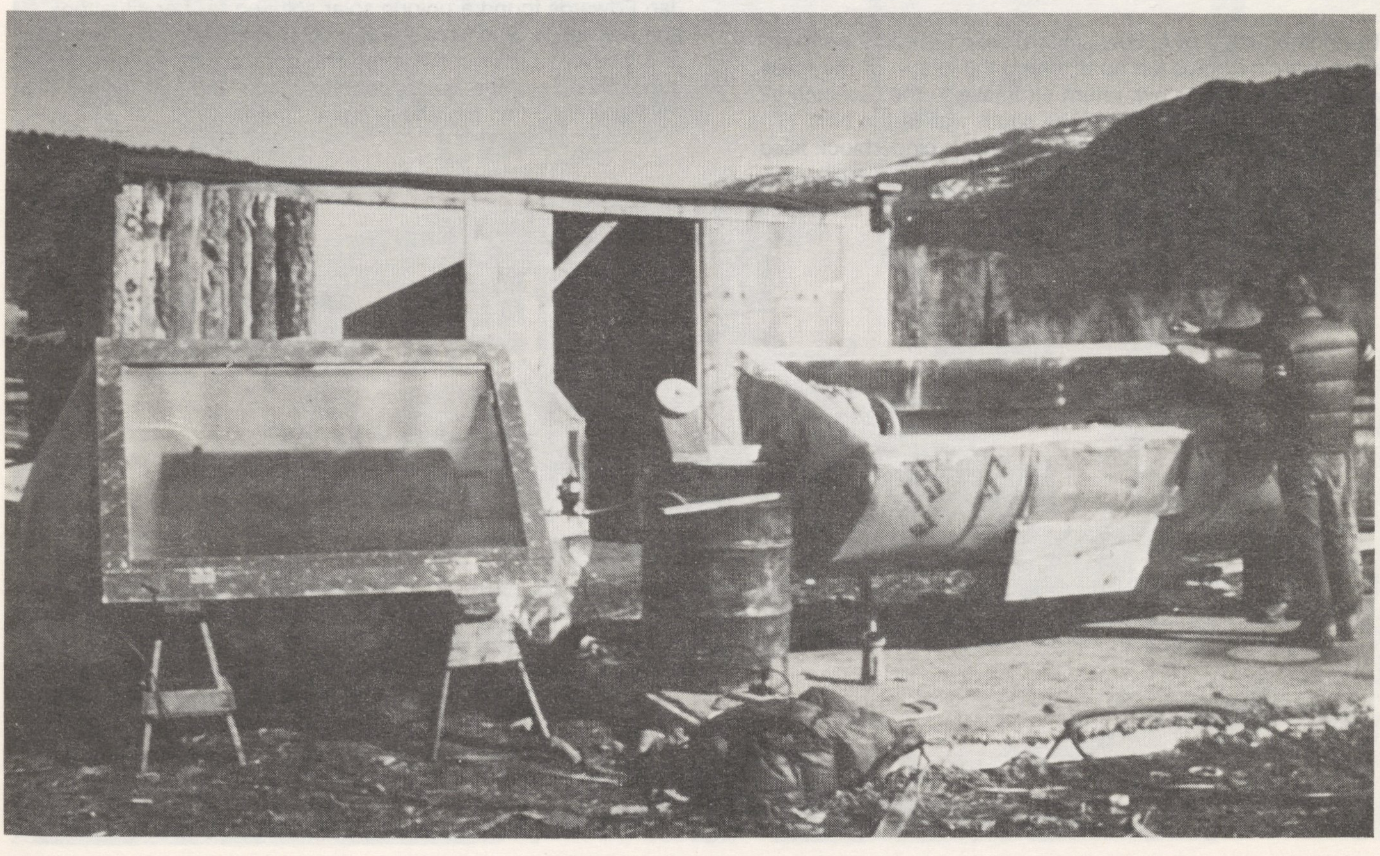
A fourplex owned by Don Ice in Carbondale, Colorado, uses a "breadbox" type water heater with "Skylid" insulating shutters to supply hot water to the apartment units. The $1,800 system cut his typical winter water heating bills from $80 to $35. (The back-up gas water heater is separately metered.) The insulated, glazed collector box contains 180 gallons of water in three 60-gallon tanks plumbed together, one on top of the next. Cold water comes into the bottom tank, becomes heated and rises through the upper two tanks and then goes to the gas water heater, where it's either heated additionally or used immediately. Movable insulation keeps the water warm at night.

Racing Two "Breadbox" Type Water Heaters

Two water heaters are being "raced" side by side, and monitored to compare their performances. The race is taking place behind Ron Shore's shop in El Jebel, Colorado. One heater is a conventional "breadbox" type, with a black metal drum of water inside an insulated, glazed box tilted toward the sun. The other heater is a long black water tank at the focal point of a reflective parabolic curve built into the back of a similarly glazed, insulated box. Indications are the parabolic "breadbox" is out-performing the other by many degrees.

Thermosiphon Water Heater

A low-cost, community-built, water heater at the San Luis Community Action Office, operates without a pump. As water heats in the ½-inch copper tubing inside the collector, it rises through insulated pipes to the top of an insulated tank located **above** the collector. Cool water from the bottom of the tank is allowed to flow back down to the bottom of the collector, where it rises as it heats. A continuous thermosiphon loop is established without the use of a pump.



"Two different types of "breadbox" water heaters are compared. The parabolic heater, on the right, appears to be out-performing the conventional breadbox heater on the left."

Add South Windows and Mass Retrofit Option: Jan Edwards' Potting Studio

Since she retrofitted her potting studio, Edwards hasn't had any frozen pots. The only back-up heating in the studio, an outbuilding behind Jan's house, is an Ashley woodstove. Winter nights in Carbondale are very cold and weeks of work can be lost if the fire goes out. "If wet pots are frozen before they're fired in the kiln, the clay is weakened and the pots are ruined," Jan says.

After two weekend workshops on solar energy, Jan designed her own solar mass wall to heat her studio. After insulating the ceiling, she tore out the south wall and replaced it with new framing and double-pane glass from floor to ceiling. She used thermopane glass units, readymade as sliding glass door units, which were much cheaper than custom-cut glass and easier to replace.

Mass Wall

Inside the glass, she built storage bins of unmortared cinderblock stacked and covered with Blockbond® which provide waterproof containers for clay and water and act as the thermal mass wall inside the glass.

The "mass wall" is counter height and about three feet deep, leaving the upper five feet of glass exposed to the inside space. This allows in plenty of natural light and direct solar gain to warm the occupants and the mass inside the building. The concrete floor and the brick kiln supply "bonus" thermal mass.

The bottom layer of hollow cinderblocks were laid on their sides, with the holes left open, along the length of the mass wall. This forms the low, return air intake to the two-inch air space between the glass and the south wall of the bins. (The south wall of the bins is built of eight-inch cinderblock filled with concrete and painted black.) Hot air rises out of this space, drawing cool air from the floor through the bottom layer of hollow cinderblocks and up between the glass and mass wall. A continuous thermosiphon loop is established when the sun shines. Jan says, "When we finished the system, we took some cigarette smoke and blew it near the floor in front of the bins. The smoke got sucked right into the Trombe wall and came whirling out into the room."

Jan also constructed some insulating shutters to keep the heat in at night. These panels are made of two inches of beadboard styrofoam inside and thermoply reflective-coated cardboard on the surface and face the mass wall when they are closed. The panels are hinged at the bottom so they can be closed over the glass area at night, and opened during the day. The reflective cardboard bounces as much as 30 percent more sunlight onto the glass. Jan says the only problem is keeping snow off them so they can be closed easily.

Cost

Jan spent about $2,000 for materials and labor, and she says, "It's really adaptable for a home, because it's so simple." It took about two months to do the whole project including insulating the buildings.

Before she built her mass wall, Jan used an average of five cords of wood a winter to keep her studio warm. Since then, she's only used scraps. Needless to say, she is delighted with her investment.

Jan Edwards found a unique solar solution for her situation and her needs. She says she is a solar energy "addict" now and it is no wonder considering she got warmth, light, beauty, atmosphere, storage space, counter space, and satisfaction—all for $2,000 and two months of spare time.

Add Window Box Heater Passive Retrofit Option: Dick Harvey's Window Box Heaters

The Harveys have built two window box heaters which extend from the south-facing windows on their house. One unit looks like a rectangular box; the other is convex. A manifold from each heater fits into the window like an air conditioner. Cool air from the room enters the heater through plastic tubes which extend from the manifold to within a few inches of the floor. The cool air flows into the box, reaches the bottom and is then heated. It becomes hotter and lighter as it comes into contact with the absorber plate, and re-enters the room through inlet vents above the cool-air ducting.

Harvey's window box heaters are made of readily available building materials and are fairly easy to construct. In the rectangular-shaped heater, the bottom of the box is particle board, with four inches of fiberglass insulation inside to prevent heat loss. A sheet of masonite covers the insulation, and 1x2 wood spacers are mounted on the masonite. The spacers form a baffle system that disperses the cool air as it flows into the collector.

A well-insulated absorbed plate comes next. The absorbed plate is corrugated aluminum coated with black, heat-resistant engine paint. The plate is mounted half an inch above a sheet of asbestos, which Dick installed to reduce fire danger and keep heat in the upper layer of the unit. Masonite and ¾-inch insulation complete the sandwich, forming an effective absorber and a barrier between the upper and lower compartments of the unit. The collector box is covered with two layers of fiberglass and is sealed with silicone sealant and wood putty.

The convex window box heater is the second one built, and according to Dick "doubles the amount of heat I get." The convex shape of the heater and reflective mirrors attached to the sides of the unit make this model "self-track the sun," significantly improving performance.

Cost

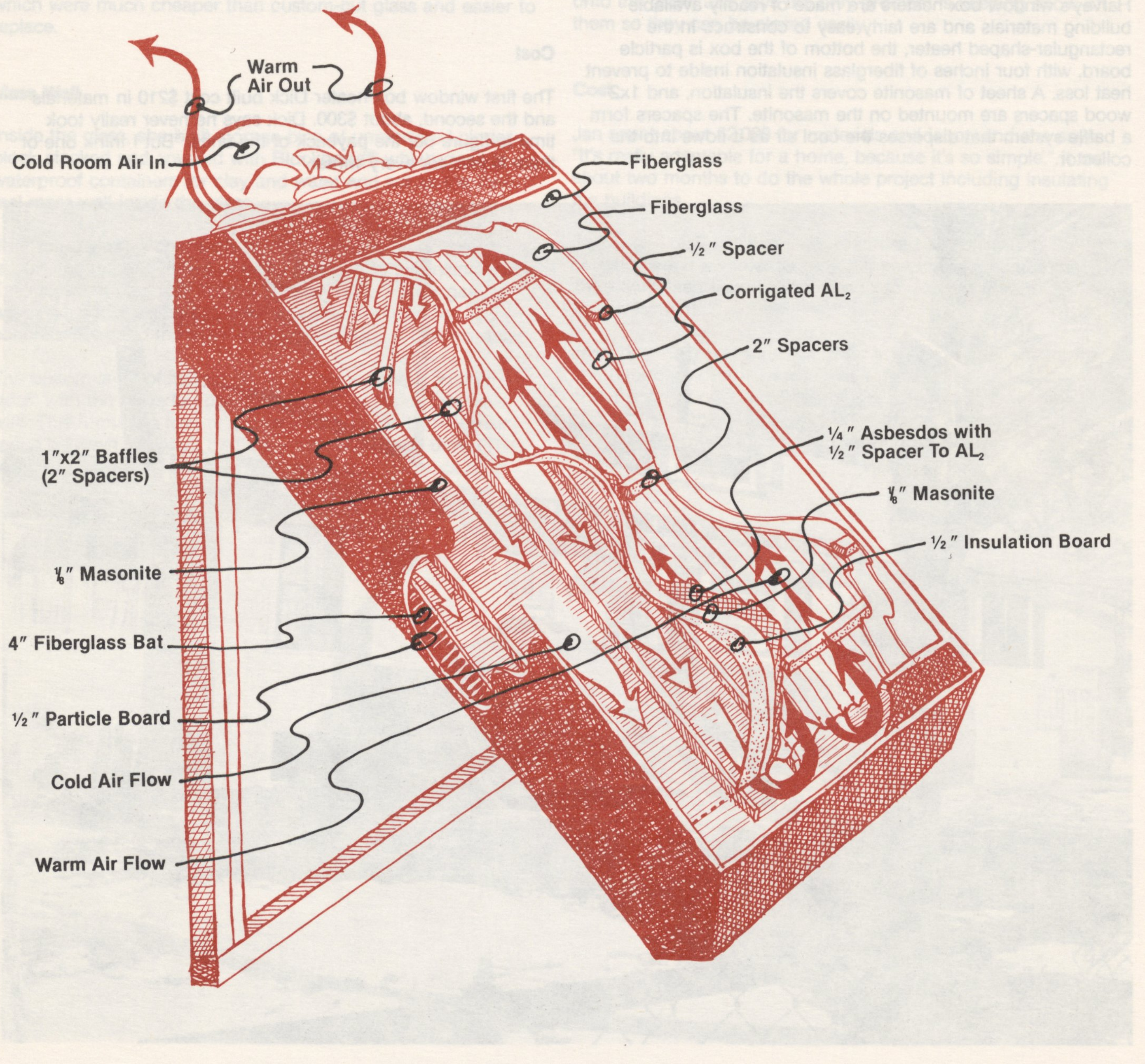
The first window box heater Dick built cost $210 in materials and the second, about $300. Dick says he never really took time to figure out the payback of the units, "But I think one of them is paid for every winter."

For Dick Harvey, solar energy started out as a hobby and got out of hand. Since building these two window box heaters, he and his family have gone on to build everything from a solar-heated dog house to a simple wind generator.

Summer Cooling

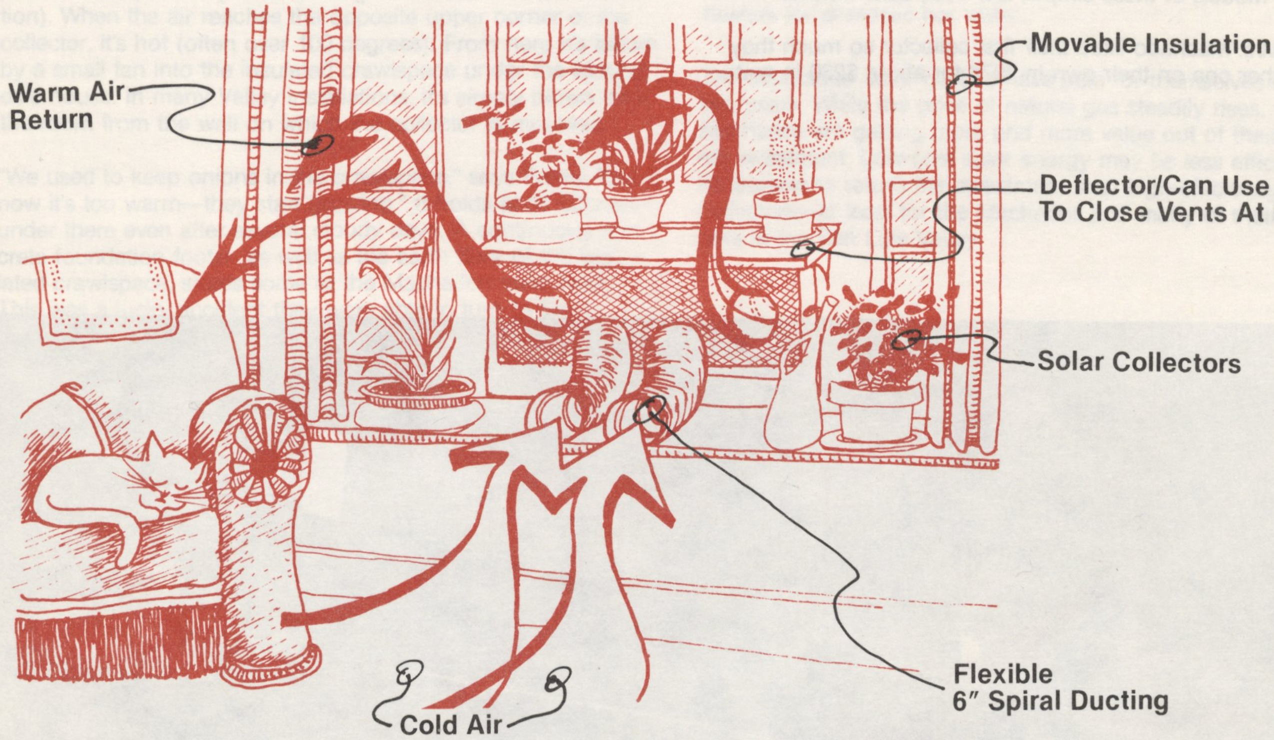
The Harveys have also found their heaters can become "coolers" in the summer. When dampers on the hot air inlet vents are closed and a vent at the top of the collector box outside is opened, "the cold air ducts become the equivalent of an exhaust fan." The hotter the absorber plate gets, the more air it pulls from the house, which is released to the atmosphere through the top ports on the collector. With all that air being sucked from the house, Dick says, "You can open a north window and you've got it made on a hot day."

Dick Harvey sells plans for his window box heaters and other do-it-yourself solar projects in a booklet called *Backyard Solar Energy*.



Heating Mode
Dick Harvey's Window Box Heater

Dick Harvey and his family hope some day "to build a house with no gas or electric hookups, and just depend on solar, wind and wood." They've found solar energy to be fun, something in which the whole family can become involved, and "a lot more healthy because of the humidity."



Heating Mode

Add Air Collectors For Daytime Heating, Active Retrofit Option: Machado Residence

Frank Machado's collector is one of the San Luis Valley's first solar space heaters.

The Machados' first solar heater was contractor Bill North's sixth solar installation. Today there are over 250 similar installations in the San Luis Valley. They are known as "North collectors" in honor of Bill North, who built and demonstrated the first local models of these simple, low-cost, solar heaters.

Mr. and Mrs. Machado liked their first collector so much they built another one on their own in 1976 for about $230 in materials. Now they have 180 square feet of air collectors that use two small fans to supply almost all of their daytime heat. At night, their 900-square-foot house is kept at about 60 degrees by a natural gas space heater in the living room.

"The vertically mounted collectors work best in December and January, and that's when we need daytime heat the most," says Frank. Also, reflection from snow during the winter months "kicks on the collectors a lot earlier," he says. "They go on about 8 a.m. and off about a half hour before sundown. The fans are thermostatically controlled according to the temperatures on the collector wall.

Mr. and Mrs. Frank Machado were so pleased with the performance of a low-cost hot air collector they added to the south wall of their home in Center in 1974, they added another one in 1976. Air is blown by a small fan into the insulated crawlspace under the house where it rises through registers in the floors.

"North" Collectors

The collectors are insulated, 2x4 wood-framed boxes with black sheet metal absorbed plates and fiberglass glazing. The back of the collector box is reflective insulating material, which might be anything from tin foil on celotex to commercial, reflective duct board. Two holes in the back, usually at opposite corners, provide the inlet for return air from the house and the outlet for solar-heated air into the house.

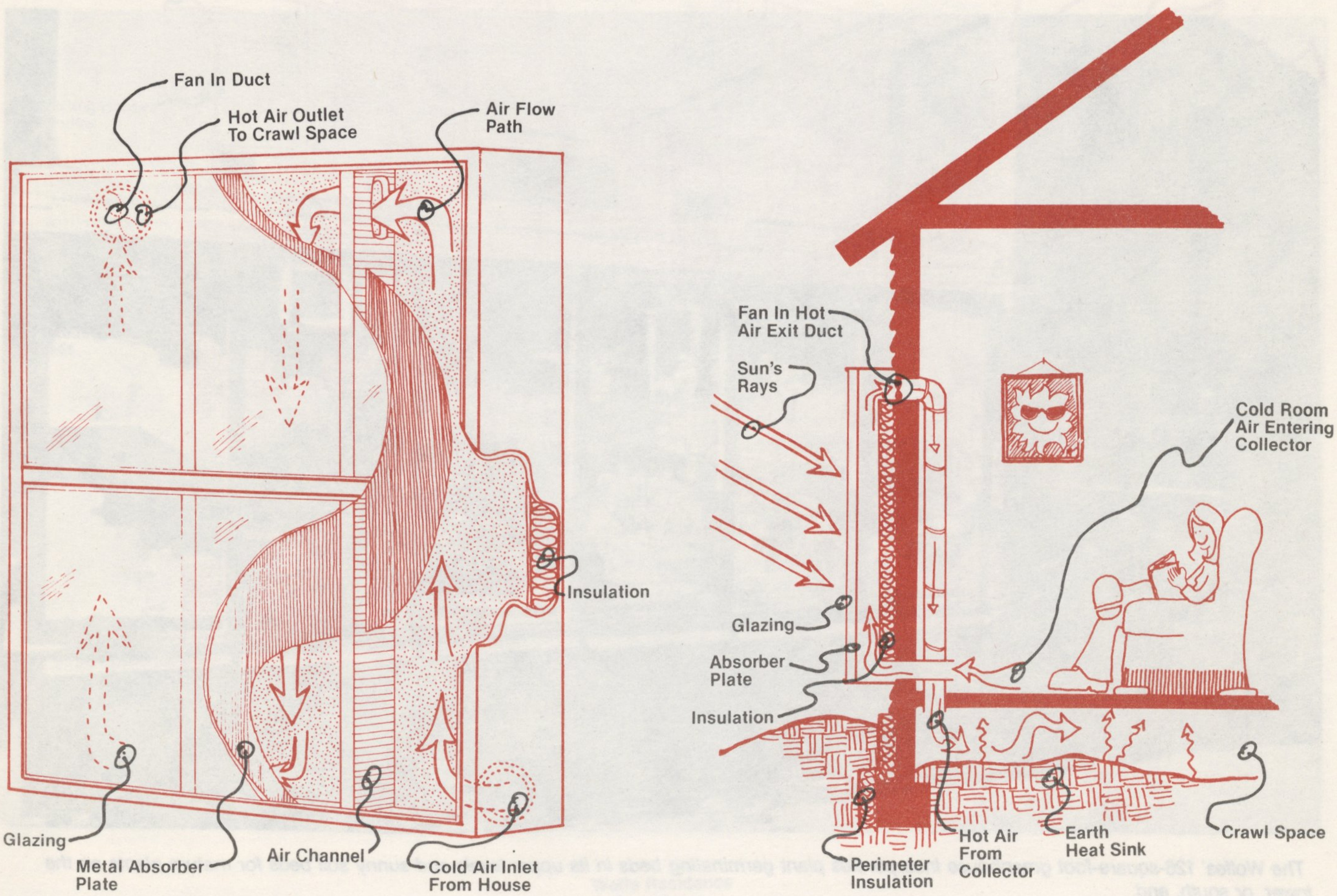
Air from inside the house is sucked into the bottom of the collector, where it picks up heat by flowing behind the absorber plate in a serpentine pattern through notched 2x4s (see illustration). When the air reaches the opposite upper corner of the collecter, it's hot (often over 100 degrees). From here it's blown by a small fan into the insulated crawlspace under the Machado's house. In many Valley installations, it's simply blown into the room from the wall on which the collector is mounted.

"We used to keep onions in the crawlspace," says Frank, "but now it's too warm—they start growing." It holds at 55 degrees under there even after several cloudy days. A continuous concrete foundation footer, as well as the earth floor of the insulated crawlspace, stores some of the Machados' solar heat. This was a lucky accident they were able to turn to their advantage by insulating the perimeter of the crawlspace.

"It pays to insulate; that's the first thing," Frank says. They've added insulation to the ceiling (10 inches of fiberglass) and to the walls (blown-in cellulose). They also put covers on the cold air returns at night to prevent infiltration and back flow through the collectors. In addition, they get "lots of passive solar gain through the south windows." During the winter, they stuff fiberglass between their storm and north windows, with the reflective side facing in. They take these down in the summer when they open north windows for ventilation.

"Heck yeah, I'd recommend solar, it beats paying for natural gas," Frank says. He's considering adding a slanted solar water collector along the skirt of the house under the vertical air heaters for domestic hot water.

The Machados' solar heaters have paid for themselves in about two years. While the price of natural gas steadily rises, the Machados are getting more and more value out of their modest investment. Low-cost solar energy may be less efficient, but it's quicker to return the investment than high-efficiency collectors—at least for the Machados and many of their neighbors in the San Luis Valley.



Add Trombe Wall and Greenhouse Passive Retrofit Option: Wolfe Residence

"We find that passive solar energy is very active for people," says Janet Wolfe with a smile. Every morning and evening the Wolfes open and close their insulating, reflective shutters to button up their Trombe wall and greenhouse.

The price of natural gas in Durango went from 6 cents per 100-cubic-feet in 1972 to 24 cents per 100-cubic-feet in 1977, and it's still going up. The Wolfes used 1,605 100-cubic-feet of natural gas in 1976. The following year, after adding their Trombe wall and greenhouse, they only used 1,321 100-cubic-feet. They saved natural gas, but their winter utility bill for the year was $75 higher because prices went up so much. Both gas and electric rates have continued to rise, so it is hard to tell exactly how many dollars the system has saved.

Trombe Wall

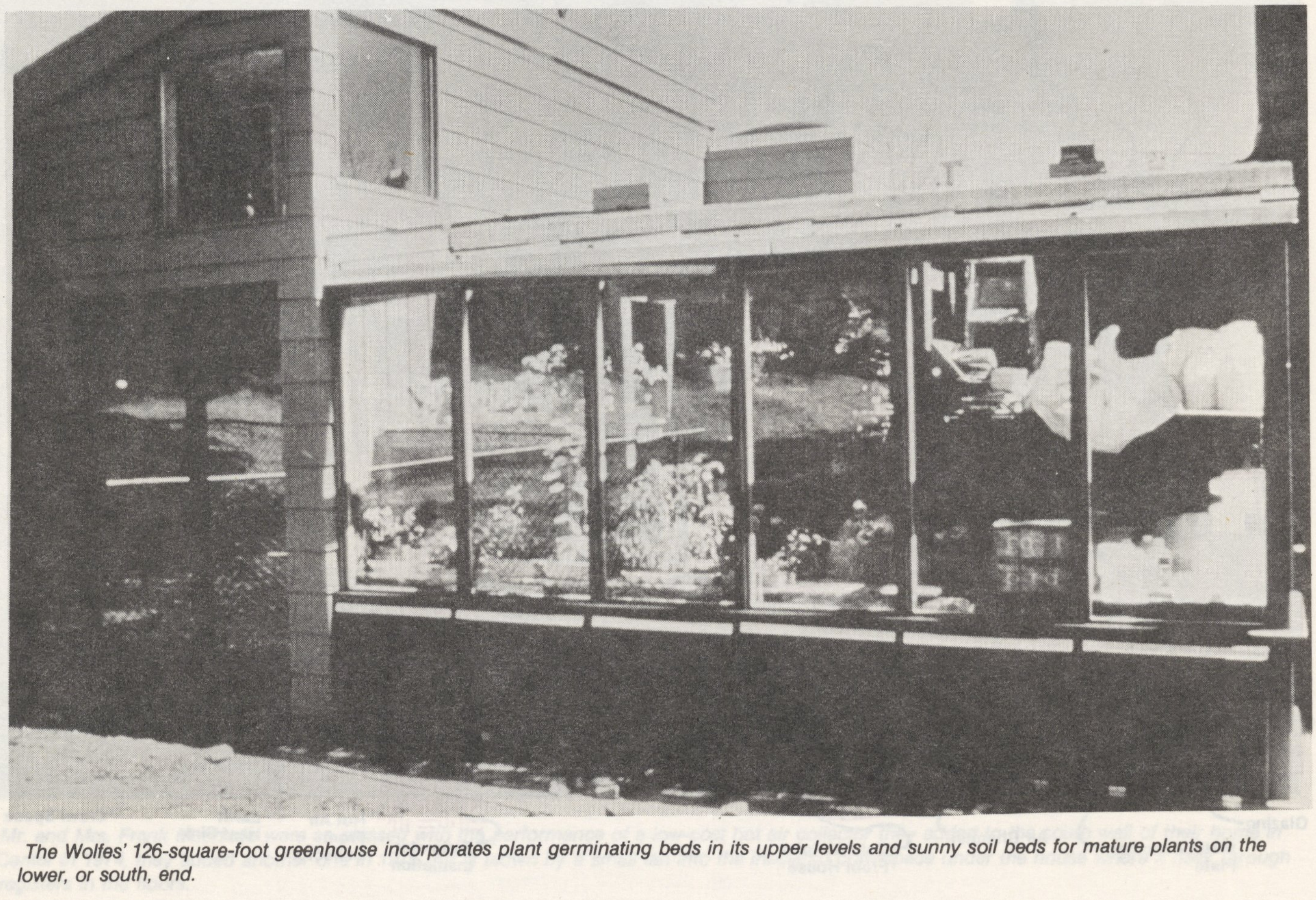
The Wolfes' 63-square-foot Trombe wall consists of two layers of blond brick mortared together in a continuous mass. Right beside it is a long vertical window that lets in light and heat directly. It makes a beautiful south interior wall, giving the effect of a fireplace. The outside layer of brick is painted black and covered with glass. Several bricks have been intentionally left out along the ceiling and floor forming openings that serve as the Trombe wall inlets and outlets. (See discussion of Trombe walls, p.9).

The top openings must be closed off at night to prevent "reverse thermosiphoning" of warm air from the ceiling into the cool glass-covered area. Although this reversal of the normal daytime flow of air is less likely with insulating shutters like the Wolfes', it's a potential heat-robber.

Greenhouse

The Wolfes' greenhouse has 126 square feet of floor space, much of which is occupied by thermal storage barrels, soil planting beds, and dozens of plants. Six 50-gallon black barrels of water lie on their sides along the south glass wall and four stand on end along the back wall. The lower barrels on the south make a base for sunny soil beds for mature plants, while the upper levels on top of the back barrels are ideal for germination beds. Reflecting and insulating panels protect the "front line" of storage from night heat loss.

In the right-hand corner of the photograph you can see the beginnings of a water wall the Wolfes are gradually adding to their greenhouse. Dr. Wolfe brings home discarded plastic surgical bottles from the hospital. These are filled with water, and are easily stacked because of their square shape. Discarded plastic milk cartons can be used in the same way to form a somewhat translucent mass storage wall that also lets in diffuse light for the plants.



The Wolfes' 126-square-foot greenhouse incorporates plant germinating beds in its upper levels and sunny soil beds for mature plants on the lower, or south, end.

Diffuse light is the favorite of plants. One problem with greenhouses is phototropism, or the tendency of plants to lean toward the sun. A water wall, which diffuses the incoming sunlight, is a good solution to this problem. Another way to avoid phototropism is to provide light from all directions by putting reflective surfaces on the north, east and west interior walls of the greenhouse.

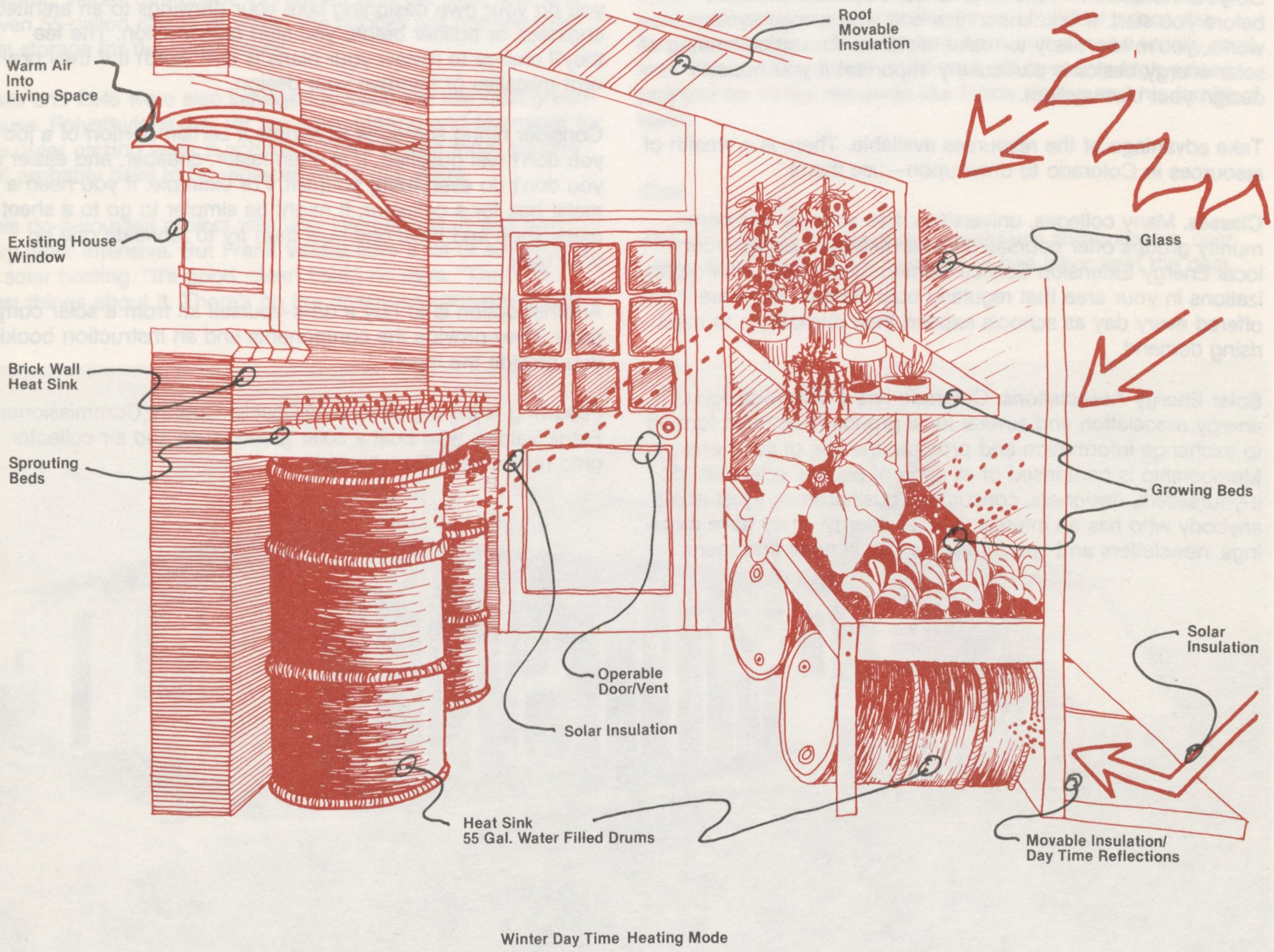
Another common greenhouse problem the Wolfes have avoided is overheating. "We've had no overheating problem in the summer in the greenhouse, because there are doors on each end," says Janet Wolfe. The Wolfes' greenhouse addition also incorporates an airlock entry to the house. All the daytime traffic in and out of the house goes through the greenhouse, which saves a lot of heat in the winter. However, Janet says air lock entryways are not a good idea in normal patterns of traffic flow.

During the summer, if the greenhouse gets too hot, the Wolfes open doors and use a shuttered ceiling for shading. When they open the east-facing greenhouse door, and the door into the house and windows on the west side of the dining room addition, a continuous draft is created ventilating the greenhouse. The west side of the addition and the Trombe wall area are conveniently shaded by a large deciduous tree in the summer months. The tree sheds its leaves in the fall so sunlight is free to strike the Trombe wall and vertical window in the winter.

Cost

The cost of the Wolfe's solar system is hard to determine, since they also got a dining room/living room extension to their kitchen and a solar greenhouse entryway. Many people would pay the total cost just for a lovely addition providing an extra 250 square feet of living space.

The total cost of the addition, built by a local contractor, was $17,000. The job was originally quoted at $13,000, but unanticipated costs were encountered during construction. This cost included architectural fees and handsome finish details in both the greenhouse and dining room.



Winter Day Time Heating Mode

Wolfe Residence
Greenhouse

Doing-It-Yourself

Building a solar system on your own can save you money. But if you are careless, and neglect a few details, you can get into trouble. If you're considering the do-it-yourself approach, here are some tips.

Evaluate your abilities honestly. Do you have the basic skills needed? Experience in carpentry, plumbing, and a familiarity with home construction are required for most solar projects. If you have never done this type of work, make sure you get instruction and help from someone who has. Start out with simple, inexpensive projects.

Find out exactly what is required to build a particular project. There are a wide range of do-it-yourself options. Some projects, like building a window box heater, can be relatively simple. Others, like retrofitting a home with an active space heating system, may require sophisticated design, management, construction and installation skills. Do some research before you select a project. What tools and materials do you need? What skills? How much will it cost? How much time will it take? How much heat will the final product be able to deliver?

Do your homework. Take time to learn the fundamentals before you start. If you know how and why a solar system works, you're less likely to make mistakes. An understanding of solar energy basics is particularly important if you hope to design your own system.

Take advantage of the resources available. There is a wealth of resources in Colorado to draw upon—use them!

Classes. Many colleges, universities, free schools and community groups offer courses on solar energy. Contact your local Energy Extension Service Center. Also, check with organizations in your area that regularly hold classes. More are offered every day as schools expand their curriculum to meet rising demand.

Solar Energy Associations. Colorado has a statewide solar energy association and several local groups have been formed to exchange information and promote the use of solar energy. Membership is comprised of all sorts of people: scientists, do-it-yourselfers, designers, consumers, businessmen—just about anybody who has an interest in solar energy. They have meetings, newsletters and special events like lectures and tours. You'll be able to meet people with experience they're willing to share, and you can keep up with recent developments.

Workshops. One- or two-day "hands-on" workshops are held periodically around the state by solar energy associations or other energy-related public interest groups. Even if you chose not to build the particular system constructed in the sessions, you'll get a good idea of the process you must go through to put a solar system together. Also, if you end up buying a system rather than building one, you'll have a better idea of what to look for in materials and workmanship.

Books. Much of the information on solar energy you'll need is available in books. In most cases, they're readily available from libraries or bookstores.

Plans and Blueprints. As solar energy use becomes popular, more individuals and groups are offering plans and blueprints for the do-it-yourselfer. Most are fairly complete and accurate and, if you have done the prerequisite research, can be valuable guides. They can save you time, and, if you look at several, give ideas on the system best suited to your circumstances.

Professionals. Colorado has some of the best solar energy specialists in the country. Take advantage of their expertise. If you do your own designing take your drawings to an architect, engineer, or builder before you start construction. The fee they'll charge to review your plans is well worth it if they prevent mistakes or improve your design.

Consider hiring someone to handle a certain portion of a job if you don't feel qualified. It is often faster, cheaper, and easier if you don't do **everything** yourself. For example, if you need a metal box for a collector, it might be simpler to go to a sheet metal shop and have one built than try to fabricate one on your own.

Another option is to buy a do-it-yourself kit from a solar company. They provide the components and an instruction booklet; you provide the labor.

Following is the experience of Costilla County Commissioner Frank Valdez, who built a solar greenhouse and air collector onto his home in San Acacio.

Do-It-Yourself Greenhouse and Air Collector
Frank Valdez, San Acacio

Frank Valdez, a Costilla County Commissioner, got some help from his cousin Arnie and built a solar greenhouse and air collector himself. He used recycled materials and built both for a total of about $300.

"I even used recycled nails," says Frank Valdez, pointing to the 100-year-old square nails he used to frame the ceiling of his adobe greenhouse. "If I can build this [greenhouse and air collector], anyone can." Frank hadn't had too much building experience before he took on this project, and he says, "the first one is pretty rough to build—you have to study as you go."

As a county commissioner, Frank "thought it was right that I should try it first. I figured I could do it, then I could push for it as a commissioner."

Greenhouse

The greenhouse, a 12-foot by 16-foot addition to the south wall of the Valdez home, is made mostly of adobe. The two side walls and the back wall are recycled adobes salvaged from a building Valdez tore down. Combined with the rock floor and seven 55-gallon drums of water, the adobes will provide thermal storage for the greenhouse.

Nails and 2x4s were also salvaged to build the low-cost greenhouse. Polyethylene film for the inner glazing and fiberglass for the outer glazing were purchased. The thin film inner glazing will probably have to be replaced every few years.

This do-it-yourself project was very inexpensive. It was also very labor intensive. But Frank Valdez sees a lot of advantages to solar heating. "It's good, clean heat," he says. "That's the best things about it. There's no fire or smoke connected with it."

"The greenhouse would be ideal for a retired couple," believes Frank. "They could grow food, **and** they could save on their heating bill. I don't have much time to fool around with plants, but for people with time it would be great." In spite of his busy schedule, Frank found time after he finished the greenhouse to build a solar air collector onto the remaining south wall.

Collector

"I used the 'North' collector plans from the San Luis Valley Solar Energy Association," says Frank. Vertical 2x4s form the baffling for the collectors. An attic fan with a thermostat and blower is used to turn on automatically whenever the collectors are hotter than 90 degrees.

Hot air is blown directly into the room on the inside of the south-facing wall. The Valdezes have no storage for their collector, but their massive old home stores heat well in the mass of its structure.

The collector Frank Valdez built is one of over 200 similar collectors throughout the San Luis Valley. Even if they wear out in five to 10 years, these collectors will have paid themselves off at least once, and proved to local residents that solar energy is a good investment. A local architect believes many of these systems will be replaced by more efficient and longer lasting commercial collectors in the long run. Until fuel prices rise enough to make such collectors economically and locally available, these do-it-yourself collectors will conserve high-priced propane for Valley residents like Frank Valdez and his family of seven.

Cost

The whole project, including greenhouse and collector, cost under $400. Recycled materials and free labor kept the cost down.

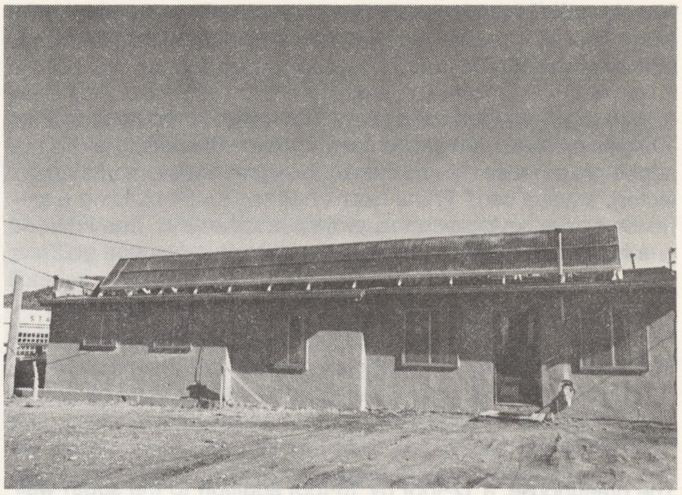
Frank Valdez's greenhouse is made mostly of recycled materials from the adobes down to the 100-year-old nails. It's a do-it-yourself, labor-intensive and inexpensive project.

San Luis Valley Low-Cost Solar Projects

San Luis Mortuary

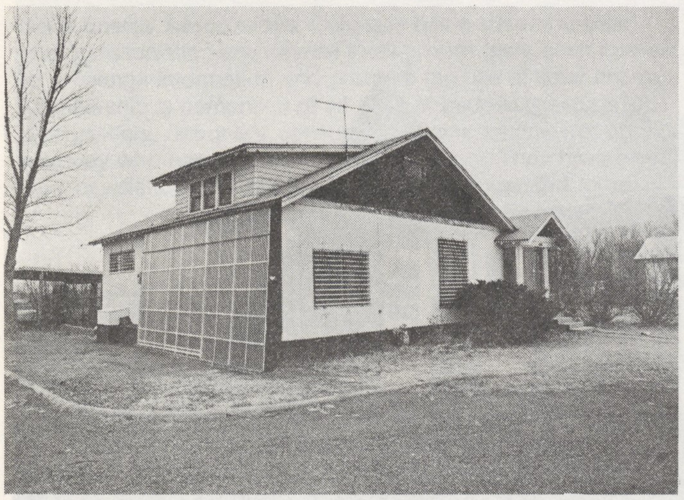
This house in San Luis, "the oldest town in Colorado," has been converted to the town mortuary. Using this "North" air collector, the building is virtually 100 percent solar-heated, since it is only occupied several days a month. The thermostatically controlled solar air heater provides enough heat to keep the building well above freezing when not in use.

San Luis Community Action Program (CAP) Office



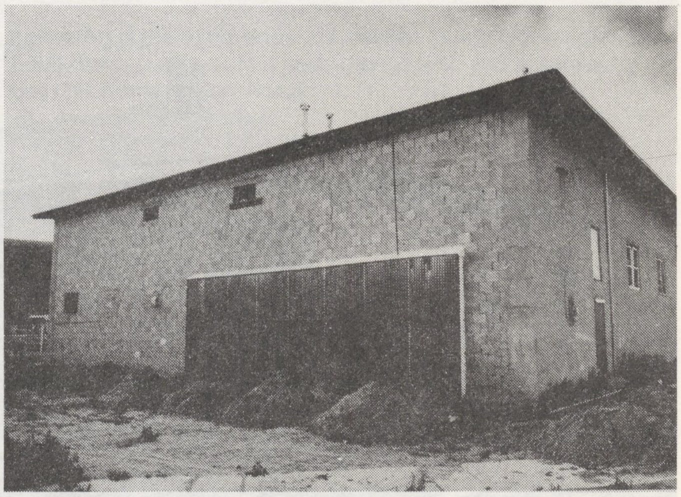
The San Luis CAP Office, which supplies insulation and winterization services to needy families, uses this building. Arnie and Maria Valdez organized the construction of this 400-square-foot air collector with volunteer labor. Since the office is only occupied in the daytime, the $2,000 system will probably supply about 50 percent of heat needs.

Norman and Lois White Residence



This retired couple in Alamosa, Colorado, uses their solar air heater to help keep their house above 55 degrees while they're gone in the winter. Norman built the collector in the summer of 1977 salvaging old motors to make a thermostatically controlled blower system. The $4 bill for February 1978 attests to the system's performance.

San Luis High School Gym



This air collector was built on to the south wall of the San Luis High School gymnasium. The collector was built from scratch by students of the school. Before installing the collector, the students didn't use the gym in winter months because it was so cold. Now the floor is warm after a sunny winter day.

Appendix -- Solar Energy Basics

A solar energy system is like many tools in our lives. We don't have to understand how it works in order to use it. There are a large number of solar designers and technicians who can take care of these things for us. Yet, unlike many other complex systems we rely on, solar energy is easily understood, especially when it comes to systems used for home heating or domestic hot water.

Solar systems take advantage of natural phenomena that we've all experienced. A few basic facts about solar energy are described in the following section. This section is optional reading, but it will help you understand basic concepts and terminology.

Energy and Heat

Energy, usually defined as the ability to do work, has many different forms. One of the most familiar forms is heat, which is simply the excited vibrations of the molecules that make up a substance. Other forms of energy are electricity, the chemical energy in natural gas, the kinetic energy of the wind and the radiant energy of the sun.

Energy is converted from one form to another by natural processes or manmade devices. For example, the energy in solar radiation striking a rock is converted into heat and the rock warms up. The chemical energy of natural gas is converted to heat when it's burned.

How Energy Gets from One Place to Another. Once energy is converted to heat, it naturally travels from a hot to a cool region. This happens in three ways: conduction, radiation and convection. The three ways heat travels all play important roles in the functioning of solar energy systems.

Conduction. Conduction is heat transfer by direct contact. Heat flows through a material by the motion of adjacent atoms and molecules. Remember when you had to walk barefoot across a section of hot pavement? You danced. That's an example of heat transfer by conduction. The sole of your foot came into direct contact with the pavement that had been baking in the sun. Your foot was heated as the vibrating molecules of the pavement bang and clash into their neighbors—the molecules of your skin. There is direct contact. And you get a hot foot.

Convection. Heat transfer by convection occurs through the motion of fluids (liquids and gases). For example, air (which is a gaseous fluid) circulating over a fire will pick up heat from the flame and carry it upward. This is **free** convection, often referred to as **thermosiphoning.** If you have ever lived in a two-story house you've probably noticed the upstairs is warmer than the first floor. This is due to free convection—hot air rises and cool air sinks.

When the motion of fluid is aided by a fan or a pump, it is called **forced** convection. A forced-air furnace uses forced convection to keep a house warm.

Radiation. Radiation is heat transfer by electromagnetic waves. Solar energy is one type of radiation. Energy from the sun travels to earth through the vacuum of space in the form of waves. No direct contact with air or liquid is required. Heat from a hot woodstove is another example of radiation.

Measuring Heat. Since all forms of energy can be converted to heat, it's possible to measure the heating potential of natural gas, electricity, solar radiation or any other fuel. Temperature and heat are not the same. Temperature measures intensity of heat, which is determined by the amount of molecular motion in a material. The greater the motion, the higher the temperature. The measure of heat, on the other hand, depends both on its temperature and how much of the material there is. For instance, it takes a lot more energy to heat a swimming pool to 80 degrees than it does to heat a gallon of water to the boiling point (212 degrees). You can't evaluate the performance of a solar system solely by the temperature to which it heats water or air. You also have to know how much fluid is being heated.

Heat energy is often measured in British thermal units, or BTUs. A BTU is defined as the amount of energy required to raise one pound of water (about a pint) one degree Fahrenheit. The heat given off by burning a kitchen match is about equal to one BTU. BTUs are used throughout this book to quantify the amount of energy in solar radiation and in other fuels so they can be compared.

The average Colorado gas-using household uses about 107 million BTUs per year for space heating and 35 million BTUs per year for water heating (a total of 142 million BTUs per year). Since gas is burned in household furnaces, these numbers reflect **the actual number of BTUs consumed**. All-electric homes, which are usually better insulated, use 68 million BTUs per year for space heating, and 17 million BTUs per year for water heating (or 85 million total). Remember that fuel is burned at the generating plant at only 30 percent efficiency and then electricity is transmitted to the home, so these numbers reflect only **the BTUs delivered** to the home and not the total BTUs consumed.

Electricity use is measured in kilowatt-hours (kWH), which is equal to using 1,000 watts over a period of one hour. If you burn ten 100-watt light bulbs for one hour, you will have used one KWH. Your electric meter counts the KWHs used in your house. One KWH is equal to 3,413 delivered BTUs.

Compare these numbers to the amount of energy we get from the sun. In round numbers, each square foot of ground (horizontal surface) in Colorado exposed to the sun receives a yearly average of 1773 BTUs per day, depending upon your location.

An average Colorado household on natural gas uses 142 million BTUs per year for space and water heating. Solar energy falling on an average house amounts to about 485 million BTUs per year. Available solar energy can easily satisfy your needs, if you can store it so it's available **when you need it**.

Of course, the sun does not shine every day, and we can't convert all the energy in solar radiation into **usable** heat. No collection system is 100 percent efficient. Some sites are shaded by buildings, mountains, or trees. Also, some buildings don't have roof or wall surfaces that are exposed conveniently to the sun, and may not be suitable for solar energy.

Solar Radiation

Only a tiny fraction of the radiation emitted by the sun is intercepted by the earth, and a large portion of that is screened by the atmosphere. Many wavelengths don't get through to the earth's surface. Those that do range from short ultraviolet rays to long infrared rays. What is seen as visible light falls between these two extremes.

The term "insolation" refers to the amount of solar radiation striking a surface on earth. The total amount of insolation is the combination of direct, diffuse and reflected solar radiation. **Direct** radiation, the most easily converted to heat, consists of the **straight and parallel rays** that cast shadows when blocked. **Diffuse** radiation is light **scattered** by dust, clouds, smog, molecules and other particles that make up the atmosphere. **Reflected** radiation consists of rays **bounced off** one surface onto another.

Solar energy systems take advantage of all three types of radiation. Although most of the heat will come from direct radiation, diffuse radiation (like on cloudy days) will provide a significant amount of energy. Systems can be designed to include secondary surfaces to reflect solar radiation onto the main collector.

How Much Solar Energy Is Available? Daytime radiation striking the earth's outer atmosphere each hour is 429 BTUs per square foot. This is called the **solar constant**. The atmosphere screens out much solar radiation, so the amount that reaches the earth is always less than the solar constant.

At Colorado's latitude on a clear, sunny day, radiation striking a surface facing directly into the sun rarely exceeds 350 BTUs per square foot per hour, and is usually closer to 275. Since solar systems are rarely much more than 50 percent efficient, it's unlikely that you'll get more than 150 BTUs per square foot of collector delivered each hour to your home, unless you're using a concentrating collector.

More accurate figures are needed for actual system designs because clouds and climatic conditions vary. The federal government has published insolation data in the **Climatic Atlas of the United States**, including data collected in Colorado at Grand Junction and Boulder. Weather stations located in your area can be located by the State Climatologist at Colorado State University in Fort Collins.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has published a series of tables called "Clear Day Insolation." The tables are for "average" clear days, and should be used in conjunction with data on the percentage of possible sunshine available at a particular location (from the **Climatic Atlas** or your local weather station).

Figures from various sources may include direct, diffuse, and reflected radiation values. Flat-plate collectors and passive solar systems can utilize all three types of radiation, while concentrators are designed for direct and reflected radiation.

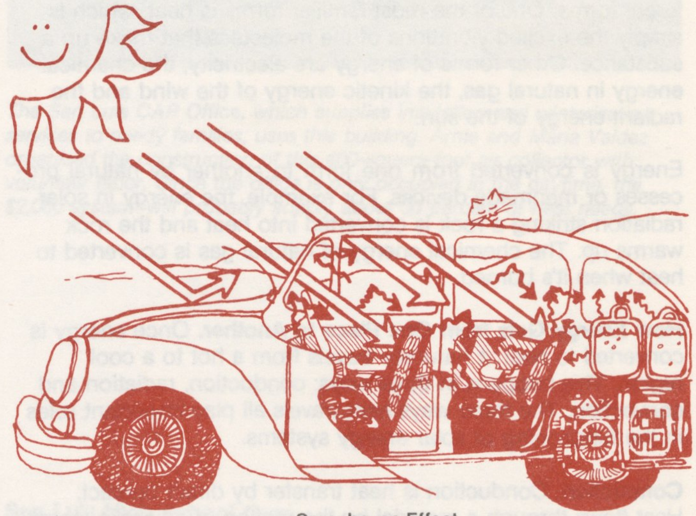
Available insolation figures are not exact. However, highly accurate numbers aren't needed for low-temperature applications like space and water heating, so the available information is generally sufficient for these design purposes.

Converting Solar Radiation to Heat. Several things occur when the sun's rays strike an object. Part of the solar energy is absorbed (the measure of which is called absorbtance), part is reflected (reflectance), and if the material is transparent or translucent, part is transmitted (transmittance). Also, materials re-radiate or emit energy they've absorbed (emittance).

A solar system converts radiation to heat depending on the absorbtance, reflectance, and transmittance of the materials in the collection system. The primary objective is to combine materials with properties that maximize the "greenhouse effect."

The greenhouse effect occurs when you leave your car in the hot sun with the windows rolled up. Short waves of sunlight pass easily through the glass, and when they strike interior surfaces in the car, they're converted to longer wavelengths. The long waves of heat won't pass through glass, so heat is trapped.

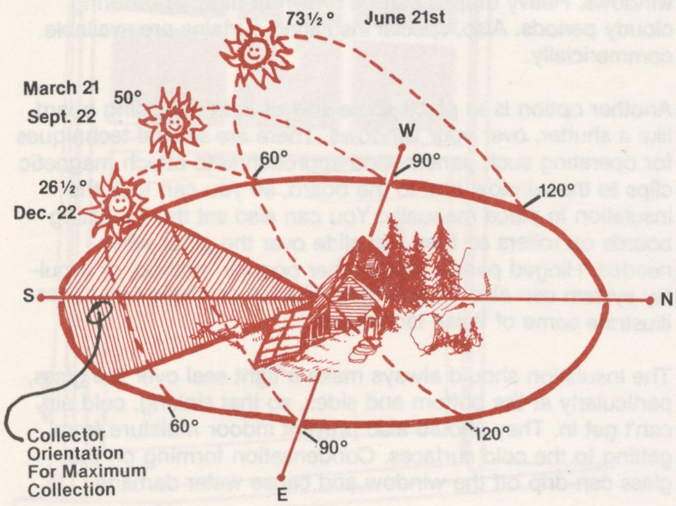
The greenhouse effect is the cornerstone of any solar system. The objective is to allow sunshine to enter a building or collector, then capture the heat with an absorbed material. Rock boxes and other thermal storage devices are designed to store the heat until it's needed.


Greenhouse Effect

Solar Position and Movement. At Colorado's latitude (about 40 degrees north of the equator), the sun doesn't pass directly overhead. At various times of the year, the sun reaches different heights in the sky. The highest point—73.5 degrees above the horizon—occurs at noon on June 21, or the **summer solstice.** The lowest point occurs on December 22, the **winter solstice**, when the sun is only 26.5 degrees above the horizon at noon. On March 21 and September 22, the sun is about 50 degrees above the horizon at noon. These days are called the spring and fall equinoxes, because the daytime and nighttime are equal (12 hours of daylight and 12 hours of darkness). Figure 25 shows the different angles of the sun through the year.

Solar collectors are generally oriented and tilted to maximize the amount of sunlight falling on them when energy is most needed. In Colorado this is usually during December, January and February.

Pointing a collecting surface due south is recommended, although deviations up to 20 degrees east or west of south still permit good performance. In certain cases, it may be desirable to orient the surface slightly in one direction or another. For instance, a person who wants peak collecting time earlier in the day will face the collector east of south toward the rising sun. Someone else may prefer to take advantage of the hot afternoon sun by facing the collector somewhat west. If a mountain blocks some afternoon sun, an east of south direction would give better performance. It's desirable to have exposure to the sun from at least 9:00 a.m. to 3:00 p.m., so watch out for buildings or trees that might shade your collecting surface.



Solar Position & Movement Orientation

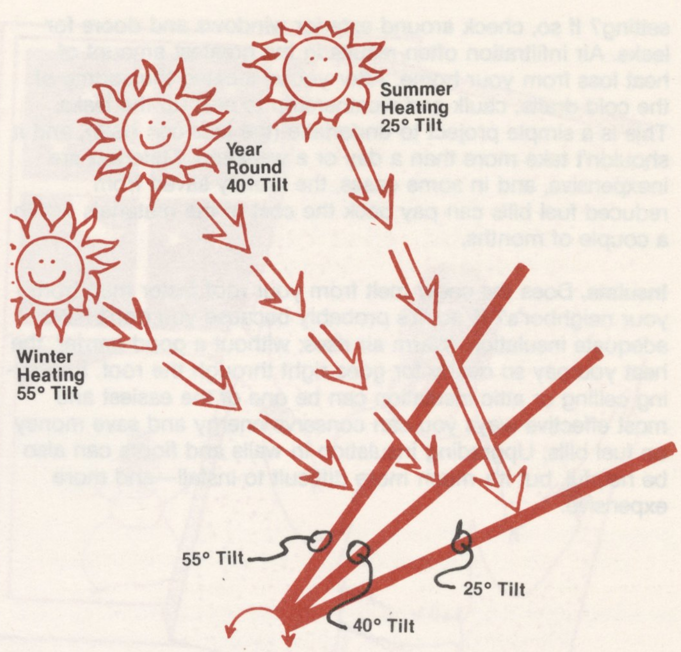
Tilt

Collection surfaces are generally tilted to make them perpendicular to the sun's rays. Since the sun's angle changes during the year, the optimal tilt depends on which season(s) of the year the collector is being used. The latitude of the site, and the amount of reflection from nearby surfaces are also factors in determining tilt.

A rule of thumb can be used to determine the best tilt angle. If the collector is used for wintertime heating, it will work best at an angle equal to the latitude in Colorado—40 degrees—plus 15 degrees. For most of Colorado, a 55-degree tilt is optimum **for winter heating** purposes. (A 10 percent deviation won't alter the performance much over the whole year.)

Collectors being used only in the summer, on the other hand, say for heating swimming pools, should be tilted less so they're perpendicular to the rays of the high summer sun. An angle of the latitude—in Colorado, 40 degrees—minus 15 degrees is better for a summertime collector. For most of Colorado a 25-degree tilt is optimum for **summer heating** (or solar-assisted cooling).

Collectors that are used year round, say for supplying hot water, are generally placed at an angle equal to the latitude.



Optimum Collector Tilt

How to Find South

There are several different methods you can use to find true south:

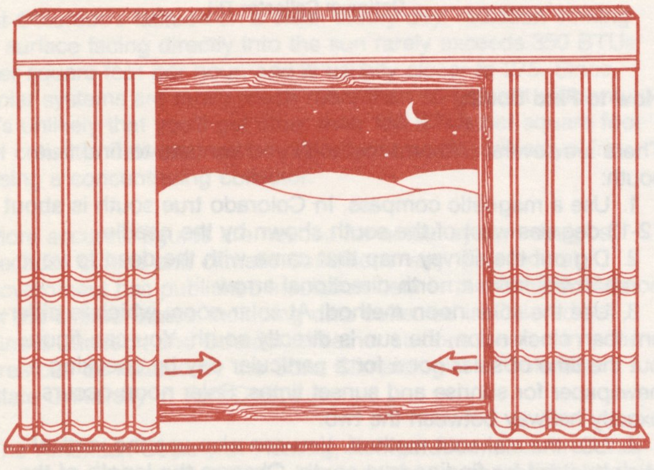
1. Use a magnetic compass. In Colorado true south is about 12-13 degrees west of the south shown by the needle.
2. Dig out the survey map that came with the deed to your home. It will have a north directional arrow.
3. Use the solar noon method. At solar noon, which is different than clock noon, the sun is directly south. You can figure out the time of solar noon for a particular day by checking a newspaper for sunrise and sunset times. Solar noon occurs exactly halfway between the two.
4. Use the stakeout method. You can also use the vertical stick by itself for finding true south. Observe the length of the shadow it cast throughout the day. When the sun is due south, the shadow will be shortest and will run directly north-south.

Before You Go Solar—Energy Conservation

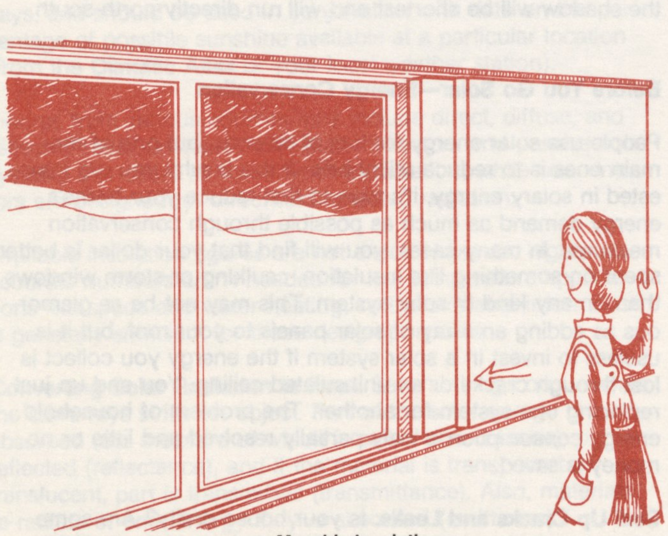
People use solar energy for lots of reasons, but one of the main ones is to reduce utility bills. If this is why you are interested in solary energy, it's wise to first reduce your home's energy demand as much as possible through conservation measures. In many cases, you will find that your dollar is better spent on something like insulation, caulking or storm windows than on any kind of solar system. This may not be as glamorous as adding an array of solar panels to your roof, but it is useless to invest in a solar system if the energy you collect is lost through cracks or an uninsulated ceiling. You end up just replacing one system for another. The problem of household energy consumption is only partially resolved and little or no money is saved.

Seal Up Cracks and Leaks. Is your house drafty? Are some rooms uncomfortable even when the thermostat is at a high setting? If so, check around exterior windows and doors for leaks. Air infiltration often results in the greatest amount of heat loss from your home. After you've located the source of the cold drafts, caulk and weatherstrip to seal up the leaks. This is a simple project to undertake (the kids can help), and it shouldn't take more than a day or a weekend. Materials are inexpensive, and in some cases, the money saved from reduced fuel bills can pay back the cost of the materials within a couple of months.

Insulate. Does the snow melt from your roof faster than from your neighbor's? If so, it's probably because you don't have adequate insulation. Warm air rises; without a good barrier, the heat you pay so dearly for goes right through the roof. Improving ceiling or attic insulation can be one of the easiest and most effective ways you can conserve energy and save money on fuel bills. Upgrading insulation in walls and floors can also be helpful, but it's much more difficult to install—and more expensive.



Movable Insulation
Heavy Drapes



Movable Insulation
Sliding Tracks

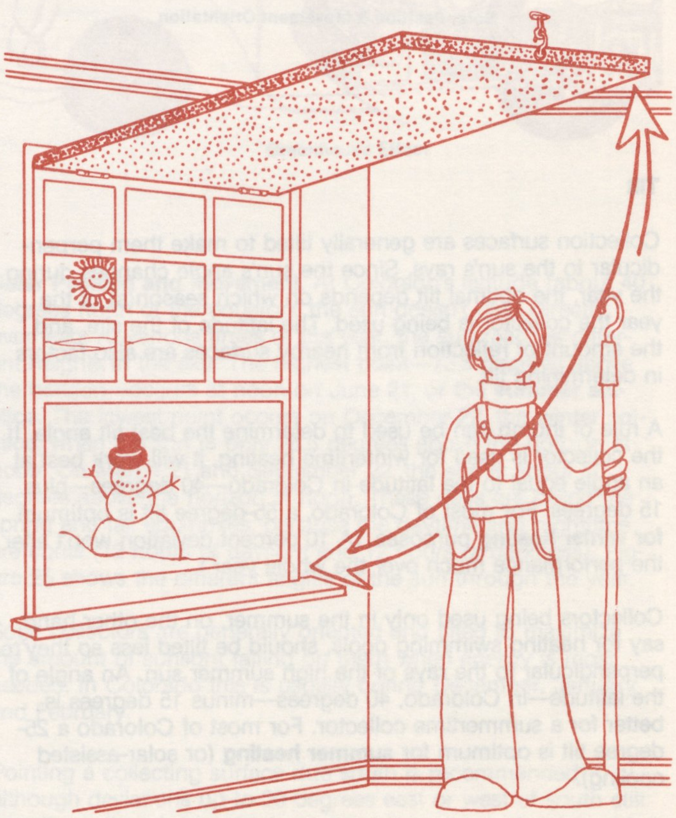
Protect Glass from Heat Loss. A double-pane window facing south can provide energy to a building because it traps solar heat during the day. However, glass is a notoriously bad insulator; windows are one of the biggest energy losers in a building. You are probably losing more heat through the glass in your home than through the entire wall area.

To reduce this loss, you can add storm windows or a sheet of plastic to create two layers that have an insulating dead air space between them. This is especially important on the north side of a building, which is exposed to prevailing winter winds.

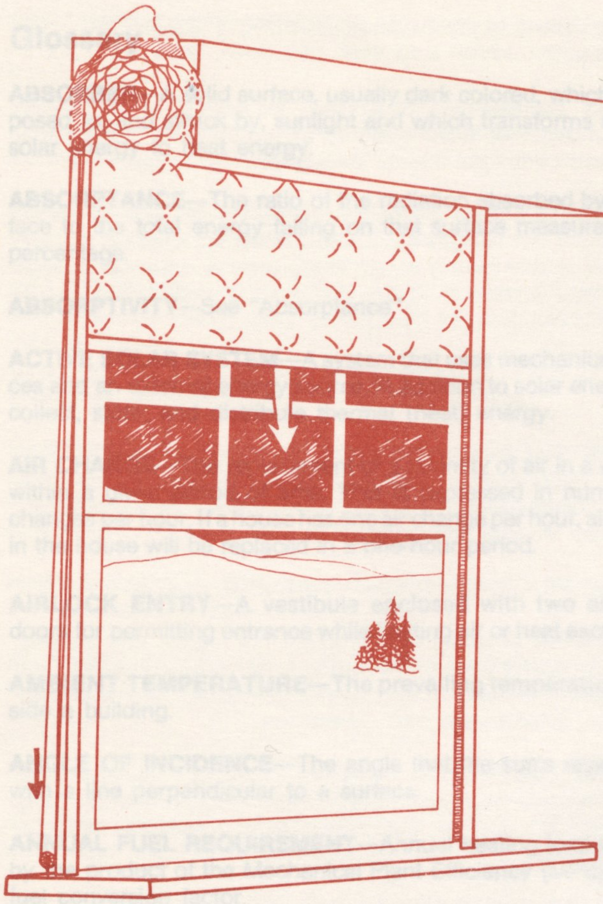
Movable insulation can also drastically reduce heat loss from windows. Heavy drapes can be drawn at night and during cloudy periods. Also, special insulating curtains are available commercially.

Another option is to place some sort of rigid insulating board, like a shutter, over your windows. There are several techniques for operating such panels. One approach is to attach magnetic clips to the window and to the board, so you can lock the insulation in place manually. You can also set the insulating boards on rollers so they can slide over the glass when needed. Hinged panels are another popular method, or a pulley system can also be arranged. Figures on these two pages illustrate some of these techniques.

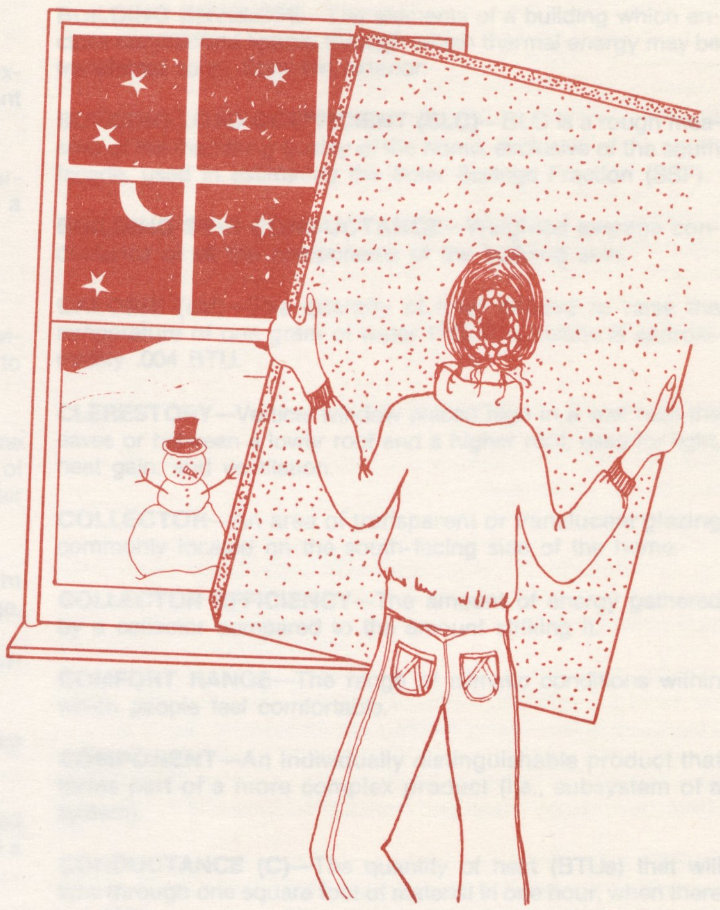
The insulation should always make a tight seal over the glass, particularly at the bottom and sides, so that sinking, cold air can't get in. They should also prevent indoor moisture from getting to the cold surfaces. Condensation forming on the glass can drip off the window and cause water damage.



Movable Insulation
Hinged Panel



Movable Insulation
Quilted On Tracks



Movable Insulation
Night Wall

Check Your Hot Water Tank. Most of the time your hot water just sits in a tank. If the tank isn't well-insulated, you could be losing a lot of energy. Fiberglass wrapped around your water heater can reduce this loss by 30 percent. You can either buy the fiberglass yourself and fasten it to the tank with tape, or buy one of the water tank insulation kits available at retail stores. Make sure you leave adequate openings for the top vent and the bottom air intake on gas-fired tanks. Also, try turning your water heater thermostat down to the low setting. Many people find they get satisfactory hot water and significant reduction in gas or electrical use by just turning down the thermostat.

You can also wrap insulation around any ducts or pipes carrying hot air or water through unheated basements or cold rooms. A lot of heat can be lost before it ever reaches its destination. Special duct and pipe insulation can be purchased for this, or you can use regular batt insulation, which is usually cheaper.

Check Your Fireplace. There's nothing like a fireplace to cozy up a room and delight the eye. However, even though it's warm when you're sitting right next to the fire, fireplaces generally suck more heat from a house than they add. Combustion air, already heated by your furnace, is drawn from the room right up the chimney. Keep the damper closed when not in use, and consider adding a glass door for reducing draft when the fire's burning.

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Glossary

ABSORBER—A solid surface, usually dark colored, which is exposed to, and struck by, sunlight and which transforms radiant solar energy to heat energy.

ABSORPTANCE—The ratio of the radiation absorbed by a surface to the total energy falling on that surface measured as a percentage.

ABSORPTIVITY—See "Absorptance."

ACTIVE SOLAR SYSTEM—A system that uses mechanical devices and an external energy source, in addition to solar energy, to collect, store, and distribute thermal (heat) energy.

AIR CHANGE—The replacement of a quantity of air in a volume within a given period of time. This is expressed in number of changes per hour. If a house has one air change per hour, all the air in the house will be replaced in a one-hour period.

AIRLOCK ENTRY—A vestibule enclosed with two air-tight doors for permitting entrance while limiting air or heat exchange.

AMBIENT TEMPERATURE—The prevailing temperature outside a building.

ANGLE OF INCIDENCE—The angle that the sun's rays make with a line perpendicular to a surface.

ANNUAL FUEL REQUIREMENT—Annual heating load divided by the product of the Mechanical Plant Efficiency (MPE) and a fuel conversion factor.

APERTURE—That part of the south-facing glazing that contributes to solar heating; literally, an opening.

ASHRAE—Abbreviation for the American Society of Heating, Air-Conditioning and Refrigerating Engineers.

AUXILIARY ENERGY SYSTEM—Equipment utilizing energy other than solar both to supplement the output provided by the solar energy system, as required by the design conditions, and to provide full energy backup requirements during periods when the solar heating or domestic hot water systems are inoperable.

AUXILIARY HEATING FRACTION (AHF)—That part of the total building heating requirements supplied by the auxiliary heating system.

AZIMUTH—The angular distance between true south and the point on the horizon directly below the sun.

BACK-UP SYSTEM—See "Auxiliary Energy System."

BERM—A man-made mound or small hill of earth.

BLACK BODY—A theoretically perfect absorber.

BTU (BRITISH THERMAL UNIT)—Basic heat measurement, equivalent to the amount of heat needed to raise 1 pound of water 1° Fahrenheit.

BTU/DD/FT² (HEATED AREA)—A unit commonly used to express the inherent ability of the building shell to resist heat loss.

BUILDING ENVELOPE—The elements of a building which enclose conditioned spaces through which thermal energy may be transferred to or from the exterior.

BUILDING LOAD COEFFICIENT (BLC)—BLC is a rough measure of the insulating quality of the home, exclusive of the south facade, used in estimating the Solar Savings Fraction (SSF).

BUILDING SKIN CONDUCTANCE—Weighted average conductance of all the components of the building skin.

CALORIE (cal)—The quantity of heat needed to raise the temperature of one gram of water 1°C. One calorie is approximately .004 BTU.

CLERESTORY—Vertical window placed high in a wall near the eaves or between a lower roof and a higher roof, used for light, heat gain, and ventilation.

COLLECTOR—An area of transparent or translucent glazing commonly located on the south-facing side of the home.

COLLECTOR EFFICIENCY—The amount of energy gathered by a collector compared to the amount striking it.

COMFORT RANGE—The range of climatic conditions within which people feel comfortable.

COMPONENT—An individually distinguishable product that forms part of a more complex product (i.e., subsystem of a system).

CONDUCTANCE (C)—The quantity of heat (BTUs) that will flow through one square foot of material in one hour, when there is a 1°F temperature difference between both surfaces. Conductance values are given for a specific thickness of materials, not per inch of thickness.

CONDUCTION—The transmission of heat through materials.

CONDUCTIVITY (k)—The quantity of heat (BTUs) that will flow through one square foot of a material, one inch thick, in one hour, when there is a temperature difference of 1°F between both surfaces.

CONTROL—A device or devices that regulate heat flow between the building and the exterior.

CONVECTION—The transfer of heat by movement of a fluid (liquid or gas).

CONVECTION, FORCED—Heat transfer through a medium such as air or water by currents caused by a device powered by an external energy source.

CONVECTION, NATURAL—Heat transfer of a fluid such as air or water that results from the natural rising of the lighter, warm fluid and the sinking of the heavier, cool fluid.

CONVECTIVE LOOP—The flow of air in a closed path induced by rising hot air and falling cold air.

"COOLTH"—A term used to describe the quality of a material at a lower than ambient temperature. "Coolth" is to cooling as warmth is to heating.

DECLINATION—The angular distance of the sun north or south of the celestial equator. The declination varies between +23½° (summer) to −23½° (winter).

DEGREE DAY (DD), COOLING—See degree day for heating, except that the base temperature is established at 65°F, and cooling degree days are measured above the base.

DEGREE DAY (DD), HEATING—A unit of heat measurement equal to one degree variation from a standard temperature (usually 65°F) in the average temperature of one day. If the standard is 65°F and the average outside temperature for one day is 50°F, then the number of degree days recorded for that day would be 15.

DELTA T ($\triangle$T)—A difference in temperature.

DENSITY (p)—The mass of a substance which is expressed in pounds per cubic foot.

DESIGN LIFE—The period of time during which a heating, cooling, or domestic hot water system is expected to perform its intended function without required major maintenance or replacement.

DESIGN TEMPERATURE—A designated temperature close to the most severe winter or summer temperature extremes of an area, used in estimating heating and/or cooling demand.

DIFFUSE RADIATION—Sunlight that is scattered by air molecules, dust, water vapor and translucent materials.

DIRECT GAIN (DG)—A passive system in which solar radiation is admitted directly into the conditioned (or living) space, where it is converted to heat and stored.

DIRECT RADIATION—Light that has traveled a straight path from the sun, as opposed to diffuse radiation.

DISTRIBUTION—Method by which heat is delivered to the living areas.

DRY BULB TEMPERATURE—A measure of the temperature of the air.

DWH—Domestic hot water.

ECONOMIC EFFICIENCY—Maximizing net benefits or minimizing costs for a given level of benefits.

EFFICIENCY—In solar applications, the amount of useful solar energy collected divided by the amount of solar energy available to the collector.

EMISSIVITY—The ability to radiate heat in the form of long wave radiation.

EMITTANCE—The ratio of the amount of heat radiated by a surface to the amount which would be radiated by a black body at the same temperature. Emittance values range from 0.05 for brightly polished metals to 0.96 for flat black paint.

ENERGY—The capacity for doing work. It takes a number of forms which may be transformed from one into another, such as thermal (heat), mechanical (work), electrical, and chemical; customarily measured in kilowatt-hours (kwh) or British thermal units (BTU).

ENERGY TRANSPORT SYSTEM—The portion of the heating and domestic hot water systems which contains heat transfer fluids and transports energy throughout the system.

EQUINOX—Either of the two times during the year when the sun crosses the celestial equator and when the length of day and night are approximately equal. These are the autumnal equinox on or about September 22 and the vernal equinox which is on or about March 22.

FIRST COST—A measure of the initial cost of a component or system.

FLAT PLATE COLLECTOR—A panel of metal or other suitable material that converts sunlight into heat. The solar radiative absorbing surface is essentially flat and the aperture and absorber are similar in area and geometry.

FORCED VENTILATION—See "Ventilation, Forced."

GLAZING—A covering of transparent or translucent material (glass or plastic) used for admitting light. Glazing reduces heat losses from reradiation and convection. Examples: windows, skylights, greenhouses and clerestories.

GREENHOUSE EFFECT—Ability of a glazing material to both transmit short wave solar radiation into a space and trap long wave heat generated by the conversion of the short wave radiation into heat.

GROSS FLOOR AREA—The sum of the areas of all floors of a building, including basements, cellars, mezzanine and intermediate floored tiers, and penthouses of headroom height, measured from the exterior faces of exterior walls or from the centerline of the walls separating buildings.

GROSS WALL AREA—The gross area of exterior walls consists of all opaque wall areas (including foundation walls, areas between floor spandrels, peripheral edges of floors, window areas including sash, and door areas) where such surfaces are exposed to outdoor air and enclose a heated or mechanically cooled space, including interstitial areas between two such spaces.

HEAT—The form of energy that is transferred by virtue of a temperature difference.

HEAT CAPACITY—The property of a material defined as the quantity of heat needed to raise one cubic foot of the material 1°F. Numerically, the density multiplied by the specific heat.

HEAT EXCHANGER—A device specifically designed to transfer heat between two fluids.

HEAT GAIN—An increase in the amount of heat contained in a space, resulting from solar radiation and the flow of heat through the building envelope plus internal heat gain.

HEAT LOSS—A decrease in the amount of heat contained in a space, resulting from heat flow through walls, windows, roof and other building envelope components.

HEAT LOSS COEFFICIENT (UA)—The rate of energy transfer through the walls, roof, and floor of a house, calculated in BTU/Hr/°F.

HEAT SINK—A substance which is capable of accepting and storing heat, a heat reservoir.

HEAT TRANSFER MEDIUM—A medium—liquid, air or solid—which is used to transport thermal energy.

HEATED SPACE—Space within a building which is provided with a positive heat supply to maintain the air temperature at 50°F or higher.

HVAC—Heating, ventilating and air-conditioning.

HVAC SYSTEM—A system that provides either collectively or individually the processes of comfort control including heating, ventilating, and/or air-conditioning within or associated with a building.

HYBRID SYSTEM—Solar heating system that combines active and passive techniques.

INCIDENT ANGLE—The angle between the incident ray from the sun and a line drawn perpendicular to the solar collector surface.

INDIRECT GAIN PASSIVE SYSTEM—A solar heating system in which sunlight first strikes a thermal mass located between the sun and a space. The sunlight absorbed by the mass is converted to heat and then transferred into the living space.

INDUCED VENTILATION—See "Ventilation, Induced."

INFILTRATION—The uncontrolled inward air leakage through cracks and interstices in any building element and around windows and doors of a building, caused by the pressure effects of wind and/or the effect of differences in the indoor and outdoor air density.

INFRARED RADIATION—See "Radiation, Infrared."

INSOLATION—Total amount of solar radiation incident upon an exposed surface measured in Btu/hr/ft^2 or in Langleys.

INSULATION—A material having a relatively high resistance to heat flow and used principally to reduce heat flow.

INTERNAL HEAT GAIN—Heat generated by equipment, appliances, lights, and people.

ISOLATED GAIN PASSIVE SYSTEM—A system where solar collection and heat storage are isolated from the living spaces.

LIFE CYCLE COST—A measure of total system cost including initial, maintenance, and operating costs over its lifespan. The accumulation generally includes a discounting of future costs to reflect the relative value of money over time.

LOAD COLLECTOR RATIO (LCR)—The Building Load Coefficient (BLC) divided by the total passive solar collector area. The LCR is used to determine the Solar Savings Fraction.

MAGNETIC SOUTH—South as indicated by a compass; changes markedly with geographic location.

MECHANICAL PLANT EFFICIENCY (MPE)—The efficiency of the mechanical system, usually obtainable from the equipment manufacturer.

MICROCLIMATE—The climate of a defined local area, such as a house or building site, formed by a unique combination of factors such as wind, topography, solar exposure, soil and vegetation.

MMBTU—Million (10^6) BTU's. The predominant unit of measure for energy in the United States.

MOVABLE INSULATION—Insulation placed over windows when needed to prevent heat loss or gain, and removed for light, view, venting, or heat.

NATURAL VENTILATION—See "Ventilation, Natural."

NIGHT INSULATION (NI)—See "Movable Insulation."

NOCTURNAL COOLING—Cooling by nighttime radiation, convection, and evaporation.

NON—DEPLETABLE ENERGY SOURCES—Sources of energy (excluding minerals) derived from incoming solar radiation, including photosynthetic processes; from phenomena resulting therefrom, including wind, waves, and tides, lake or pond thermal differences; and energy derived from the earth, or gravity.

OPAQUE—Impenetrable by light.

OUTSIDE AIR—Air taken from the outdoors and, therefore, not previously circulated through the system.

PASSIVE SOLAR SYSTEM—An assembly of natural and architectural components, including collectors, thermal storage device(s), and transfer fluid, which converts solar energy into thermal energy in a controlled manner and in which no fans or pumps are used to accomplish the transfer of thermal energy. The prime elements in a passive solar system are usually some form of thermal capacitance and solar energy control.

PAYBACK—A traditional measure of economic viability of investment projects. A payback period is defined in several ways, one of which is the number of years required to accumulate fuel savings which exactly equal the initial capital cost of the system. Payback often does not give an accurate representation of the total life cycle value of the investment.

PEAK LOAD—The design heating and cooling load used in mechanical system sizing. Usually set to meet human comfort requirements 93%-97% of the time.

PERCENT SOLAR—A crude measure of the amount of heating or cooling provided by a solar system compared to the total demand.

PHASE CHANGE MATERIAL—A material such as salt or wax which stores thermal energy when it melts and releases heat when it solidifies.

POWER—In connection with machines, power is the time rate of doing work. In connection with the transmission of energy of all types, power refers to the rate at which energy is transmitted. In customary units, it is measured in watts (W) or British thermal units per hour (BTU/hr).

RADIATION—The direct transport of energy through a space by means of electromagnetic waves.

RADIATION, SOLAR—See "Solar Radiation."

RECOVERED ENERGY—Energy utilized which would otherwise be wasted from an energy utilization system.

REFLECTANCE—The ratio of the light reflected by a surface to the light falling upon it.

REFLECTED RADIATION—Solar radiation reflected by light colored or polished surfaces. Can be used to increase solar gain.

REFRACTION—The change in direction of light rays as they enter a transparent medium such as water, air or glass.

REHEAT—The application of sensible heat to supply air that has been previously cooled below the temperature of the conditioned space by either mechanical refrigeration or the introduction of outdoor air to provide cooling.

RESISTANCE (R)—The tendency of a material to reduce the flow of heat (see R-Value).

ROCK STORAGE SYSTEM—A solar energy system in which the collected heat is stored in a rock bin for later use. This type of storage can be used in an active, hybrid or passive system. However, rock storage is primarily used with a system which circulates air as the transfer medium between the collector and storage, and from the storage to the heated space.

R-VALUE—A unit of thermal resistance used for comparing insulating values of different materials. The reciprocal of the conductivity. The higher the R-value of a material, the greater its insulating capabilities.

SELECTIVE SURFACE—A coating with high solar radiation absorptance and low thermal emittance, used on the surface of an absorber to increase system efficiency.

SENSIBLE HEAT—Heat that results in a temperature change.

SHADING COEFFICIENT (SC)—The ratio of the solar heat gain through a specific glazing system under a given set of conditions, to the total solar heat gain through a single layer of clear, double-strength glass under the same conditions.

SOLAR ALTITUDE—The angle of the sun above the horizon measured in a vertical plane.

SOLAR CONSTANT—The amount of solar radiation that reaches the outside of the earth's atmosphere.

SOLAR HEATING FRACTION (SHF)—The percentage of heating needs supplied by the passive solar system.

SOLAR RADIATION—Electromagnetic radiation emitted by the sun.

SOLAR RETROFIT—The application of a solar heating or cooling system to an existing building.

SOLAR SAVING FRACTION (SSF)—The difference in auxiliary heat required with and without the solar collection aperture (solar wall). The reference building is simply the same building without a solar wall.

$$\text{SSF} = \frac{\text{solar savings}}{\text{reference net thermal load}}, \text{ or,}$$

$$\text{SSF} = 1 - \frac{\text{aux. heat required by solar heating}}{\text{aux. heat required by reference bldg.}}$$

SOLAR TIME—The hours of the day reckoned by the apparent position of the sun. Solar noon is that instant on any day at which time the sun reaches its maximum altitude for that day. Solar time is very rarely the same as local standard time in any locality.

SOLAR WINDOW—An opening that is designed or placed primarily to admit solar energy into a space.

SPECIFIC HEAT—The number of BTUs required to raise the temperature of one pound of a material 1°F.

SPECULAR—An imaging reflection. A mirror is a specular reflector.

STORAGE—The assembly used for storing thermal energy so that it can be used when required.

STRATIFICATION—In the context of solar heating, the formation of layers in a substance where the top layer is warmer than the bottom.

SUNTEMPERED—A structure which is designed or oriented to take into account climatic conditions but which does not possess strict passive features such as thermal mass.

THERMAL CONDUCTANCE—See "Conductance."

THERMAL CAPACITY—See "Heat Capacity."

THERMAL CONDUCTANCE—See "Conductance."

THERMAL ENERGY—Heat possessed by a material resulting from the motion of molecules.

THERMAL MASS—A thermally absorptive component used to store heat energy. In a passive solar system, the mass absorbs the sun's heat during the day and radiates it at night as the temperatures drop. Thermal Mass can also refer to the overall amount of heat storage capacity available in a given system or assembly.

THERMAL STORAGE CAPACITY—The ability of a material, per square foot of exposed surface area, to absorb and store heat. Numerically, the density times the specific heat times the thickness.

THERMAL STORAGE ROOF—A passive system in which the storage mass is located on the roof. Mass can be water or masonry and usually has movable insulation.

THERMAL STORAGE WALL—A passive system in which the storage mass is a wall located between the collector and the living space(s) to be heated. The mass can be a variety of materials including water or masonry.

THERMAL TRANSMITTANCE (U)—Overall coefficient of heat transmission (air-to-air) expressed in units of BTU per hour per square foot per degree F. The U-value applies to combinations of different materials used in a series along the heat flow path, single materials that comprise a building section, cavity air spaces, and surface air films on both sides of a building element.

THERMOCIRCULATION—The convective circulation of fluid which occurs when warm fluid rises and is displaced by denser, cooler fluid in the same system.

THERMOSIPHON—See "Thermocirculation."

TILT ANGLE—The angle of a collector relative to the ground. A rule of thumb collector angle for winter heating is the latitude +10°.

TIME LAG—The period of time between the absorption of solar radiation by a material and its release into a space. Time lag is an important consideration in sizing a thermal storage wall.

TRANSLUCENT—Transmitting light but causing sufficient diffusion to eliminate perception of distinct images.

TRANSMITTANCE—The ratio of radiant energy transmitted through a transparent or translucent substance to the total radiant energy incident on its surface.

TRANSPARENT—Transmitting light so that objects or images can be seen as if there were no intervening material.

TROMBE WALL—Another name for a "Thermal Storage Wall," named after its inventor, Dr. Felix Trombe.

U-VALUE—The number of BTUs that flow through one square foot of roof, wall or floor, in one hour, when there is a 1°F difference in temperature between the inside and outside air, under steady state conditions. The U-value is the reciprocal of the resistance or R-value (see Thermal Transmittance.)

VAPOR BARRIER—A layer of material, resistant to the flow of water in the gaseous state, used to prevent condensation of water within insulation or dead air spaces.

VENTILATION, FORCED—Mechanically assisted movement of fresh air through a building using some sort of fan or blower.

VENTILATION, INDUCED—The thermally assisted movement of fresh air through a building, such as by thermocirculation.

VENTILATION, NATURAL—The unassisted movement of fresh air through a building.

WATER WALL—A passive technique for collecting solar energy. Water walls are usually black, water-filled containers exposed to the sun. These collect and store heat, which is used to warm a living space.

WET BULB TEMPERATURE—The lowest temperature attainable by evaporating water into the air.

WYTHE—Each continuous vertical section of a wall one masonry unit in thickness and tied to an adjacent vertical section or sections.

ZONE—A space or group of spaces within a building with heating and/or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device.