Chapter 3

Solar Windows

Sunlight falling gently through windows is by far the most common way for solar energy to heat our country's 70,000,000 buildings. But loosely fitting, single-glazed windows usually lose more heat than they contribute in the form of solar heat gain. On the other hand, a properly-designed south window, with the addition of a reflective surface on the ground (such as snow, a pond, or an aluminized mirror) and with an insulating cover at night, can supply up to twice as much solar energy to a building as a good “active" solar collector of the same surface area.

Proper design criteria include the following:

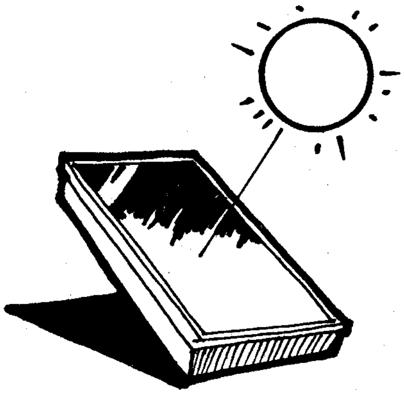
> In one sense, of course, most of the world's buildings are already principally solar heated. Think about the huge, year-round heating job the sun does, using land and sea as thermal mass, to keep the whole world between −50°F and +100°F when, without the sun, we'd be at −473°F all the time. That's *most of all of the heating done on earth*, and we'd do well to remember it when we hear talk of alternatives to solar energy use or that solar can't really do the job.

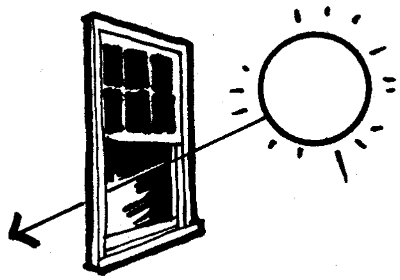
The right **timing**. Sunlight must enter a house at only the right time of the year and the right times of the day. This simply means careful design in response to known solar geometry and climate.

The right **amount** of solar heat. If you desire fairly stable indoor temperatures, this must be engineered. If you desire a fairly wide range of temperatures, great-but just don't assume that you do, or that other occupants or your friends will find it comfortable, and then have to later excuse a poorly engineered system when it gets too hot. Too much glass and too little mass is a common but unnecessary error in properly well-insulated passive solar houses.

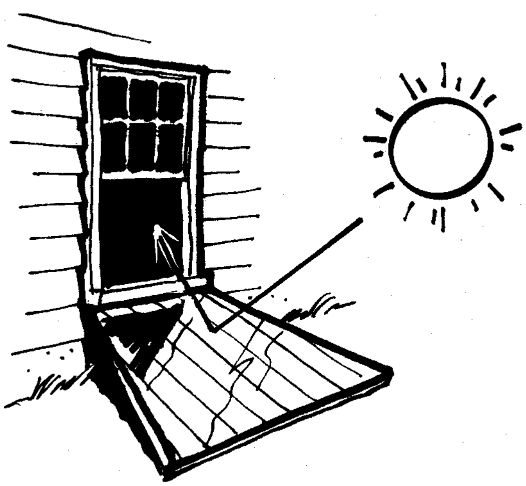
The right **type** of glazing. Clear glass is both attractive and efficient and has its place, but so have clear and translucent materials, such as diffusing glass, plastic films, fiberglass-based glazings, and acrylics. Reflective glazings can reduce unwanted solar gains. (See Appendix 6 for more help on selecting the right glazing material.)

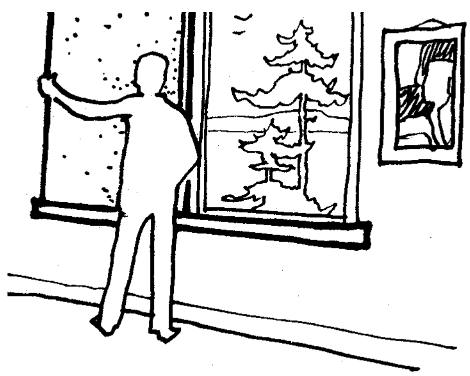
Windows and Solar Collectors Compared





Properly designed solar collectors supply between 50,000 and 85,000 Btus per square foot of surface area per heating season in a climate where the sun shines half the time. (This is equivalent to the energy from 1/2 to 1 gallon of home heating oil, or from 15 to 25 kwh of electricity, - or from 100 to 140 cubic feet of gas.) Solar gain through a square foot of south facing, double glass in the same climate is about 140,000 Btus. Conduction heat loss through that square foot (ignoring air infiltration for the moment) is about 70,000 Btus in a 5,000 degree day climate. The net contribution to the building, then, is 70,000 Btus (140,00 solar ,gain less 70,000 heat loss). Therefore, in a climate like that of St. Louis, ordinary double glazed south-facing windows can produce about the same amount of heat per square foot as solar collectors. Reflectors will boost heat production of both designs. Movable insulation and/or triple-glazing can dramatically reduce heat loss from windows, greatly boosting their net energy input to the house.





Solar Gain

Appendix 2 provides month-by-month, hourly-hour clear-day sunlight (or "insolation") data for vertical, south-facing surfaces for six different northern latitudes. Together with Appendix 3 (U.S. sunshine maps for each month), it can be used to determine the approximate amount of solar radiation likely to come through south-facing glass anywhere in the United States at anytime.

For example, from Appendix 2, the total clear-day solar radiation on a south-facing, vertical surface in January at 40° north latitude (Philadelphia, Kansas City) is 1726 Btus per square foot. In Kansas City, the "mean (average) percentage of possible sunshine" in January is 50 percent. (See the U.S. sunshine map for January.) Approximately 82 percent of the sunshine that hits a layer of ordinary glass during the day actually gets through it. Therefore, the average total amount of solar radiation penetrating one layer of vertical, south-facing, double-strength glass in Kansas City during the month of January is approximately

(31 days per month) x (1726 Btus per square foot per day)
x (50 percent possible sunshine) x
(82 percent transmittance)
22,000 Btus per square foot per month.

Over the course of a normal heating season in a 50-percent-possible-sunshine climate, the total solar gain will be between 130,000 and 190,000 Btus per square foot. (A more accurate number may be obtained by doing the calculations on a month-by-month basis for each month of the heating season for a particular location, taking into account the heating needs of the particular house.)

If a second layer of clear glass is added to the first, about 82 percent of the light that penetrates the first layer will penetrate the second. Converting the first example, then, 18,000 Btus (0.82 x 22,000) are transmitted by double glass compared with 22,000 by single. But remember heat losses are reduced by 50 percent when you do this!

These monthly solar gains can be roughly compared with the monthly heating demands of the house to determine the percent of the heat supplied by the sun. When solar provides less than 40 percent of the heat, the above analysis is relatively accurate for preliminary design purposes. However, a more detailed and rigorous analysis is required when the solar windows are large enough to be supplying more than 40 percent of the heating load.

In cold climates, 300 square feet of direct gain will supply roughly half the heat for a well insulated, 1500 square foot house. Half as much area is needed in a mild climate.

Minimum heat loss. Keep heat losses back out through the glazing as low as is practical. Use several layers of glazing according to the material and climate. Cold climates also warrant movable insulation at night.

Control of glare and fading. Some people simply do not like working in direct sunlight. In fact, many people prefer the softer north light. Southern exposure means low fuel bills, but it also means window glare and squinting. Too much glass can also mean loss of privacy. Overhead light (such as from a skylight) is often a good compromise, offering solar gain with the least glare. In colder climates, however, this can mean added heat loss at night. Make sure the overhead glass is shaded during the summer!

Thermal Mass

The sun does not shine twenty-four hours a day, and thus, unlike a furnace, it is not waiting on call to supply us with heat whenever we need it. Therefore, when we depend on the sun for heat, we must do as nature does-store the sun's energy when it is shining for use when it is not. Nature stores the sun's energy a number of ways. Plants use photosynthesis during the day, and then they rest at night. Lakes become heated during the day and maintain relatively constant temperatures day and night. For hundreds of years people have been growing and harvesting food during the summer and storing it for use during the winter. Indians of the American Southwest have for centuries used thick adobe walls that act like big thermal sponges to soak up large amounts of sunlight. As their exterior surfaces warm up during the day, the heat slowly moves throughout the adobe, protecting the interior from overheating. At night, the walls cool off, allowing the adobe to soak up heat again the next day, thus keeping the houses cool.

In contrast, massive central masonry chimneys of New England colonial houses absorb any excess *interior* daytime warmth. The stored heat helps keep the houses warm well through the night.

When massive materials are located inside houses where the sun can strike them directly, they combine the

Rules of Thumb for Thermal Mass If sunlight strikes directly on the mass (such as a brick floor), each square foot of a window needs roughly 2 cubic feet of concrete, brick, or stone to prevent overheating and to provide heat at night. If sunlight does not strike the mass, but heats the air that in turn heats the mass, four times as much mass is required.

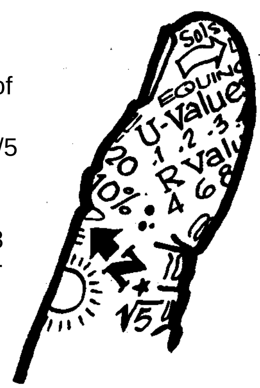
The ability of a material to store heat is rated by its "specific heat," meaning the number of Btus required to raise 1 pound of the material 1 deg F in temperature. Water, which is the standard by which other materials are rated, has a specific heat of 1.0, which means that 1 Btu is required to raise 1 pound of water 1°. The pound of water, in turn, releases 1 Btu when it drops 1°.

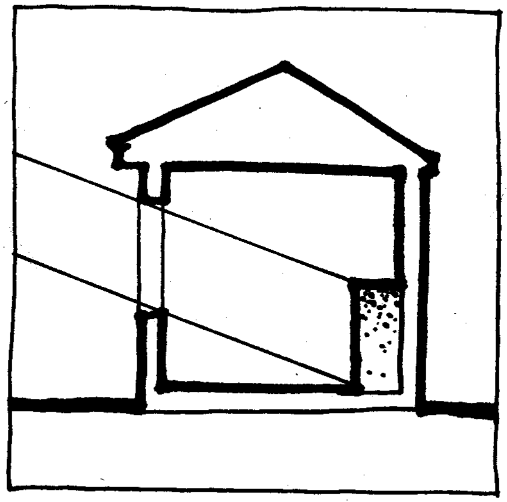
The specific heat of materials that might be considered for use in the construction of buildings are listed below. The second column of numbers in the table shows the densities of the materials in relation to each other. The material's heat capacity per cubic foot (listed in the third column) was obtained by multiplying its specific heat by its

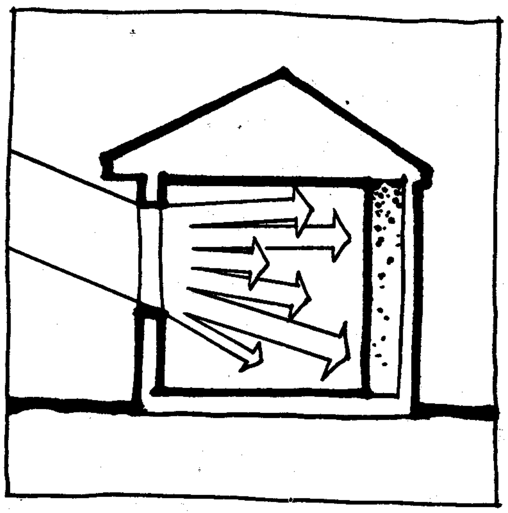
Specific Heats, Densities, and Heat Capacities of Common Materials

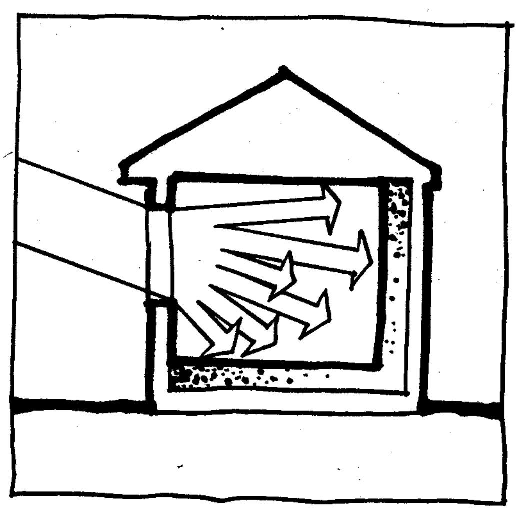
Material	*Specific Heat (Btus stored per pound per degree change of temperature)*	*Density (pounds per cubic foot)*	*Heat Capacity (Btus stored per cubic foot per degree change of temperature)*
Air (75°F)	0.24	0.075	0.018
Sand	0.191	94.6	18.1
White pine	0.67	27.0	18.1
Gypsum	0.26	78.0	20.3
Adobe	0.24	106.0	25.0
White Oak	0.57	47.0	26.8
Concrete	0.20	.140.0	28.0
Brick	0.20	140.0	28.0
Heavy stone	0.21	180.0	38.0
Water	1.00	62.5	62.5

density. Note that the density of water is least among the materials listed but that its heat capacity per cubic foot is still highest because of its high specific heat. The low specific heat of concrete (0.2, or 1/5 that of water) is partially compensated by its heavy weight and it stores considerable heat (28 Btus per cubic foot for concrete, or about one-half that of 62.5 for water). Except for water, the best readily available materials are concrete, brick, and stone.









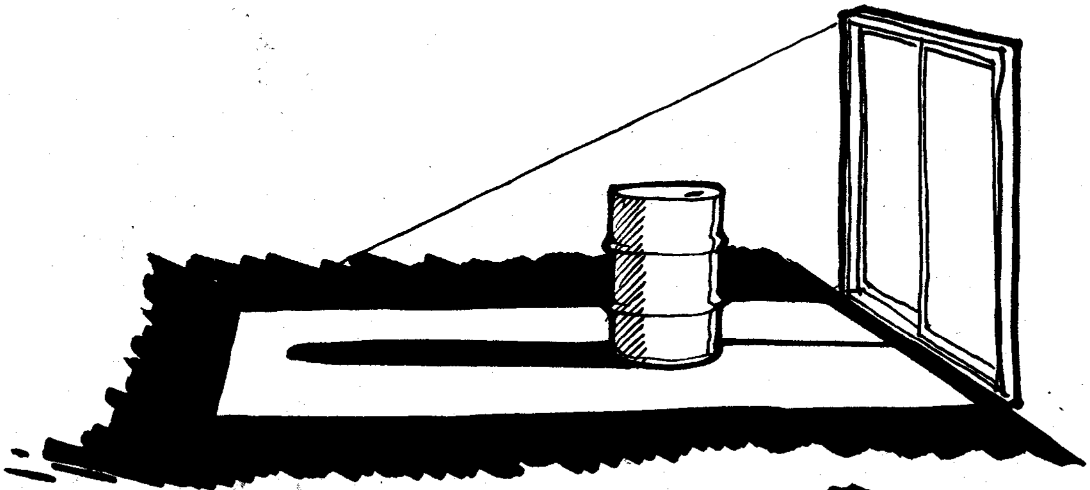
benefits of Southwest adobe and New England chimneys. The resulting "thermal mass" tempers the overheating effects of sunlight from large windows and absorbs excess energy for later use.

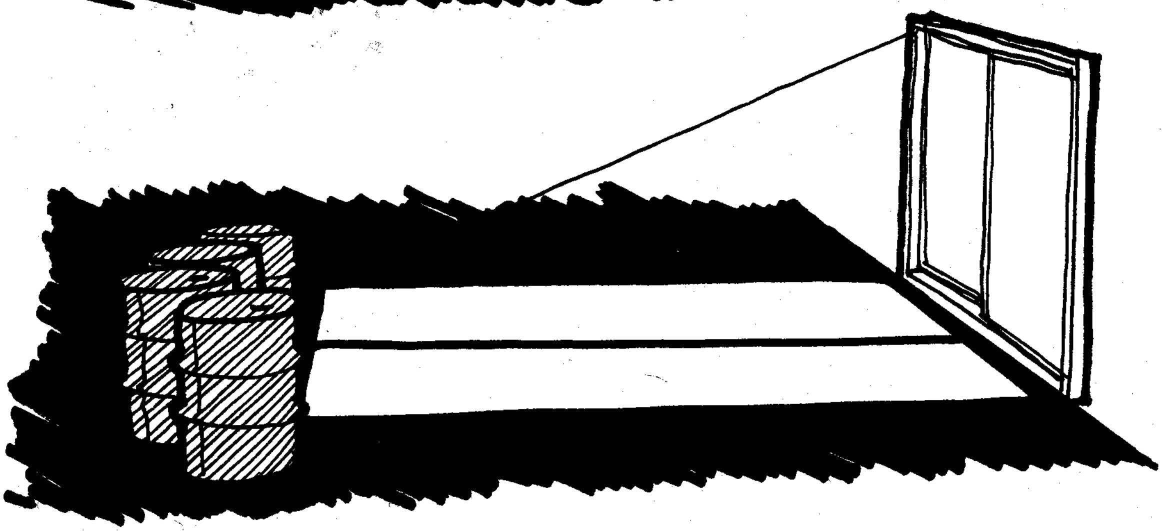
Generally, the more thermal mass the better. But if its *too* thick, heat may not get through. The more directly the sun strikes the mass, the less the house temperature will fluctuate. Unfortunately, thermal mass, such as brick walls, concrete floors, or water storage tubes, are often expensive and/or unsuitable to the homeowner. Thus, moderately-sized solar windows, which require limited amounts of thermal mass, are often the best solution. Solar walls and/or solar rooms can supplement the solar windows to achieve the lowest possible fuel bills and the highest possible levels of comfort.

An unheated, lightweight house, such as a wood-framed one, drops in temperature relatively quickly even if it is well-insulated. A heavy, massive, well-insulated structure built of concrete, brick, or stone maintains its temperature longer. To be most effective, the heavy materials should be on the inside of the insulating envelope of the house. When left unheated, a house that is well insulated and also buried into the side of a hill cools off very slowly and eventually reaches a temperature close to that of the soil. Although earth is a good means of sheltering your house from the extremes of weather, soil is a poor insulator and will draw heat out of the building endlessly if you don't insulate well.

If you prefer to close draperies to keep the sun out, or if you insist on wall-to-wall carpeting or big rugs, solar windows might not make sense for you. Alternatively, reconsider how you desire to furnish your house. The warmth of brick floors, walls, and fireplaces and the sensation of light and heat coming through windows can be exhilarating, possibly more so than wall-to-wall synthetic fabrics.

Clear glass allows the bright rays of the sun to shine directly on specific surfaces in the room, leaving others in shadow. Translucent glazing, on the other hand, diffuses light and distributes it more widely, assuring more even heat distribution to many interior surfaces at the same time. This results in more even temperatures and greater heat absorption and storage throughout.





The temperature swings of thermal mass placed in direct sunlight will be about twice the temperature swings of the room itself. Mass shaded from the sun inside the room (such as in north walls) will fluctuate in temperature about half as much as the room. Thus, solar radiated mass stores four times more energy than the shaded mass.

Too little heat storage will allow wide temperature swings and permit overheating, which in turn wastes heat

Concrete Floors

Concrete floors are commonly used for storing heat from solar windows. Consider this oversimplified case: A 20 by 40 foot house has a concrete floor 8 inches thick (530 cubic feet). By late afternoon the slab has been solar heated by 150 square feet of window to an average of 75°F. During the night, the outdoor temperature averages 25° and the indoor air averages 65°. A well-insulated house may lose heat at a rate of about 200 Btus per hour for each degree of temperature difference (called Delta T, or ΔT) between the outdoors and indoors. The temperature of the slab drops as it loses heat to the house.

The heat lost from the house is the product of the total heat loss rate, the time, and the average temperature difference between indoors and outdoors. In this case, the heat loss during the 15 hour winter night is

$$(15 \text{ hours}) \times (200 \text{ Btus per hour per °F}) \times (65°-25°) = 120{,}000 \text{ Btus.}$$

With a heat capacity of about 28 Btus per cubic foot per degree of temperature change, the 530 cubic foot concrete slab stores roughly 15,000 Btus for each degree rise in temperature. for each degree drop in temperature, the slab releases the same 15,000 Btus. If the floor drops 8 degrees, from 75°F to 67°F, it will release just enough heat, 120,000 Btus, to replace the heat lost by the house during the night.

When you calculate mass floor areas, realize that the mass must be left exposed in order to work. Although concrete floors perform well, even the best designed floors for solar exposure very often get covered or shaded by rugs or furniture.

due to greater heat loss from the house, (especially if you open windows to vent that extra heat). Conversely, more mass increases both comfort and the efficiency of the passive system.

The effectiveness of mass also depends on its thickness. The deeper parts of thick walls and floors are insulated by the surface layers and do not store as much heat. Therefore, 100 square feet of 8-inch-thick wall is more effective than SO square feet of 16-inch-thick wall, even though they both weigh the same.

Provide for thermal mass in the simplest way possible, otherwise it can be costly and can complicate construction. When used wisely, on-site locally available building materials (gravel, stone, etc.) can be the best kinds of thermal mass. Their use requires less energy than it takes to make and transport brick and concrete.

Movable Insulation

Glass loses heat up to 30 times faster than well-insulated walls, so the nighttime insulation of glass in winter climates is very important. So is the use of double glazing, which has only half the loss rate of single glass. If the double glazing faces south, it gains more heat than it loses during the winter, virtually anywhere in the country.

In climates of more than 5,000 degree days, the extra cost of triple glazing is usually justified by the energy savings. However, more than three-layered glass seldom is, since each layer of glass also blocks fifteen to twenty percent of the solar energy that passes through the preceding layer. Multilayered, non-glass glazing systems of high transmittance (up to 97 percent), such as Teflon™, can often use four or five layers effectively. The reason for this is that they are so clear that an additional layer

Energy Savings from Movable Insulation

To determine the annual energy savings using movable insulation, first find the difference between the U-value of the window as it is and the U-value of the window using movable insulation. Then multiply this difference times the number of degree days where you live times 24 hours per day.

For example, suppose that an insulating panel with a heat flow resistance of R-10 is being considered for windows in Minneapolis with two layers of glass. Assume that the insulation will be in place an average of 12 hours per day. The U-value of the glass is 0.55 Btus per square foot per hour per degree (from Appendix 4). The U-value for the insulated window system is 0.24. The difference between the two is 0.31 (0.55 minus 0.24). Minneapolis averages 8382 degree days per year (from Appendix 5). Therefore,

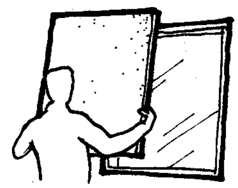
Annual energy savings
= (0.31 Btus per square foot per °F)
× (8382 degree days per year)
× (24 hours per day)
= 62,362 Btus per square foot per year

For a 10-square-foot window, the savings is roughly equivalent to the heating energy obtained from 180 kwh of electric resistance heating ($7–$12 at most electric rates), from 10 gallons of oil burned in most furnaces, or from 10 square feet of an active solar collector of average design. A tight-fitting shutter also reduces heat loss due to air leakage around the window frame, making the above savings a conservative estimate.

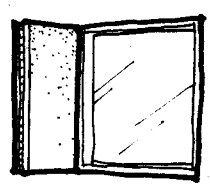
reduces heat loss significantly, yet blocks very little of the incoming sun. These thin plastics are not commonly used in home construction however, for existing homes, thin film plastics are frequently used in place of glass storm windows. Companies are developing products that will make thin filmed plastic windows easier to use for both new and existing homes.

But the most direct options for preventing unwanted heat loss through solar windows are:

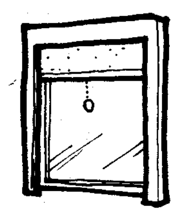
- sheets of rigid insulation manually inserted at night and removed in the morning



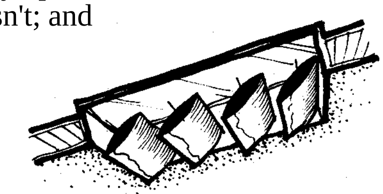
- framed and hinged insulation panels.



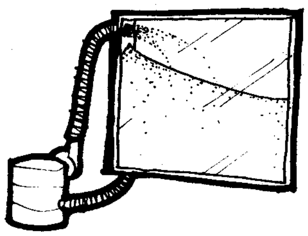
- roller-like shade devices of one or more sheets of aluminized Mylar, sometimes in combination with cloth and other materials.



- sun-powered louvers, such as Skylid™, which automatically open when the sun shines and close when it doesn't; and



- mechanically-powered systems, such as Bead wall™, which use blowers to fill the air space between two layers of glazing with insulating beads at night.



The insulating values of good movable insulating devices range in heat flow resistance from R-4 to R-10. During the day when the sun is shining, windows are net energy producers. But since outdoor temperatures are much lower at night, up to three quarters of a window's 24-hour heat loss can be prevented by the proper use of these devices.

A window loses heat to the out-of-doors in proportion to the temperature of the air space between the window and the insulation provided. A loose-fitting insulating shutter will allow room air into that space and diminish the insulating effect. Therefore, a snug fit and sealed edges are important.

A few cautioning words: Sun shining on an ordinary window covered on the inside by a tight insulating shade can create enough thermal stress to break the glass. A white or highly-reflective surface facing the glass is the best solution, but not foolproof. Also, moisture can condense at night on the cold window glass facing the insulation, causing deterioration of the wooden frames. Tight-fitting insulation is the best solution for preventing excessive condensation. Otherwise, provisions for collecting and draining the condensation may be necessary.

Also, remember to conform to all codes; don't use insulation materials that are flammable or in other ways hazardous without protecting them properly.