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Remodeling is the perfect time to improve daylighting, direct gain heating, and shading with passive solar techniques. It can also provide the best opportunity to add solar water heating or even photovoltaics to a home.

Remodeling with the Sun

by Steven Bodzin

RICHARD H. EPSTEIN, GREENFIELD/EPSTEIN ARCHITECTS

The passion for passive solar is not what it used to be; enthusiasm peaked sometime in the late 1970s. Today, even energy-conscious builders focus on improving insulation and air tightness more than on how the remodeled house will interact with the sun.

But the heating, lighting, and cooling benefits of passive solar are far from lost, even if they have been forgotten by some. More than 20 years of trial and error have helped mature solar methods and technologies. Today's solar professional has a toolbox of proven strategies that can give almost any home better solar performance.

While many of the big advances in solar technology have been in off-the-grid applications, innovative passive solar ideas and technologies are also available for the average residence. The biggest developments have been in improved windows, which open new possibilities in direct gain heating and daylighting. A home with many windows also needs adequate shading, and should have heat storage. These basic solar improvements can be combined with remodeling projects, especially if the remodel involves adding windows, revamping floors, building an addition, adding landscaping, or replacing the domestic hot water system.

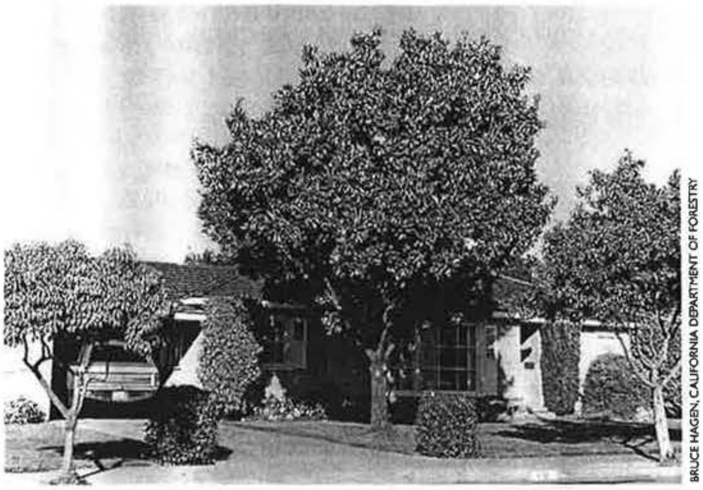
Adding Windows

Windows are the piece of "energy equipment" most likely to be replaced in a remodel, such as when a wall is to be added or a window moved. Sunspaces are a popular addition, and they are almost nothing but windows (see "The Sunspace: A Passive Solar Room"). While replacing windows is not always the most cost-effective improvement, changing from single-pane windows or damaged sashes to double-glazed, low-emissivity windows with insulating sashes will improve comfort substantially.

The cost of multiple glazings, low-emissivity coatings, warm-edge spacers, insulating sashes, and inert gas fills have all come down in recent years. These high-tech components lower U-values and reduce air infiltration. Some manufacturers design individual windows to enhance either heating or cooling; the main difference is in the window's solar heat gain coefficient (SHGC) (see "Selecting Windows for Energy Efficiency," *HE* July/Aug '95, p. 11).

Windows that face the sun heat the

The above photos of the Berger residence in Boulder, Colorado show a marked difference after a remodel. In addition to adding space, the Bergers sheathed the exterior in foam insulation to take advantage of the existing brick walls' thermal mass. The addition of an "air lock" on the front door helps limit air infiltration.



BRUCE HAGEN, CALIFORNIA DEPARTMENT OF FORESTRY

A good example of planting for cooling purposes, this magnolia tree effectively shades windows from summer sun, while allowing winter daylight in. Shrubbery near the garage protects another window from the heat and glare of afternoon sun. (To avoid another type of energy problem, avoid planting tall-growing trees near or under power lines!)

house with direct gain. Older windows, though they let in solar heat, also lost a lot of heat through air leaks and poor insulation. Today, windows sold for cold climates let in solar heat and are well insulated and airtight as well. Thus, cold-climate builders no longer need to worry about orienting all of the glass toward the south and blocking north, west, and east views. Simulation modeling has shown that, with advanced windows, increased window area on a house can cut heating energy use, even in chilly Wisconsin. Of course, proper installation is necessary to keep window details from contributing to infiltration and moisture problems (see "Energy-Efficient Window Retrofits: Install with Care," *HE* Jan/Feb '97, p. 23). Improper use of glazing can provide too much heat, especially in the summer. Proper shading and orientation are still essential.

North Glass

The north side is where multiple glazings and low air infiltration rates are most crucial. Almost all sunshine comes from the east, south, and west, and the north wind is often the coldest. When the only windows available were drafty, single-glazed units, windows facing north lost heat all winter. However, today's windows can face north without losing much heat. More importantly, north glass provides consistent color and intensity of daylight, without annoying glare. Low-glare daylighting can reduce energy consumption in a home office or studio by eliminating the need for daytime electric lights. Contrary to the design philosophy of the '70s, solar-conscious design should include some north glass.

East and West Glass

Windows on the east and west receive light and heat, but they are hard to shade from the summer sun. East windows don't waste as much energy—they let in morning sunshine and chase off the nighttime chill. However, west windows are almost never energy winners, as they overload the house with heat on summer afternoons.

East-facing and west-facing glass are far more acceptable if they are selected for the right characteristics. In any climate, multiple glazings and gas fills make the window insulate better. Different window films and coatings will be appropriate, depending on your combination of heat, cold, sun, and clouds.

You can use more east- and west-facing glass if you shade the windows. Outdoor vegetation works well to shade the low-angle sun. Tall shrubs, hedges, and arbors all rise to block it, and the shade from a single well-placed, mature tree will reduce annual air conditioning use in a typical American home by 2%–8% (see "Shade Trees as a Demand-Side Resource," *HE* Mar/Apr '95, p. 11). Glass with a low SHGC has built-in shading, meaning that it reduces the amount of solar energy that gets in. Retrofit window films stick onto clear glass to reduce the amount of energy the window lets through. These films are inexpensive, but they should be professionally installed to prevent unsightly bubbles and cracks.

Awnings can reduce heat gain through an east or west window by 77%. However, to get this kind of shading, the awning has to cover the top 65% or 75% of the window, depending on latitude. Slatted awnings will allow you to see outside through the covered area, but they provide less shade. Retracting or removing awnings in the winter lets in more morning sun and prevents snow damage.

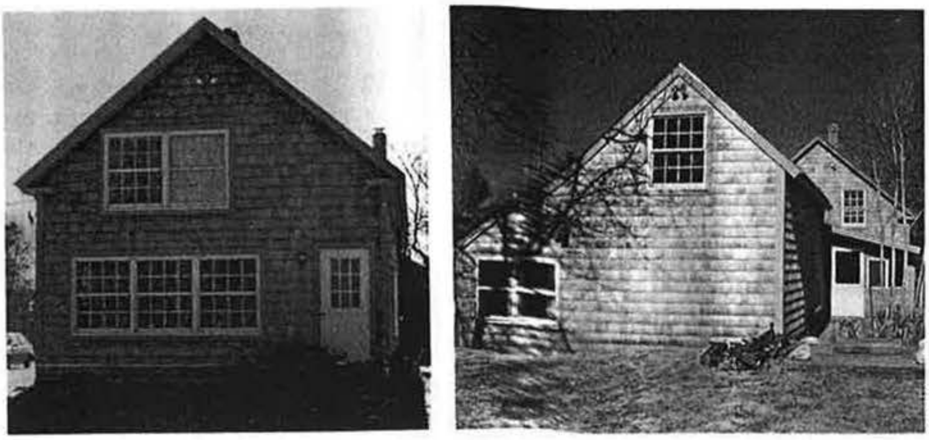
Awnings should have a small vent space where they meet the house, to prevent heat buildup against the window. Be sure that awnings don't obstruct emergency access or egress—most building codes require awnings to end at least 80 inches above the ground if they extend over walkways. Also, if you must penetrate the building shell to install the awnings, seal the envelope properly against water and air infiltration.

South Glass

In the Northern Hemisphere, the winter sun rises in the southeast and passes low through the southern sky to set in the southwest. Thus, the best place for windows is the south side of the house, where the winter sun can penetrate deep into the living space, warm-

RICHARD H. EPSTEIN, GREENFIELD EPSTEIN ARCHITECTS

Four major elements of solar design are visible in this interior view: a poured concrete floor designed for thermal mass (in winter it stores heat radiating through the wall of windows), an exterior trellis and projections for summer shading, extensive daylighting, and operable windows for venting excess heat and providing fresh air.



M. FUCHS

This Massachusetts farmhouse is a perfect illustration of what not to do in a remodel. The photo on the left shows the window-filled north side of the house, which is usually shaded. Previous homeowners had converted the south side (right) into an unconditioned utility room, effectively blocking solar gain for that side of the house. The current owners are looking into adding a wing with good southern exposure to bring down their heating bills.

ing the house when heat is needed most. South windows are easy to shade from the summer sun—in the summer, the sun rises in the northeast, passes almost overhead, and sets in the northwest (see "Angles and Overhangs").

It is usually possible to use an awning or a long roof overhang to shade a south window. Installing awnings is generally easier and cheaper than building an overhang on an existing house. On a south-facing window, awnings will block as much as 65% of the summer sun's heat, including conducted and reflected heat. Solar-conscious roof overhangs extend the eaves farther than normal. The drawbacks of overhangs are that they are difficult to add unless the remodel includes plans for work on the roof, and there is no way to retract them. But they are a permanent improvement, so the house will continue to benefit from them long after awnings would have broken down.

An extreme type of shading that works for south, east, or west windows is an exterior roll blind. These blinds roll down over the outside of the window, preventing light from entering. They are useful against heat gain, but they block views, ventilation, and daylighting. If the occupants tend to be home during the day, the best exterior shades either will be suspended away from the windows, to allow ventilation and let in some light, or will be shade screens, which block direct sunlight but let in air, reflected light, and views.

At one time, it was conventional wisdom to use deciduous trees to shade southern windows. However, according to sources at the National Renewable Energy Laboratory, the trunk and branches of a leafless tree can still block 40% of winter sunshine. They now recommend removing vegetation from the south side of the house and using overhangs to manage summer sun.

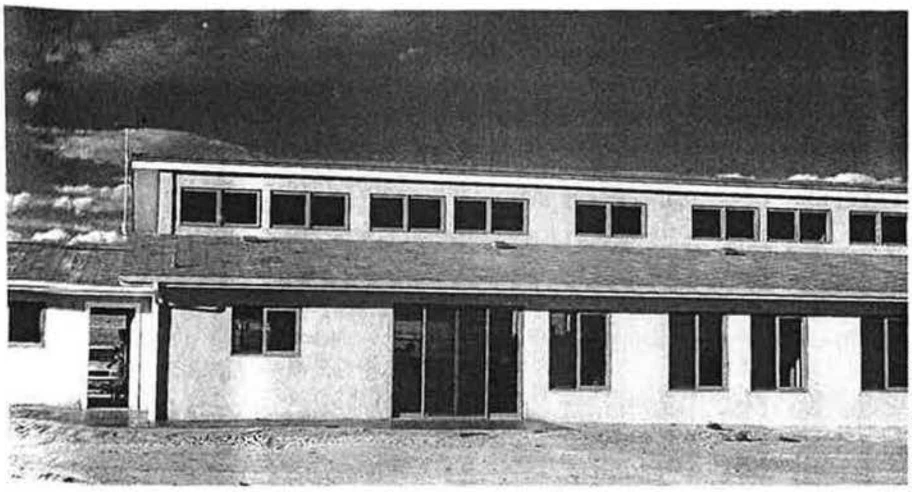
Interior window shades are less effective than exterior ones because they stop sunlight after it has entered the home. All the same, new blinds or draperies can help reduce summer heat gain and winter heat loss. Light-colored shades can reduce a window's SHGC by as much as 43%. (Dark blinds will soak up more sun, releasing the energy as heat inside the house.) For better winter comfort, heavy insulating drapes are still very useful with single-pane windows, if new efficient windows are out of the budget.

Daylighting

Just as you design the home to optimize solar heating, design it for maximum solar lighting by increasing the number of windows that would let natural light into rooms that are used during the day. This can save the residents energy, elevate their moods, and boost the value of the house. Daylighting, in fact, is the main reason to have windows on the north, west, and east sides. Rooms often used during the day, such as the kitchen, living room, and play areas, are the most important candidates for daylighting.

Sunlight for illumination is different from sunlight for direct-gain heating. For heating, you want direct, bright light shining on dark surfaces. For daylighting, you want diffuse light shining on light surfaces. Glare from direct sunlight is especially annoying in home offices and TV rooms.

The apparently contradictory requirements of direct gain and daylighting can both be fulfilled with careful design. One established rule of thumb is that glazing area equal to 5% of the floor area will provide adequate daylight. Direct gain heating usually requires around 7% of the floor area. Architectural modeling software, such as *Energy-10* from the Passive Solar Industries Council, is now available to help design daylighting strategies. Whether you use a computer or a rule of thumb, the key is to note where the sun shines at different times of different days, and how this interacts with the residents' lives.



TIERRA CONCRETE HOMES

This home designed by Tierra Homes of Pueblo, Colorado, uses clerestory windows to take advantage of solar heat and light year-round, and ventilation in the summer.

The Sunspace: A Passive-Solar Room

An attractive and popular passive-solar remodel is the addition of a sunspace. A sunspace is a tightly constructed, windowed enclosure that provides heat, light, and ventilation for the house. It can be an entryway, a sitting room, or a greenhouse. Because it has so many windows, the sunspace will work best with thermal mass. The most effective sunspaces are able to distribute their heat throughout the house to offset heating load. They can also help ventilate the house in hot weather.

Windows

The most important decision in designing a sunspace is deciding what windows to use. A sunspace should have as much south glass as possible. Some, especially those designed as greenhouses or heaters, also have sloping glass walls and overhead windows. However, sloped windows are hard to shade from the summer sun, so they tend to overheat. They also lose more heat at night and in the winter; can be covered by snow; and often break, leak, or fog up.

If overhead or sloping glass is necessary, use specially designed very low-emittance glass, often sold under such trade names as Low-E^2 or Super Low-E. These windows reject summer heat especially well and are available in designs made to stand up to the extra strains of horizontal placement. For vertical glass, windows should be at least as high efficiency as the windows in the rest of the house.

Sunrooms need different glazings, depending on climate. For most climates, the best windows are low-e double-pane units with a solar heat gain coefficient (SHGC) above 0.75. If the sunroom exists mainly to provide heat, the low-e coating should be on the glazing closest to the indoors. This is because the coating itself heats up when exposed to the sun, thereby warming the glass. If the sunroom is in a hot climate, it should have low-e coatings on the outer glazing layer and a low SHGC—around 0.25.

Shading

Sunspaces require at least as much shade as the main living space. Overhead windows should have retractable awnings or insulated curtains. These devices can reduce heat gain on the hottest days and will reduce heat loss at night. Because sunrooms have so much glass and are not necessarily occupied during the day (unlike the kitchen), outdoor shades and awnings are sometimes feasible. However, the best techniques for shading are to avoid overhead glass and to build-in adequate overhangs.

Walls

The sunspace should be separated from the house by an exterior door and an insulated exterior wall—ideally one made of massive material, such as exposed brick or concrete. If the space is primarily for living or heating, the east wall, west wall, and floor should be insulated and sealed against air and water infiltration. If the sunspace is an addition or a porch conversion, its junction with the house structure should be carefully air sealed.

Thermal Mass

Like other spaces with lots of south glass, sunspaces need thermal mass to remain comfortable. A sunspace designed as living space should have plenty of thermal mass, using some combination of a cement floor and a masonry north wall. A sunspace is subject to extreme conditions, so use computer simulations to determine how much thermal mass you need.

If the sunspace doesn't have much thermal mass, it might not be comfortable as a sitting room. However, it can still work as a solar-heated entryway. It won't overheat as long as there's adequate air movement between it and the house, and a warm entryway can be a relief in the winter. The sunspace won't heat or cool the house too much if it can be sealed off from the main living space.

Ventilation

To spread heat into the house in winter and ventilate the sunspace in summer, the sunspace should have operable vents to and from the nearby rooms. The sunspace should be ventilated into rooms that are used during the day, such as the kitchen, playroom, or living room, so that these rooms will benefit from the solar heating.

It is often easiest to ventilate the sunspace through the middle of the house wall. For example, there are often operable windows between the sunspace and the house. For this type of vent, there should be 8 ft^2 of net free vent area (NFVA) for every 100 ft^2 of south glass in the sunspace. Less vent area is needed if the vents are separated by at least 8 vertical feet. For split vents, every 100 ft^2 of south glass requires at least 2.5 ft^2 of NFVA near the ceiling and an equal amount near the floor.

The sunspace should also have vents to the outdoors to help ventilate in the summer. Operable windows, especially on the ceiling, ventilate the space well.

Greenhouses

Sunspaces built as greenhouses have special needs. Plants have limited temperature tolerance; they shade the floor; they need year-round direct sunlight; and they release moisture. In addition, they need light from at least two directions. Greenhouses tend to develop molds because of moisture from the plants, so they do not make good living spaces. They also don't provide the house with heat, as the plants absorb much of the energy and also cool the space.

Traditional greenhouse design has called for east, west, and ceiling windows, and many greenhouses are still built this way. The extra windows cause excessive heat gain on sunny summer days and excessive heat loss at night and in winter. As a result, a greenhouse rarely provides its house with solar heating or cooling. In some climates, typical greenhouses cannot even store enough heat to keep the plants from freezing on winter nights. They need extra insulation in the floor, and in the winter, they should have panels of foam board insulation over ceiling windows at night. A greenhouse that is airtight will stay warm enough for the plants without backup heat from the house in almost any climate.

To provide the multidirectional light that plants require, the greenhouse can use minimal east and west windows, or even just effective reflectors redirecting light from south windows. This way, the room can more easily be built to shade out the most extreme summer sun, which can scorch plants.

Thermal mass in a greenhouse can be shaded by all the plants, so it is especially important to supply adequate mass on the north wall. Jugs and 55-gallon drums of water are useful for greenhouses, since water has more thermal mass than any other readily available material. To increase the sun's access to thermal mass, greenhouses sometimes have windows all the way down to the floor. The bottoms of the windows allow the sun to shine on thermal mass materials rather than plants.

Because plants can't tolerate extreme heat, an electric fan is often built into an outside wall. Whether the greenhouse uses natural or mechanical ventilation, it should draw air through the house and out, to keep molds and moisture from entering the house.

On the Roof

Clerestory windows bring daylight and winter heat into the heart of the house, and ventilate it in the summer—all without compromising privacy. They offer one of the most tried-and-true ways to combine direct gain, daylighting, and induced ventilation. Clerestories are set high into walls, just below the eaves, or into cathedral ceilings on a south-facing roof. They permit the low winter sun to shine in, illuminating and heating much of the house. Because they are usually wide rather than tall, they require only a small overhang to block summer heat gain. They also encourage natural ventilation, as hot air rises to escape the house at the top. In the summer, clerestories should be open, to let the hottest air flow out. To keep winter heat in, however, these windows should be made of well-insulated glass.

Shingles and Roofing Tiles

If the remodel involves installing a new roof, photovoltaic (PV) roof shingles might be cost-effective. These new roofing systems are coated with a film that converts sunlight to electricity. The shingles or tiles snap together, so the small amount of current in each one ends up flowing out at the edge of the roof as a significant current. Designed for grid-connected houses, these roofing systems are designed to look similar to traditional roofing, and to be installed by traditional roofers. The roofers install the tiles, and an electrician spends a short time connecting the roof system with the electrical system. Each 100 ft^2 of PV roof will generate 1 kW of electricity, but note that the roof must be oriented toward the south, and that snow cover will prevent the solar cells from receiving sunlight. These PV roof systems are available from some roofing supply companies.

As long as roof work is being done, a white roof or an attic radiant barrier can reduce the amount of summer heat that penetrates into the attic or top floor (see "White Roofs for Cool Homes," *HE* Nov/Dec '96, p. 28). Both of these reflect solar energy back into outer space, rather than absorbing it and turning it into heat. Experiments have shown that radiant barriers can reduce air conditioning energy use by 8%, and a reflective roof coating can reduce summer roof temperatures by over 60°F.

Walls and Floors

The three basic passive solar strategies—direct gain, shading, and daylighting—can be implemented in any home. It's more difficult to install thermal mass. Regardless of the care given to windows and shading design, a house can overheat in the summer and feel cool in the winter if solar gains aren't stored and then slowly released. Materials with high thermal mass, like masonry and stone, heat and cool slowly, moderating the house temperature. Many architects who have access to advanced computer modeling still use rules of thumb for thermal mass. A rule of thumb promoted by the National Renewable Energy Laboratory is that the thermal mass should have nine times as much surface area exposed to sunlight as the area of the glazing, and that the materials should be 6 inches thick. The exact amount and materials needed vary, depending on where the house is.

Remodeling projects provide a chance to expose the cement, stone, and metal already in a house structure, or add new mass. A sunny kitchen or dining room can gain thermal mass with a floor of ceramic or clay tiles, especially in a rich color. A thin layer of counter tiles over wood or other less heat-absorbing materials will provide

Angles and Overhangs

Overhangs or awnings can provide a house with summer shade and winter sun. The optimal size of awnings and overhangs will depend on the home's location and on the climate. The Passive Solar Industries Council publishes this information in locally customized *Builder Guides* for hundreds of cities and towns across the United States. Without this resource, the designer needs to determine how high the sun will be in both summer and winter. This angle is known as the altitude of the sun (see Figure 1). A simple formula will convert the summer and winter altitudes into overhang sizes.

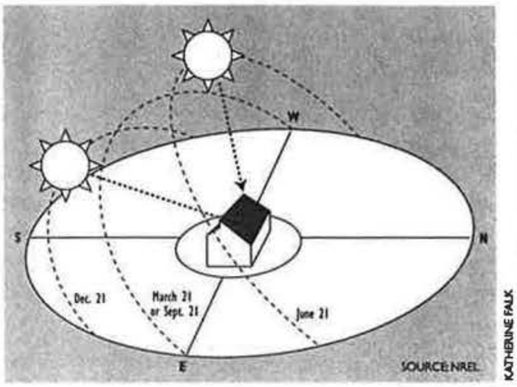


Figure 1. This figure shows the path of the sun through the sky at different times of the year. Notice how the winter sun will shine under an overhang, while the summer sun will be blocked.

Tables of altitudes are included in many books on solar design. You can also get the information by calling the Efficiency and Renewable Energy Clearinghouse of the U.S. Department of Energy, at (800) DOE-EREC and requesting National Renewable Energy Laboratory Publication TP-463-7904. On-line reference tables for many locations and every month are available at http://rredc.nrel.gov/solar/old_data/nsrdb/ bluebook/.

These tables show the sun's altitude for each latitude, in each month. If a house needs an overhang that will allow the sun in from November through February, but will provide shade from April through August, the designer will use the February angles as the winter design angles, and the August angles as the summer design angles.

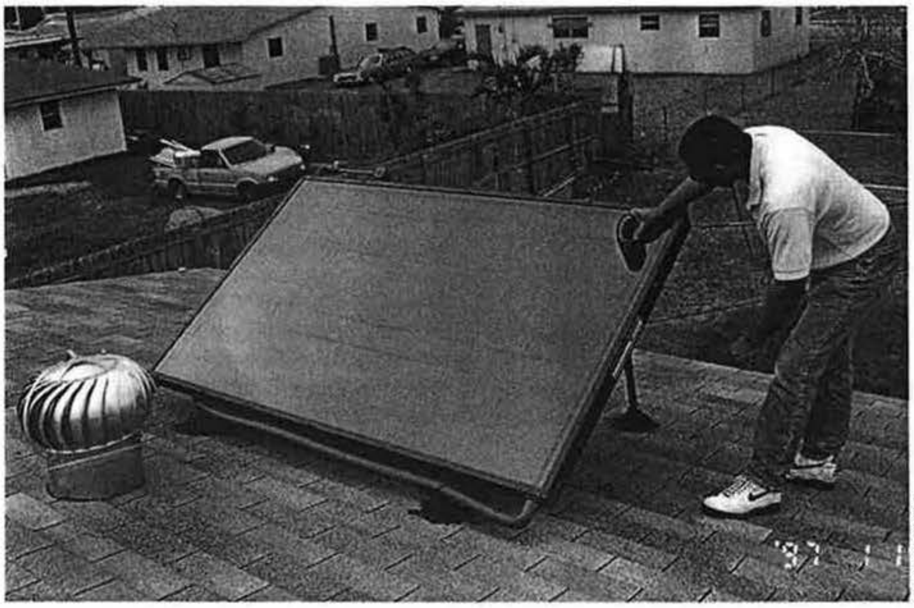
With the winter and summer altitude in hand, the designer can calculate the optimal overhang and awning sizes, using these equations:

$$Y = \frac{H \times \tan(90\text{-}S)}{(1 / \tan(W)) - \tan(90\text{-}S)}$$

$$X = Y / \tan(W)$$

H = height of window opening
S = summer sun altitude (in degrees)
W = winter sun altitude (in degrees)
X = length of overhang
Y = height of overhang above window

Source: Center for Renewable Energy and Sustainable Technology, http://solstice.crest.org/staff/ceg/sunangle/overhang.html.



COURTESY OF FSEC

An installer measures the angle of a solar hot water collector atop this Miami, Florida roof. The sunny climate of the area makes solar water heating an attractive and relatively cost-effective retrofit.

limited thermal mass. Thicker tiles are more helpful, and a concrete slab floor is best of all.

In houses built on insulated slab foundations, exposing the slab floor provides excellent thermal mass. Exposed concrete can be attractive, durable, and easy to build. However, the weight of concrete can pose structural problems. A couple of inches of lightweight concrete usually won't overload the house structure, but lightweight concrete stores less heat per volume than heavy concrete. For aesthetics, you can cover concrete with paving bricks, slate, quarry tiles, or dark ceramic tiles. Don't cover thermal mass floors with rugs; leave them as bare as possible to soak up and release heat. Properly insulated floors with solar gain should not be cold. Uninsulated slabs should not be used for thermal mass in cold climates. They will be too cold in the winter, so leave them covered with carpets to prevent cold feet.

Another strategy is to replace a wood-framed interior wall that receives direct sunlight with a wall made of concrete block, adobe block, stone, or masonry. (Note that cement blocks should be filled with concrete to improve their thermal mass.) Some house structures won't stand up to the added weight of these materials. Consult a structural engineer before you add thousands of pounds of thermal mass materials.

In areas where summer nights stay hot, indoor space needs to be shaded from the summer sun. It's especially important that thermal mass be shaded, or it can build up sweltering heat over the course of several days. However, it should be placed to soak up the winter sun. In the Southwest, a masonry fireplace is often placed in the wall opposite a south window, where the summer sun won't strike it but the winter sun will. In a climate with cool summer nights—in mountains, for example—thermal mass that receives summer sunshine will stabilize indoor temperature near the average of day and night temperature.

Massive walls can be sandblasted to create a wide variety of appearances. However, light-colored paint reflects much of the energy that a wall could be absorbing, effectively reducing the thermal mass.

Solar Hot Water

Many people replace water heating equipment or put in a new pool or spa when they remodel. If the homeowners have access to competent, reliable contractors, solar water heating can be very cost-effective. Solar-heated pools are cost-effective almost everywhere (see "Swimming Pools Soak Up the Sun," *HE* May/June '96, p. 37), and domestic hot water is cost-effective where the climate is relatively sunny and the other options are expensive to operate.

However, contractor support is crucial for these systems. Far too many shoddy solar hot water systems were built by fly-by-night contractors in the '70s, then left to fall apart (see "Wisconsin's 'Orphan' Solar Program," *HE* May/June '95, p. 38). Today, many solar hot water installations have utility support, making it more likely that the homeowner will have somewhere to turn for maintenance in the future.

There are two ways to move hot water between the collectors and the storage tank. In active distribution, a mechanical pump does the work. Passive systems rely on the buoyancy of heated water to lift the hot water into an elevated storage tank. There is controversy as to which is the superior technology; a lot depends on the climate. In passive solar systems, the water is transported without any pumps, using just city water pressure and the principle that hot water rises. Passive systems demand careful design, but have no moving parts. Active solar systems allow more flexibility in design and installation, and are easier to protect against freezing. However, active systems have more mechanical parts, so they tend to need more maintenance.

Homeowners considering solar-heated domestic hot water must find someone who has designed such systems before. The designer should be well versed in protecting the system against freezing, overheating, corrosion, and leakage. A rooftop installation must be sensitive to the integrity of the roof. All installations require careful collector and storage tank sizing. In most metropolitan areas, there are professionals who have years of experience with these systems. Be sure to shop around.

Photovoltaics—Making Electricity

Since the 1970s, researchers have been pushing the limits of PV. Today, photovoltaics are cost-effective on more homes than ever before. PV roof shingles are just one way that homeowners can now derive at least part of their electricity from the sun.

In many states, grid-connected photovoltaic systems have become cost-effective thanks to a program called net metering (see "California Supports PV with Net Energy Metering," *HE* May/June '96, p. 6). Under net metering, a home PV system produces electricity and supplies the excess to the utility, running the meter backward. When the home needs more power than its PVs are producing, it uses utility electricity, running the meter forward again. This system makes expensive battery storage unnecessary; ratepayers essentially bank their electricity with the utility, withdrawing it as needed.

New types of photovoltaic system include high-efficiency panels, roof shingles, and garden lights (see "Small PV Grows in the Garden," May/June '96, p. 6).

Panels

Solar panels have improved in recent years, producing steadily more power per square foot of panel. Today's widely available solar cells convert about 10% of incident solar energy into electricity, compared to about 6% in the 1970s. More importantly, the cost per watt of generating capacity has steadily declined. However, declining electricity prices, the end of solar tax credits in 1985, and increasing home energy efficiency have made residential PV panels less popular. Homes with utility lines usually have other energy investments that will save more money and energy than PVs.

All the same, today, if an electric installation is more than ¼ mile from an existing electric line, it is almost always cost-effective to use PV instead of a utility hookup. The National Park Service now requires that new hookups located more than 300 ft from an existing line install photovoltaics.

*Steven Bodzin is **Home Energy's** associate editor.*

Further Reading

U.S. Department of Energy's Energy Efficiency and Renewable Energy Clearinghouse (DOE-EREC). Phone:(800) DOE-EREC.

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