Part One: Introduction

1. **Introduction to the Passive Solar Design Strategies Package**

2. **Passive Solar Performance Potential in Cape Hatteras, North Carolina**

1. Introduction to the Passive Solar Design Strategies Package

The idea of passive solar is simple, but applying it effectively does require information and attention to the details of design and construction. Some passive solar techniques are modest and low-cost, and require only small changes in a builder's standard practice. At the other end of the spectrum, some passive solar systems can almost eliminate a house's need for purchased energy – but probably at a relatively high first cost.

In between are a broad range of energy-conserving passive solar techniques. Whether or not they are cost-effective, practical and attractive enough to offer a market advantage to any individual builder depends on very specific factors such as local costs, climate and market characteristics.

Passive Solar Design Strategies: Guidelines for Builders is written to help give builders the information they need to make these decisions.

Passive Solar Design Strategies is a package in two basic parts:

- The **Guidelines** booklet contains information about passive solar techniques and how they work, and provides specific examples of systems which will save various percentages of energy;
- The **Worksheets** offer a simple, fill-in-the-blank method to pre-evaluate the performance of a specific design.

The Guidelines Booklet

Some principles of passive solar design remain the same in every climate. But the important thing about passive solar is that it makes better use of the opportunities in a house's surroundings. So, many fundamental aspects of the passive solar house's design will depend on the conditions in a small local area, and even on the features of the building site itself. Many of the suggestions in this booklet apply specifically to Cape Hatteras, North Carolina, but there is also information in each section of the booklet which will be useful in any climate.

Part One of the Guidelines booklet introduces *Passive Solar Design Strategies*, and presents the performance potential of several different passive solar systems in the Cape Hatteras climate. Although in practice many factors will affect actual energy performance, this information will give you a general idea of how various systems will perform in your area.

Part Two of the booklet discusses the basic concepts of passive solar design and construction: what the advantages of passive solar are, how passive solar relates to other kinds of energy conservation measures, how the primary passive solar systems work, and what the builder's most important considerations should be when evaluating and using different passive solar strategies.

Part Three gives more specific advice about techniques for suntempering, direct gain systems, thermal storage mass walls and sunspaces, and for natural cooling strategies to help offset air-conditioning needs.

Included in this section of the Guidelines booklet are tables showing how a typical, reasonably energy-efficient house can be changed to need from 20-60% less energy. The Base Case house is compared with a series of Example cases to illustrate exactly how these increased levels of energy-efficiency might be achieved.

The Base Case House is a reasonably energy-efficient house based on a 1987 National Association of Home Builders study of housing characteristics, divided into seven different regions. The Base Case used for Cape Hatteras, North Carolina is from the 2,500-3,500 heating degree days region.

The examples show how to achieve 20, 40 and 60% energy-use reductions using three basic strategies:

- **Added Insulation**: increasing insulation levels without adding solar features.
- **Suntempering**: increasing south-facing glazing to a maximum of 7% of the house's total floor area, but without adding thermal mass (energy storage) beyond what is already in the framing, standard floor coverings and gypsum wall-board and ceiling surfaces. Insulation levels are also increased.
- **Passive Solar**: using three different design approaches: Direct Gain, Sunspace, and Thermal Storage Wall, and increased levels of insulation.

For all strategies, the energy savings indicated are based on the assumption that the guidelines in this booklet about energy-efficient design and construction have been followed, so the houses are properly sited and tightly built with high-quality windows and doors.

The Guidelines booklet has been kept as brief and straightforward as possible, but more detailed information is available if needed. Some references are indicated in the text, and a list of other information sources can be found in the References. Also included at the end of this booklet are a brief glossary, a summary of the Example tables for Cape Hatteras, North Carolina, and a page explaining some of the background and assumptions behind the Guidelines and Worksheets.

The Worksheets

The Worksheets are specifically tailored for Cape Hatteras, North Carolina, and are a very important part of this package because they allow you to compare on paper different passive solar strategies or combinations of strategies, and the effect that changes will have on the overall performance of the house.

The most effective way to use the Worksheets is to make multiple copies before you fill them out the first time. You can then use the Worksheets to calculate several different designs. For instance, you could first calculate the performance of the basic house you build now, then fill out Worksheets for that house plus added insulation plus a sunspace, and then for a third possibility such as a Thermal Storage Wall.

The Worksheets provide a way to calculate quickly and with reasonable accuracy how well a design is likely to perform in four key ways: how well it will conserve heat energy; how much the solar features will contribute to its total heating energy needs; how comfortable the house will be; and how much the house's annual cooling load (need for air conditioning) will be.

The Worksheets are supported by "look-up" tables containing pre-calculated factors and numbers for the local area. Some of the blanks in the Worksheets call for information about the house — for example, floor area, projected area of passive solar glazing, and so forth. Other blanks require a number from one of the tables — for example, from the Solar System Savings Fraction table or from the Heat Gain Factor table.

The Worksheets allow calculation of the following performance indicators:

- **Worksheet I: Conservation Performance Level**: determines how well the house's basic energy conservation measures (insulation, sealing, caulking, etc.) are working to prevent unwanted heat loss in the winter. The bottom line of this Worksheet is a number measuring heat loss in British thermal units per square foot per year (Btu/sf-yr) — the lower the heat loss, the better.
- **Worksheet II: Auxiliary Heat Performance Level**: determines how much heat has to be supplied (that is, provided by the heating system) after taking into account the heat contributed by passive solar. This worksheet arrives at a number estimating the amount of heating energy the house's non-solar heating system has to provide in Btu/yr-sf. Again, the lower, the better.
- **Worksheet III: Thermal Mass/Comfort**: determines whether the house has adequate thermal mass to assure comfort and good thermal performance. Worksheet III calculates the number of degrees the temperature inside the house is likely to vary, or "swing", during a sunny winter day without the heating system operating. A well-designed house should have a temperature swing of no more than 13 degrees, and the less the better.
- **Worksheet IV: Summer Cooling Performance Level**: indicates how much air conditioning the house will need in the summer (it is not, however, intended for use in sizing equipment, but as an indication of the reductions in annual cooling load made possible by the use of natural cooling). The natural cooling guidelines in this booklet should make the house's total cooling load — the bottom line of this Worksheet, in Btu/yr-sf — smaller than in a "conventional" house.

So, the Worksheets provide you with four key numbers indicating the projected performance of the various designs you are evaluating.

The Example Tables in Part Three are also related to Worksheet numbers, so that you can compare them to the designs you are evaluating. For example, the Passive Solar Sunspace Example Case which uses 40% less energy than the Base Case House (page 29) has:

- a Conservation Performance Level of approximately 21,009 Btu/yr-sf,
- an Auxiliary Heat Performance Level of approximately 13,448 Btu/yr-sf, and
- a Summer Cooling Performance Level of 10,500 Btu/yr-sf.

(In this example, the energy savings are achieved by no increase in insulation over the Base Case, adding a sunspace with south glazing area equal to 10.6% of the house's floor area, and using a ceiling fan to cut some of the air conditioning load.)

2. Passive Solar Performance Potential

The energy performance of passive solar strategies varies significantly, depending on climate, the specific design of the system, and the way it is built and operated. Of course, energy performance is not the only consideration. A system which will give excellent energy performance may not be as marketable in your area or as easily adaptable to your designs as a system which saves less energy but fits your other needs.

In the following table, several different passive solar systems are presented along with two numbers which indicate their performance. The **Percent Solar Savings** is a measure of how much the passive solar system is reducing the house's need for purchased energy. For example, the Percent Solar Savings for the Base Case is 9.6%, because even in a non-solar house, the south-facing windows are contributing some heat energy.

The **Yield** is the annual net heating energy benefit of adding the passive solar system, measured in Btu saved per year per square foot of additional south glazing.

The figures given are for a 1,500 sf, single-story house with a floor over a crawlspace. The Base Case has 45 sf of south-facing glazing. For the purposes of this example, the Suntempered has 100 sf of south-facing glass, and each passive solar system has 145 sf.

The energy savings presented in this example assume that all the systems are designed and built according to the suggestions in this booklet. It's also important to remember that the figures below are for annual net *heating* benefits. The natural cooling section in Part Three gives advice about shading and other techniques which would make sure the winter heating benefits are not at the expense of higher summer cooling loads.

Please note that throughout the Guidelines and Worksheets the glazing areas given are for the actual *net* area of the glass itself. A common rule of thumb is that the net glass area is 80 percent of the rough frame opening. For example, if a south glass area of 100 sf is desired, the required area of the rough frame opening would be about 125 sf.

Performance Potential of Passive Solar Strategies in Cape Hatteras, North Carolina

1,500 sf, Single Story House

Case	Percent Solar Savings	Yield Btu Saved per Square Foot of South Glass
Base Case (45 sf of south-facing double glass)	9.6	not applicable
Suntempered (100 sf of south-facing double glass)	18.1	49,722
Direct Gain (145 sf of south glass)		
Double Glass	24.0	47,051
Triple or low-e glass	25.5	54,803
Double glass with R-4 night insulation[1]	28.0	65,007
Double glass with R-9 night insulation[1]	28.9	68,440
Sunspace (145 sf of south glass)		
Attached with opaque end walls[2]	23.4	48,877
Attached with glazed end walls[2]	22.7	46,125
Semi-enclosed with vertical glazing[3]	24.7	51,233
Semi-enclosed with 50° sloped glazing[3]	29.8	71,488
Thermal Storage Wall — Masonry/Concrete (145 sf of south glass)		
Black surface, double glazing	22.8	45,553
Selective surface, single glazing	29.1	69,498
Selective surface, double glazing	28.3	66,975
Thermal Storage Wall — Water Wall (145 sf of south glass)		
Selective surface, single glazing	33.1	83,655

1. Night insulation is assumed to cover the south glass each night and removed when sun is available. Experience has shown that many homeowners find this inconvenient and so the potential energy savings are often not achieved. Using low-e or other energy-efficient glazing is more reliable.

2. The attached sunspace is assumed to have, in addition to glazed walls, roof glazing at a slope of 30 degrees from the horizontal, or a 7:12 pitch. (See diagram SSB1 in the Worksheets.)

3. The semi-enclosed sunspace has only the south wall exposed to the out-of-doors. The glazing has a slope of 50° from the horizontal, or a 14:12 pitch. The side walls are adjacent to conditioned space in the house. (See diagram SSD1 in the Worksheets.)

Part Two: Basics of Passive Solar

1. **Why Passive Solar? More Than A Question of Energy**
2. **Key Concepts: Energy Conservation, Suntempering, Passive Solar**
3. **Improving Conservation Performance**
4. **Mechanical Systems**
5. **South Glass**
6. **Thermal Mass**
7. **Orientation**
8. **Site Planning for Solar Access**
9. **Interior Space Planning**
10. **Putting It Together: The House As A System**

1. Why Passive Solar? More than a Question of Energy

Houses today are more energy-efficient than ever before. However, the vast majority of new houses still ignore a lot of energy saving opportunities – opportunities available in the sunlight falling on the house, in the landscaping, breezes and other natural elements of the site, and opportunities in the structure and materials of the house itself, which, with thoughtful design, could be used to collect and use free energy. Passive solar (the name distinguishes it from "active" or mechanical solar technologies) is simply a way to take maximum advantage of these opportunities.

Home buyers are also increasingly sophisticated about energy issues, although the average home buyer is probably much more familiar with insulation than with passive solar. The "energy crisis" may be temporarily over, but very few people perceive their own household energy bills as getting smaller – quite the opposite. So a house with significantly lower monthly energy costs year-round will have a strong market advantage over a comparable house down the street, no matter what international oil prices may be.

But there are many different ways to reduce energy bills, and some are more marketable than others. For instance, adding insulation can markedly improve energy-efficiency – but added insulation is invisible to the prospective home buyer. A sunny, open living area lit by south-facing windows, on the other hand, may be a key selling point. Windows in general are popular with homebuyers, and passive solar can make windows energy *producers* instead of energy liabilities.

Another example: high-efficiency heating equipment can account for significant energy savings – but it won't be as much fun on a winter morning as breakfast in a bright, attractive sunspace.

The point is not that a builder should choose passive solar *instead* of other energy-conserving measures. The important thing is that passive solar can *add* not only energy-efficiency, but also very saleable amenities – style, comfort, attractive interiors, curb appeal and resale value.

In fact, in some local markets, builders report that they don't even make specific reference to "passive solar". They just present their houses as the state of the art in energy-efficiency and style, and they use passive solar as a part of the package

The U. S. Department of Energy and the Solar Energy Research Institute (SERI) conducted extensive national surveys of passive solar homes, home owners and potential buyers. Some key findings:

- **passive solar homes work** – they generally require an average of about 30% less energy for heating than "conventional" houses, with some houses saving much more.
- **occupants of passive solar homes are pleased** with the performance of their homes (over 90% "very satisfied"), but they rank the comfort and pleasant living environment as just as important (in some regions, more important) to their satisfaction, and in their decision to buy the house, as energy considerations.
- both passive solar **home owners and lenders perceive the resale value of passive solar houses as high**.

Advantages of Passive Solar

- **Energy performance**: Lower energy bills all year-round
- **Attractive living environment**: large windows and views, sunny interiors, open floor plans
- **Comfort**: quiet (no operating noise), solid construction, warmer in winter, cooler in summer (even during a power failure)
- **Value**: high owner satisfaction, high resale value
- **Low Maintenance**: durable, nothing to operate or repair
- **Investment**: independent of future rises in fuel costs, will continue to save money long after any initial costs have been recovered.

2. Key Concepts: Energy Conservation, Suntempering, Passive Solar

The strategies for enhancing energy performance which are presented here fall into three general categories:

- **Energy Conservation**: insulation levels, control of air infiltration, glazing type and location and mechanical equipment.
- **Suntempering**: a limited use of passive solar techniques; modestly increasing south-facing window area, usually by relocating windows from other sides of the house, but without adding thermal mass.
- **Passive Solar**: going beyond conservation and suntempering to a complete system of collection, storage and use of solar energy: using more south glass, adding significant thermal mass, and taking steps to control and distribute heat energy throughout the house.

What is immediately clear is that these categories overlap. For instance, a good energy-conservation package is the necessary starting point of *all* well-designed suntempered and passive solar houses. There's no use collecting solar energy if it is immediately lost through leaky windows or poorly insulated walls.

In the same way, many of the measures that are often considered part of suntempering or passive solar – such as orienting to take advantage of summer breezes, or landscaping for natural cooling, or facing a long wall of the house south – can help a house conserve energy even if no "solar" features are planned.

The essential elements in a passive solar house are **south-facing glass** and **thermal mass**.

In the simplest terms, a passive solar system collects solar energy through south-facing glass and stores solar energy in thermal mass – materials with a high capacity for storing heat (e.g., brick, concrete masonry, concrete slab, tile, water). The more south-facing glass is used in the house, the more thermal mass must be provided, or the house will overheat and the solar system will not perform as expected.

With too much glass and/or insufficient mass, solar energy can work *too* well, and the house can be uncomfortably hot even on a winter day.

Although the concept is simple, in practice the relationship between the amount of glazing and the amount of mass is complicated by many factors, and has been a subject of considerable study and experiment. From a comfort and energy standpoint, it would be difficult to add too much mass. Thermal mass will hold warmth longer in winter and keep houses cooler in summer. But thermal mass has a cost, and so adding too much can be unnecessarily expensive.

The following sections of the Guidelines booklet discuss the size and location of glass and mass, as well as other considerations which are basic to both suntempered and full passive solar houses: improving conservation performance; mechanical systems; orientation; site planning for solar access; interior space planning; and taking an integrated approach to the house as a total system.

3. Improving Conservation Performance

The techniques described in this section relate to **Worksheet I: Conservation Performance Level**, which measures the house's heat loss. The energy conservation measures that reduce heat loss also tend to reduce the house's need for air conditioning.

The most important measures for improving the house's basic ability to conserve the heat generated either by the sun or by the house's conventional heating system are in the following areas:

- **Insulation**
- **Air infiltration**
- **Non-solar glazing**

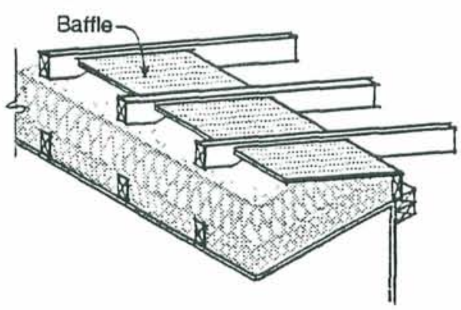
Insulation

Adding insulation to walls, floors, ceilings, roof and foundation improves their thermal resistance (R-value) – their resistance to heat flowing out of the house.

A quality job of *installation* of the insulation can have almost as much effect on energy performance as the R-value, so careful construction supervision is important. An inspection just before the drywall is hung can enable the builder or site supervisor to make improvements which are easy at that time but will make a big difference in the energy use of the home for years to come.

The thermal resistance of **ceiling/roof assemblies, walls and floors** is affected not only by the R-value of the insulation itself, but also the resistance of other elements in the construction assembly – framing effects, sheathing, interior drywall, and so on. The Worksheets include tables that show Equivalent Construction R-Values which account for these and other effects. For instance, ventilated crawlspaces and unheated basements provide a buffering effect which is accounted for in the Worksheet tables.

With attics, framing effects are minimized if the insulation covers the ceiling trusses, either by using blown-in insulation or by running an additional layer of batts in the opposite direction of the ceiling joists. Ridge and/or eave vents are needed for ventilation.



Insulation in an Attic
Insulation should extend over the top ceiling joists and ventilation should be provided at the eaves.

In framed ceiling/roof assemblies, an insulating sheathing over the top decking will increase the R-value.

Slab edge insulation should be at least two feet deep, extending from the surface of the floor. Materials for slab edge insulation should be selected for underground durability. One material with a proven track record is extruded polystyrene. Exposed insulation should be protected from physical damage by attaching a protection board, for instance, or by covering the insulation with a factory-applied protective surface.

Heated basement walls should be fully insulated to at least four feet below grade, but the portion of the wall below that depth only needs to be insulated to about half the R-value of the upper portion. Insulation can be placed on the outside surface of the wall, or on the inside surface of the wall, or in the cores of the masonry units.

If the basement walls are insulated on the outside, the materials should be durable underground, and exposed insulation should be protected from damage. In the case of a finished basement or walk-out basement, placing insulation on the interior may be less costly than insulating the exterior foundation.

Air Infiltration

Sealing the house carefully to reduce air infiltration – air leakage – is as necessary to energy conservation as adding insulation. Air will flow rapidly through cracks and crevices in the wall, in the same way water flows through the drain in a bathtub, so even a small opening can bypass the insulation and lead to big energy losses.

The tightness of houses is generally measured in the number of air changes per hour (ACH). A good, comfortable, energy-efficient house, built along the guidelines in the table on this page, will have approximately 0.35 to 0.50 air changes per hour under normal winter conditions.

Increasing the tightness of the house beyond that may improve the energy performance, but it may also create problems with indoor air quality, moisture build-up, and adequately venting fireplaces and furnaces.

The use of house sealing subcontractors to do the tightening and check it with a blower door can often save the builder time and problems, especially when trying to achieve particularly high levels of infiltration control.

Checklist for Minimizing Air Leakage

- ✓ Tighten seals around windows and doors, and weatherstripping around all openings to the outside or to unconditioned rooms;
- ✓ Caulk around all windows and doors before drywall is hung; seal all penetrations (plumbing, electrical, etc.);
- ✓ Insulate behind wall outlets and/or plumbing lines in exterior walls;
- ✓ Caulk under headers and sills;
- ✓ Chink spaces between rough openings and millwork with insulation, or for a better seal, fill with foam;
- ✓ Seal larger openings such as ducts into attics or crawlspaces with taped polyethylene covered with insulation;
- ✓ Locate continuous vapor retardants located on the warm side of the insulation (building wrap, continuous interior polyethylene, etc.);
- ✓ Install dampers and/or glass doors on fireplaces; outside combustion air intake;
- ✓ Install backdraft dampers on all exhaust fan openings;
- ✓ Caulk and seal the basement slab joint with the basement wall;
- ✓ Remove wood grade stakes from slabs and seal;
- ✓ Cover and seal sump cracks;
- ✓ Close core voids in top of block foundation walls;
- ✓ Control concrete and masonry cracking;
- ✓ Use of air tight drywall methods are also acceptable (see Reference 11);
- ✓ Employ appropriate radon mitigation techniques (see Reference 12).

Non-South Glazing

South-facing windows are considered solar glazing. The south windows in *any* house are contributing some solar heat energy to the house's heating needs – whether it's a significant, usable amount or hardly worth measuring will depend on design, location and other factors which are dealt with later in the booklet, under the discussions of suntempering and passive solar systems.

North windows in almost every climate lose significant heat energy and gain very little useful sunlight in the winter. East and west windows are likely to increase air conditioning needs unless these problems are minimized with careful attention to shading.

But most of the reasons people want windows have very little to do with energy, so the best design will probably be a good working compromise between efficiency and other benefits.

Double-glazing of all non-solar glazing is advisable. Low-e glazing on all non-solar windows may be an especially useful solution because some low-e coatings can insulate in winter and shield against unwanted heat gain in summer.

Manufacturers will provide actual R-values for their windows (the thermal performance of glazing can be expressed either as an R-value or its reciprocal, U-value; in this booklet all thermal performance values are given in terms of R-value). A chart is also provided with the Worksheets to show approximate window R-values for various types. (the Equivalent Glazing R-Value pertains to the entire rough frame opening of the window.)

North windows should be used with care. Sometimes views or the diffuse northern light are desirable, but in general north-facing windows should not be large. Very large north-facing windows should have high insulation value, or R-value. Since north windows receive relatively little direct sun in summer, they do not present much of a shading problem. So if the choice were between an average-sized north-facing window and an east or west-facing window, north would actually be a better choice, considering both summer and winter performance.

East windows catch the morning sun. Not enough to provide significant energy, but, unfortunately, usually enough to cause potential overheating problems in summer. If the views or other elements in the house's design dictate east windows, shading should be done with particular care.

West windows may be the most problematical, and there are few shading systems that will be effective enough to offset the potential for overheating from a large west-facing window. Glass with a low shading coefficient may be one effective approach – for example, tinted glass or some types of low-e glass which provide some shading while allowing almost clear views. The cost of properly shading both east and west windows should be balanced against the benefits.

As many windows as possible should be kept operable, to provide for easy natural ventilation in summer. (See also Orientation, page 16, non-south window size recommendations, page 34, and Shading, page 35)

4. Mechanical Systems

The passive solar features in the house and the mechanical heating and cooling systems (HVAC) will interact all year round and so the most effective approach will be to design the system as an integrated whole. HVAC design is, of course, a complex subject, but the three areas below are particularly worth noting in passive solar houses:

- **System Sizing.** Mechanical systems are often oversized for the relatively low heating loads in well-insulated passive solar houses. Oversized systems will cost more in the first place, and will cycle on and off more often, wasting energy. The back-up systems in passive solar houses should be sized to provide 100% of the heating or cooling load on the design day, *but no larger.* Comparing estimates on system sizes from more than one contractor is probably a good idea.
- **Night Setback.** Clock thermostats for automatic night setback are usually very effective – but in passive solar systems with large amounts of thermal mass (and thus a large capacity for storing energy and releasing it during the night), night setback of the thermostat may not save very much energy.
- **Ducts.** One area often neglected but of key importance to the house's energy performance is the design and location of the ducts. Both the supply and return ducts should be located within insulated areas, or well insulated if they run in cold areas of the house, and well sealed at the joints. The joints where the ducts turn up into exterior walls or penetrate the ceiling should be caulked and particularly tight.

In the National Association of Home Builders' Energy-Efficient House Project, all the rooms were fed with low, central air supplies, as opposed to the usual placement of registers under windows at the end of long runs. This resulted in good comfort and energy performance.

The performance of even the most beautifully designed passive solar house can easily be undermined by details like uninsulated ducts, or by overlooking other basic energy conservation measures.

5. South-Facing Glass

South-facing solar glass is a key component of any passive solar system. The system must include enough solar glazing for good performance in winter, but not so much that cooling performance in summer will be compromised. The amount of solar glazing must also be carefully related to the amount of thermal mass. Suntempered houses require no additional thermal mass beyond that already in the wallboard, framing and furnishings of a typical house. *Passive solar houses must have additional thermal mass.*

There are three types of limits on the amount of south-facing glass that can be used effectively in a house. The first is a limit on the amount of glazing for suntempered houses. This limit (without adding thermal mass) is 7% of the house's total floor area.

For direct gain systems in passive solar houses, the maximum amount of south-facing glazing is 12% of total floor area, regardless of how much additional thermal mass is provided. Further details about the most effective sizing of south glass and thermal mass for direct gain systems are provided in Part Three.

The third limit on south-facing glass is the total of all passive solar systems combined, which should not exceed 12% of total floor area. Using more south glass than this limit could lead to overheating even in winter.

For example, a passive solar system for a 1,500 sf house might combine 150 sf of direct gain glazing with 120 sf of sunspace glazing for a total of 270 sf of solar glazing, or 18% of the total floor area, well within the direct gain limit of 12% and the overall limit of 12%. For a design like this, thermal mass would be required both in the house and within the sunspace.

The Natural Cooling guidelines in Part Three include recommendations on the window area that should be operable to allow for natural ventilation.

When the solar glazing is tilted, its winter effectiveness as a solar collector usually increases. However, tilted glazing can cause serious overheating in the summer if it is not shaded very carefully. Ordinary vertical glazing is easier to shade, less likely to overheat, less susceptible to damage and leaking, and so is almost always a better year-round solution.

6. Thermal Mass

Some heat storage capacity, or thermal mass, is present in all houses, in the framing, gypsum wall and ceiling board, typical furnishings and floor coverings. In suntempered houses, this modest amount of mass is sufficient for the modest amount of south-facing glass. But more thermal mass is required in passive solar houses, and the question is not only how much, but what kind and where it should be located.

The thermal mass in a passive solar system is usually a conventional construction material such as brick, cast concrete, concrete masonry, concrete slabs, or tile, and is usually placed in the floor or interior walls. Other materials can also be used for thermal mass, such as "phase change" materials, which store and release heat through a chemical reaction. Water actually has a higher unit thermal storage capacity than concrete or masonry. Water tubes and units called "water walls" are commercially available (general recommendations for these systems are included in the section on Thermal Storage Wall systems).

The thermal storage capabilities of a given material depend on the material's conductivity, specific heat and density. Most of the concrete and masonry materials typically used in passive solar have similar specific heats. Conductivity increases with increasing density. So the major factor affecting performance is density. The higher the density the better.

The design issues related to thermal mass depend on the passive system type. For sunspaces and thermal storage wall systems, the required mass of the system is included in the design itself. For direct gain, the added mass must be within the rooms receiving the sunlight. The sections on Direct Gain systems, Sunspaces and Thermal Storage Walls contain more information on techniques for sizing and locating thermal mass in those systems.

Heat Storage Properties of Materials

Material	Density (lb/ft^3)	Heat Capacity (Btu/in-sf-°F)
Poured Concrete	120 - 150	2.0 - 2.5
Clay Masonry		
Molded Brick	120 - 130	2.0 - 2.2
Extruded Brick	125 - 135	2.1 - 2.3
Pavers	130 - 135	2.2 - 2.3
Concrete Masonry		
Block	80 - 140	1.3 - 2.3
Brick	115 - 140	1.9 - 2.3
Pavers	130 - 150	2.2 - 2.5
Gypsum Wallboard	50	0.83

Provided courtesy of the National Concrete Masonry Association

7. Orientation

The *ideal* orientation for solar glazing is within 5 degrees of true south. This orientation will provide maximum performance. Glazing oriented to within 15 degrees of true south will perform almost as well, and orientations up to 30 degrees off – although less effective – will still provide a substantial level of solar contribution.

In Cape Hatteras, magnetic north as indicated on the compass is actually 6 degrees west of true north, and this should be corrected for when planning for orientation of south glazing.

When glazing is oriented more than 15 degrees off true south, not only is winter solar performance reduced, but summer air conditioning loads also significantly increase, especially as the orientation goes west. The warmer the climate, the more east- and west-facing glass will tend to cause overheating problems. In general, southeast orientations present less of a problem than southwest.

In the ideal situation, the house should be oriented east-west and so have its longest wall facing south. But as a practical matter, if the house's short side has good southern exposure it will usually accommodate sufficient glazing for an effective passive solar system, provided the heat can be transferred to the northern zones of the house.

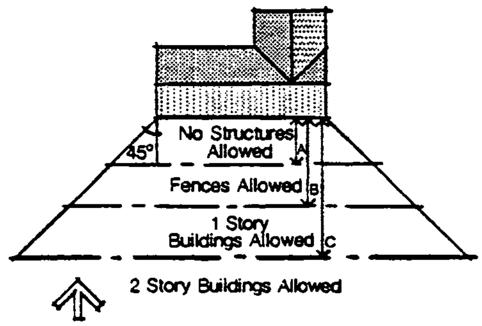
8. Site Planning for Solar Access

The basic objective of site planning for maximum energy performance is to allow the south side as much unshaded exposure as possible during the winter months.

As discussed above, a good solar orientation is possible within a relatively large southern arc, so the flexibility exists to achieve a workable balance between energy performance and other important factors such as the slope of the site, the individual house plan, the direction of prevailing breezes for summer cooling, the views, the street lay-out, and so on.

But planning for solar access does place some restrictions even on an individual site, and presents even more challenges when planning a complete subdivision. Over the years, developers and builders of many different kinds of projects all over the country have come up with flexible ways to provide adequate solar access.

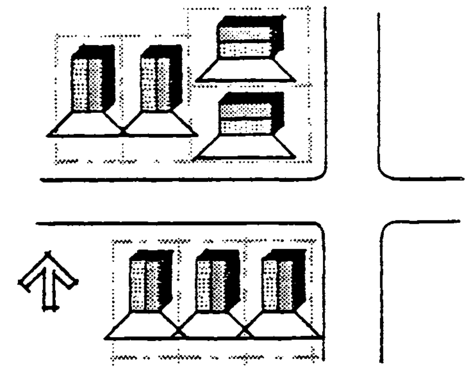
Once again, there is an ideal situation and then some degree of flexibility to address practical concerns. Ideally, the glazing on the house should be exposed to sunlight with no obstructions within an arc of 60 degrees on either side of true south, but reasonably good solar access will still be guaranteed if the glazing is unshaded within an arc of 45 degrees. The figure on this page shows the optimum situation for providing unshaded southern exposure during the winter. See also the figure on page 35 showing landscaping for summer shade.



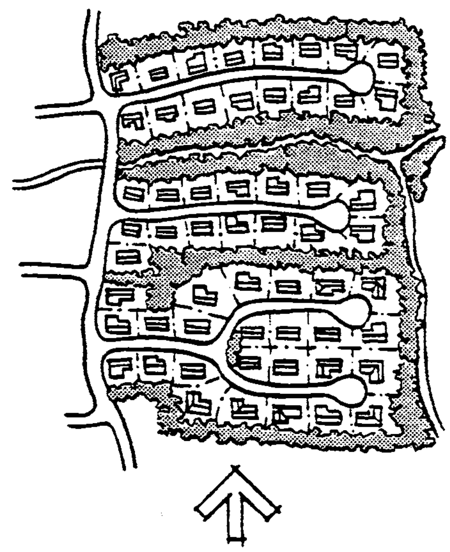
Ideal Solar Access
Buildings, trees or other obstructions should not be located so as to shade the south wall of solar buildings. At this latitude, A = 10 ft., B = 18 ft., and C = 42 ft.

Of course, not all lots are large enough to accommodate this kind of optimum solar access, so it's important to carefully assess shading patterns on smaller lots to make the best compromise.

Protecting solar access is easiest in subdivisions with streets that run within 25 degrees of east-west, because all lots will either face or back up to south. Where the streets run north- south, creation of east-west cul-de-sacs will help ensure solar access.



Solar Subdivision Layouts
Solar access may be provided to the rear yard, the side yard or the front yard of solar homes.



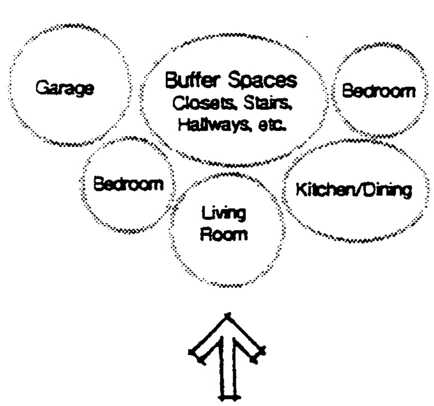
Solar Subdivision Layouts
Short east-west cul-de-sacs tied into north-south collectors is a good street pattern for solar access.

Two excellent references for ideas about subdivision lay-out to protect solar access are *Builder's Guide to Passive Solar Home Design and Land Development* and *Site Planning for Solar Access*. (See References 15 and 16)

9. Interior Space Planning

Planning room lay-out by considering how the rooms will be used in different seasons, and at different times of day, can save energy and increase comfort. In houses with passive solar features, the lay-out of rooms – and interior zones which may include more than one room – is particularly important.

In general, living areas and other high-activity rooms should be located on the south side to benefit from the solar heat. The closets, storage areas, garage and other less-used rooms can act as buffers along the north side, but entry-ways should be located away from the wind. Clustering baths, kitchens and laundry-rooms near the water heater will save the heat that would be lost from longer water lines.



Interior Space Planning
Living and high activity spaces should be located on the south.

Another general principle is that an open floor plan will allow the collected solar heat to circulate freely through natural convection.

Other ideas from effective passive solar houses:

- Orienting internal mass walls as north-south partitions that can be "charged" on both sides thus making maximum use of the mass.
- Using an east-west partition wall for thermal mass, but make sure the interior space isn't divided into a south zone which may get too warm and a north zone which may get too cold.
- Using thermal storage walls (see page 30); the walls store energy all day and slowly release it at night, and can be a good alternative to ensure privacy and to buffer noise when the south side faces the street;
- Collecting the solar energy in one zone of the house and transporting it to another by fans or natural convection through an open floor plan.
- Providing south-facing clerestories to "charge" north zones.

10. Putting it Together: The House as a System

Many different factors will affect a house's overall performance, and these factors all interact: the mechanical system, the insulation, the house's tightness, the effects of the passive solar features, the appliances, and, very importantly, the actions of the people who live in the house. In each of these areas, changes are possible which would improve the house's energy performance. Some energy savings are relatively easy to get. Others can be more expensive and more difficult to achieve, but may provide benefits over and above good energy performance.

A sensible energy-efficient house uses a combination of techniques.

In fact, probably the most important thing to remember about designing for energy performance in a way that will also enhance the comfort and value of the house is to take an integrated approach, keeping in mind the house as a total system. On the the following page is a basic checklist for energy-efficient design. These techniques are dealt with in more detail, including their impact in your location, in Part Three.

Checklist for Good Design

✓ **1. Building Orientation:** A number of innovative techniques can be used for obtaining good solar access on less-than-ideal sites (see References 15 and 16). No matter what the house's design, and no matter what the site, some options for orientation will be more energy-efficient than others, and even a very simple review of the site will probably help you choose the best option available.

✓ **2. Upgraded levels of insulation:** It is possible, of course, to achieve very high energy-efficiency with a "superinsulated" design. But in many cases, one advantage of passive solar design is that energy-efficiency can be achieved with more modest increases in insulation.

On the other hand, if very high energy performance is a priority — for example, in areas where the cost of fuel is high — the most cost-effective way to achieve it is generally through a combination of high levels of insulation and passive solar features.

✓ **3. Reduced air infiltration:** Air tightness is not only critical to energy performance, but it also makes the house more comfortable.

Indoor air quality is an important issue, and too complex for a complete discussion here, but in general, the suntempered and passive solar houses built along the guidelines in this booklet provide an alternative approach to achieving improved energy efficiency without requiring air quality controls such as air to air heat exchangers, which would be needed if the house were made extremely airtight.

✓ **4. Proper window sizing and location:** Even if the total amount of glazing is not changed, rearranging the location alone can often lead to significant energy savings at little or no added cost. Some energy-conserving designs minimize window area on all sides of the house — but it's a fact of human nature that people like windows, and windows can be energy producers if located correctly.

✓ **5. Selection of glazing:** Low-emissivity (low-e) glazing types went from revolutionary to commonplace in a very short time, and they can be highly energy-efficient choices. But the range of glazing possibilities is broader than that, and the choice will have a significant impact on energy performance. Using different types of glazing for windows with different orientations is worth considering for maximum energy performance; for example, using heat-rejecting glazing on west windows, high R-value glazing for north and east windows, and clear double-glazing on solar glazing.

✓ **6. Proper shading of windows:** If windows are not properly shaded in summer — either with shading devices, or by high-performance glazing with a low shading coefficient — the air conditioner will have to work overtime and the energy savings of the winter may be canceled out. Even more important, unwanted solar gain is uncomfortable.

✓ **7. Interior design for easy air distribution:** If the rooms in the house are planned carefully, the flow of heat in the winter will make the passive solar features more effective, and the air movement will also enhance ventilation and comfort during the summer. Often this means the kind of open floor plan which is highly marketable in most areas. Planning the rooms with attention to use patterns and energy needs can save energy in other ways, too — for instance, using less-lived-in areas like storage rooms as buffers on the north side.

✓ **8. Addition of thermal mass:** Adding effective thermal mass — for example, tiled or paved concrete slab, masonry walls, brick fireplaces, tile floors, etc. — can greatly improve the comfort in the house, holding heat better in winter and keeping rooms cooler in summer. In a passive solar system, of course, properly sized and located thermal mass is essential.

✓ **9. Selection and proper sizing of mechanical systems, and selection of energy-efficient appliances:** High-performance heating, cooling and hot water systems are extremely energy-efficient, and almost always a good investment. Mechanical equipment should have at least a 0.80 Annual Fuel Utilization Efficiency (AFUE).

Well-insulated passive solar homes will have much lower energy loads than conventional homes, and should be sized accordingly. Oversized systems will cost more and reduce the house's performance.

For guides to the selection of energy-efficient appliances, see References 12 - 14.

Part Three: Strategies for Improving Energy Performance in Cape Hatteras, North Carolina

1. The Example Tables
2. Suntempering
3. Direct Gain
4. Thermal Storage Walls
5. Sunspaces
6. Combined systems
7. Natural Cooling Techniques

1. The Example Tables

In the following sections of the Guidelines booklet, the primary passive solar systems – Suntempering, Direct Gain, Thermal Storage Walls and Sunspaces – are described in more detail.

As part of the explanation of each system, an Example table is provided. The Examples present the following information about a Base Case house, based on a National Association of Home Builders study of a typical construction:

- Insulation levels (ceilings, walls, floors)
- Tightness (measured in air changes per hour, ACH)
- The amount of glass area on each side (measured as a percentage of floor area; the actual square footage for a 1,500 sf house is also given as a reference point)
- The "percent solar savings" (the part of a house's heating energy saved by the solar features)
- and three numbers that correspond to those on the Worksheets: Conservation, Auxiliary Heat, and Cooling Performance (see page 4)

The Example tables then show how the house design could be changed to reduce winter heating energy by 20, 40 and 60%, compared to this Base Case.

There are, of course, other ways to achieve energy savings than those shown in the Examples. The Examples are designed to show an effective integration of strategies, and a useful approach to the design of the house as a total system. Using any of these combinations would result in excellent performance in your area. However, they are general indications only, and using the Worksheets will give you more information about your specific design.

The Example assumes a 1,500 sf house, but the percentages apply to a house of any size or configuration.

The R-values indicated in the Example tables are, of course, approximate and are intended to show how incremental improvements can be achieved. All R-values in the Examples and Worksheets are equivalent R-values for the entire construction assembly, not just for the cavity insulation itself, and take into account framing and buffering effects.

Other assumptions are noted for each Example. However, one more general assumption is important to note here. When the Examples were calculated, it was assumed that natural cooling strategies such as those described in this booklet were used, particularly in the very high-performance systems. The greater the percentage reduction in heating energy needs using passive solar design, the more shading and natural cooling were assumed.

The following Examples show passive solar strategies, but an Insulation Only Example table (achieving energy savings only by increasing insulation levels, without solar features) is provided in the Summary beginning on page 42, for comparison.

2. Suntempering

Suntempered and passive solar houses **both**:

- begin with good basic **energy-conservation**,
- take maximum advantage of the building site through the right **orientation** for year-round energy savings, and
- have increased **south-facing glass** to collect solar energy

Suntempering is the simplest passive solar system, and refers to modest increases in windows on the south side.

No additional thermal mass is necessary, only the "free mass" in the house – the framing, gypsum wall-board and furnishings.

In a "conventional" house, about 25% of the windows face south, which amounts to about 3% of the house's total floor area. In a suntempered house, the percentage is increased to a maximum of about 7%.

The energy savings are more modest with this system, but suntempering is a very low-cost strategy.

Of course, even though the necessity for precise sizing of glazing and thermal mass does not apply to suntempering (as long as the total south-facing glass does not exceed 7% of the total house floor area), all other recommendations about energy-efficient design such as the basic energy conservation measures, room lay-out, siting, glazing type and so on are still important for performance and comfort in suntempered homes.

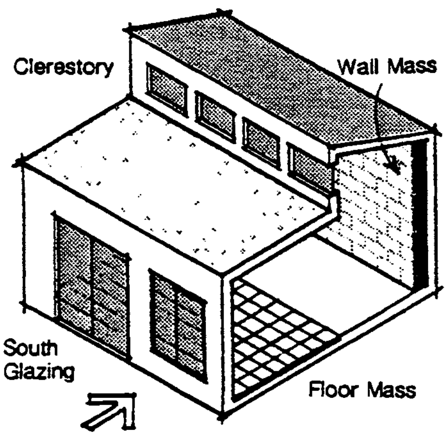
Examples of Heat Energy Savings
Suntempered
1,500 sf Single Story House

	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	25	34	45
Walls	15	12	18	25
Floor	18	15	22	30
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.75	.73	.55
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	6.7%	6.7%	6.7%
Solar System Size (square feet)				
South Glass	45	100	100	100
Percent Solar Savings	10%	20%	23%	30%
Performance (Btu/yr-sf)				
Conservation	24,789	22,288	17,536	12,804
Auxiliary Heat	22,413	17,929	13,448	8,965
Cooling	13,721	11,893	9,447	8,267

Summary: Insulation values and tightness of the house (as measured in ACH) have been increased. The window area has been slightly decreased on the west, increased slightly on the east and north, and increased significantly on the south. The performance estimates assume the use of double glazing on all sides.

3. Direct Gain

The most common passive solar system is called direct gain: sunlight through south-facing glazing falls directly into the space to be heated, and is stored in thermal mass incorporated into the floor or interior walls.



Direct Gain
Direct gain is the most common passive solar system in residential applications

Sizing Limit

Total direct gain glass area should not exceed about 12% of the house's floor area. Beyond that, problems with glare or fading of fabrics are more likely to occur, and it becomes more difficult to provide enough thermal mass for year-round comfort.

So the total south-facing glass area in a direct gain system should be between 7% (the maximum for suntempered houses) and 12%, depending on how much thermal mass will be used in the design, as discussed below.

Glazing

Double glazing is recommended for direct gain glazing in Cape Hatteras. The Performance Potential table on page 6 shows the relative performance of different types of direct gain glazing. You will note from this table that yield increases by 16% between double and triple or low-e glazing. Night insulation also improves energy performance dramatically. In fact, as the Performance Potential chart shows, covering the windows at night or on cloudy days with the equivalent of R-4 shades or other material will save almost as much energy as with R-9 material. But studies have shown that only relatively few homeowners will be diligent enough about operating their night insulation to achieve those savings. Energy-efficient glazing, on the other hand, needs no operation, and so is a more convenient and reliable option.

Thermal Mass

Thermal mass can be incorporated easily into slab-on-grade type buildings as either floor covering, walls or veneers over interior walls. If the mass is placed in the floor, it will be much more effective if sunlight falls directly on it.

Effective materials for floors include painted, colored or vinyl-covered concrete, brick (face brick or pavers have even higher density than ordinary building brick), quarry tile, and dark-colored ceramic tile.

For houses built with crawlspaces or basements,the incorporation of significant amounts of heavy thermal mass is a little more difficult. Thermal mass floor coverings over basements, crawlspaces and lower stories would generally be limited to thin set tile or other thin mass floors.

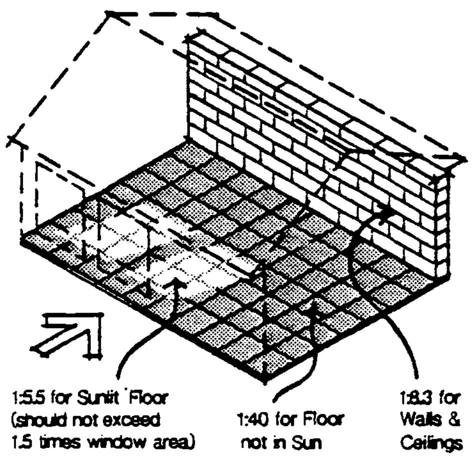
When more mass is required, the next best option is for interior walls or interior masonry fireplaces. When evaluating costs, the dual function of mass walls should be remembered. They often serve as structural elements or for fire protection as well as for thermal storage. Another option is to switch to another passive solar system type such as attached slab-on-grade sunspaces or thermal storage walls built directly on exterior foundation walls.

Sunlit thermal mass floors should be relatively dark in color, to absorb and store energy more effectively. However, mass walls and ceilings should be light in color to help distribute both heat and light more evenly.

Ratio of Glass to Mass . The following procedure can be used to determine the maximum amount of direct-gain glazing for a given amount of thermal mass. If the amount of direct-gain glazing to be used is already known, thermal mass can be added until this procedure produces the desired proportions:

- Start with a direct gain glass area equal to 7% of the house's total floor area. As noted above, the "free mass" in the house will be able to accommodate this much solar energy.
- An additional 1.0 sf of direct gain glazing may be added for every 5.5 sf of *uncovered, sunlit* mass floor. Carpet or area rugs will seriously reduce the effectiveness of the mass. The maximum floor mass that can be considered as "sunlit" may be estimated as about 1.5 times the south window area.
- An additional 1.0 square foot of direct gain glazing may be added for every 40 sf of thermal mass in the floor of the room, but *not* in the sun.
- An additional 1.0 square foot of direct gain glazing may be added for each 8.3 sf of thermal mass placed in the wall or ceiling of the room. Mass in the wall or ceiling does not have to be located directly in the sunlight, as long as it is in the same room, with no other walls between the mass and the area where the sunlight is falling.

More south-facing glazing than the maximum as determined here would tend to overheat the room, and to reduce energy performance as well.

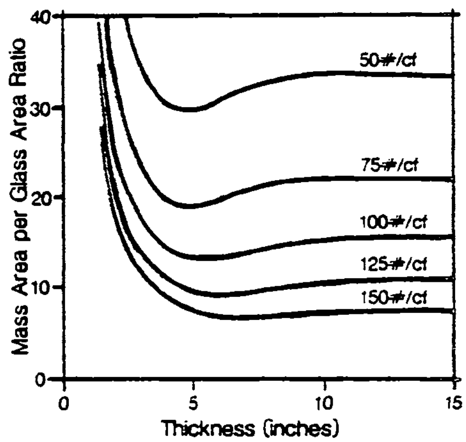


Mass Location and Effectiveness
Additional mass must be provided for south facing glass over 7% of the floor area. The ratio of mass area to additional glass area depends on its location within the direct gain space.

Thickness. For most materials, the effectiveness of the thermal mass in the floor or interior wall increases proportionally with thickness up to about 4 inches. After that, the effectiveness doesn't increase as significantly.

A two-inch mass floor will be about two-thirds as effective in a direct gain system as a four-inch mass floor. But a six-inch mass floor will only perform about eight percent better than a four-inch floor.

The following figure shows the effectiveness of thermal mass in relation to density and thickness. The vertical axis shows how many square feet of mass area are needed for each added square foot of direct gain. As you can see, performance increases start leveling off after a few inches of thermal mass.



Mass Thickness
The effectiveness of thermal mass depends on the density of the material and thickness. This graph is for wall or ceiling mass in the direct gain space.

Worksheet III: Comfort Performance Level should be used to make sure the house has adequate thermal mass.

Examples of Heat Energy Savings
Passive Solar—Direct Gain
1,500 sf Single Story House

	Base Case	20%	40%	60%
R-values				
Ceiling/Roof	27	24	31	41
Walls	15	11	16	23
Floor	18	14	20	27
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.69	.74	.65
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	7.5%	9.3%	12.0%
Added Thermal Mass				
Percent of Floor Area	0.0%	26.9%	38.1%	54.0%
Solar System Size (square feet)				
South Glass	45	112	140	180
Added Thermal Mass	0	404	571	810
Percent Solar Savings	10%	21%	29%	40%
Performance (Btu/yr-sf)				
Conservation	24,789	22,741	18,896	15,021
Auxiliary Heat	22,413	17,930	13,448	8,965
Cooling	13,721	12,475	10,970	11,086

Summary: South-facing glazing has been substantially increased, and thermal mass added. These estimates assume double glazing on all sides and adequate added thermal mass. For these examples, added mass area is assumed to be six times the excess south glass area.

4. Sunspaces

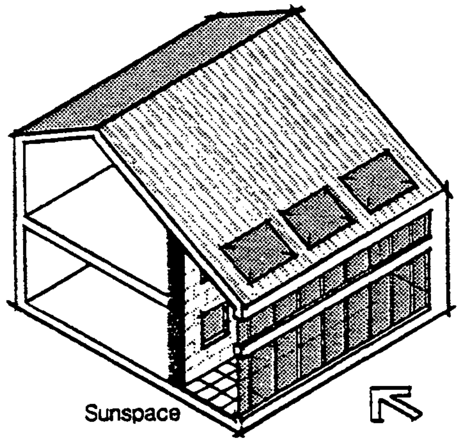
The sunspace is a very popular passive solar feature, adding an attractive living space as well as energy performance. There are many variations on the basic theme of the sunspace, and the possibilities for sunspace design are extraordinarily diverse (References 17 through 20 include specific design ideas).

The sunspace concept used in this booklet can be used year-round, will provide most or all of its own energy needs, and will contribute to the energy needs of the rest of the house as well.

Sunspaces are referred to as "isolated gain" passive solar systems, because the sunlight is collected in an area which can be closed off from the rest of the house. During the day, the doors or windows between the sunspace and the house can be opened to circulate collected heat, and then closed at night, and the temperature in the sunspace allowed to fall.

The sunspace should not be on the same heating system as the rest of the house. A well designed sunspace will probably need no mechanical heating system, but if necessary, a small fan or heater may be used to protect plants on extremely cold winter nights.

The sunspace should be just as tightly constructed and insulated as the rest of the house.



Sunspaces
Sunspaces provide useful passive solar heating and also provide a valuable amenity to homes.

Thermal Mass

A sunspace has extensive south-facing glass, so sufficient thermal mass is very important. Without it, the sunspace is liable to be uncomfortably hot during the day, and too cold for plants or people at night.

However, the temperature in the sunspace can vary more than in the house itself, so about three square feet of thermal mass for each square foot of sunspace glazing should be adequate. With this glass-to-mass ratio, on a clear winter day a temperature swing of about 30°F should be expected.

The sunspace floor is a good location for thermal mass. The mass floors should be dark in color. No more than 15-25% of the floor slab should be covered with rugs or plants. The lower edge of the south-facing windows should be no more than six inches from the floor or the planter bed to make sure the mass in the floor receives sufficient direct sunlight. If the windows sills are higher than that, additional mass will have to be located in the wall.

Another good location for thermal mass is the common wall (the wall separating the sunspace from the rest of the house). Options for the common wall are discussed in more detail below.

Water in various types of containers is another form of energy storage often used in sunspaces.

Glazing

Single-glazing may be used for sunspaces, although double-glazing will further improve comfort, in terms of energy savings. The performance potential table on page 6 shows the relative performance of different types of glazing.

Windows on the east and west walls should be small (no more than 10% of the total sunspace floor area) but they are useful for cross-ventilation.

Like tilted or sloped glazing, glazed roofs can increase solar gain, but they can also present such big overheating problems that they become counter-productive. If either glazed roofs or tilted glazing are used in the sunspace, special care should be taken to make sure they can be effectively shaded during the summer and, if necessary, on sunny days the rest of the year, too. The manufacturers of sunspaces and glazing are developing products with better ability to control both heat loss and heat gain (for example, roof glazing with low shading coefficients, shading treatments and devices, etc.).

You'll note that in the Performance Potential chart on page 6, sunspaces with glazed roofs or sloped glazing perform very well. This analysis assumes effective shading in the summer. If such shading is not economical or marketable in your area, you should consider using only vertical glazing, and accepting somewhat less energy performance in winter.

Common Wall

There are a number of options for the sunspace common wall. In mild climates, and when the sunspace is very tightly constructed, an uninsulated frame wall is probably adequate. However, insulating the common wall to about R-10 is a good idea, especially in cold climates. An insulated common wall will help guard against heat loss during prolonged cold, cloudy periods, or if the thermal storage in the sunspace is insufficient.

If the common wall is a masonry wall, it can also be used for thermal mass, in which case it should be solid masonry approximately 4 to 8 inches thick. Two other options are frame walls with masonry veneers, and concrete masonry walls with grout in the cores.

Probably the most important factor in controlling the temperature in the sunspace, and thus keeping it as comfortable and efficient as possible, is to make sure the exterior walls are tightly constructed and well-insulated.

Some solar energy may be transferred from the sunspace to the rest of the house by conduction through the common wall if it is made of thermal mass. But energy is mainly transferred by natural convection through openings in the common wall — doors, windows and/or vents.

- Doors are the most common opening in the common wall. If only doorways are used, the open area should be at least 15% of the sunspace south-glass area.
- Windows will also provide light and views. The window area in the common wall should be no larger than about 40% of the entire common wall area. If only windows are used, the operable area should be about 25% of the sunspace's total south glass area.

Summer ventilation

The sunspace must be vented to the outside to avoid overheating in the summer or on warm days in spring and fall. A properly vented and shaded sunspace can function much like a screened-in porch.

Operable windows and/or vent openings should be located for effective cross-ventilation, and to take advantage of the prevailing summer wind. Low inlets and high outlets can be used in a "stack effect", since warm air will rise. These ventilation areas should be at least 15% of the total sunspace south glass areas.

Where natural ventilation is insufficient, or access to natural breezes is blocked, a small, thermostat-controlled fan set at about 70°F will probably be a useful addition.

Examples of Heat Energy Savings
Passive Solar—Sunspace
1,500 sf Single Story House

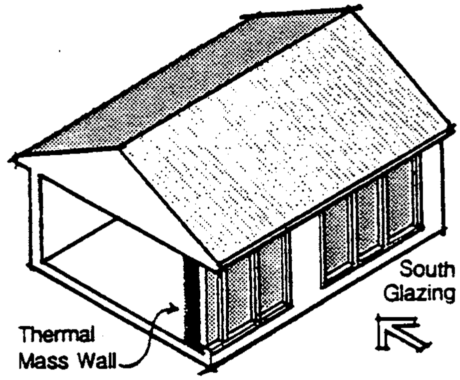
	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	22	27	35
Walls	15	10	13	19
Floor	18	13	16	23
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.68	.69	.72
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South (windows)	3.0%	3.0%	3.0%	3.0%
Sunspace	3.0%	6.7%	10.6%	16.2%
Solar System Size (square feet)				
South Glass	45	45	45	45
Sunspace Glass	0	100	160	244
Sunspace Thermal Mass	0	301	479	731
Percent Solar Savings	10%	26%	36%	50%
Performance (Btu/yr-sf)				
Conservation	24,789	24,095	21,009	17,805
Auxiliary Heat	22,413	17,930	13,448	8,965
Cooling	13,721	11,894	10,500	10,201

Summary: Insulation (for the 60% case) has been increased. North and east-facing glazing have been increased slightly. The sunspace assumed here is semi-enclosed (surrounded on three sides by conditioned rooms of the house, as in Figure SSC1 of the worksheets), with vertical south glazing. The common wall is a thermal mass wall made of masonry. Sunspace glazing is assumed to be double. Glazing on the house is assumed to be double.

5. Thermal Storage Wall

The Thermal Storage Wall – also sometimes referred to as a Trombe wall (when made of masonry), or an indirect gain system – is a south-facing glazed wall, usually built of heavy masonry, but sometimes using water containers or phase change materials. The masonry is separated from the glazing only by a small air space. Sunlight is absorbed directly into the wall instead of into the living space. The energy is then released into the living space over a relatively long period. The time lag varies with different materials, thicknesses and other factors, but typically, energy stored in a Thermal Storage Wall during the day is released during the evening and nighttime hours.

The summer heat gain from a Thermal Storage Wall is much less – roughly 74% less – than from a comparable area of direct gain glazing.



Thermal Storage Wall
A thermal storage wall is an effective passive solar system, especially to provide nighttime heating.

The most effective thickness for a Thermal Storage Wall depends on the density of the material chosen. The chart on the opposite page shows the recommended thickness of Thermal Storage Walls made of various materials. In general, the effectiveness of the Thermal Storage Wall will increase as density increases.

A masonry Thermal Storage Wall should be solid, and there should be no openings or vents either to the outside or to the living space. Although vents to the living space were once commonly built into Thermal Storage Walls, experience has demonstrated that they are ineffective.

Vents between the Thermal Storage Wall and the house tend to reduce the system's nighttime heating capability, and to increase the temperature fluctuation in the house. Vents to the outside are similarly ineffective, and do little to reduce summer heat gains.

Glazing

Double glazing is recommended for Thermal Storage Walls unless a selective surface is used. Single glazing with a selective surface performs about the same as double glazing without it.

The space between the glazing and the thermal mass should be one to three inches.

Selective Surfaces

A selective surface is a special adhesive foil applied to the exterior side of the mass of Thermal Storage Walls. Selective surfaces absorb a large percentage of solar radiation but radiate very little heat back to the out-of-doors (low emittance).

To be effective, selective surfaces must be applied carefully for 100% adhesion to the mass surface.

In Cape Hatteras, North Carolina, a selective surface will improve Thermal Storage Wall performance by 53%.

Mass Material and Thickness

In general, the effectiveness of the Thermal Storage Wall will increase as the density of the material increases.

A masonry Thermal Storage Wall should be solid. The optimum thickness of the wall depends on the density of the material chosen. The following chart indicates the recommended thickness of Thermal Storage Walls made of various materials.

Mass Wall Thickness
(inches)

Material	Density (lb/cf)	Thickness (inches)
Concrete	140	8-24
Concrete Block	130	7-18
Clay Brick	120	7-16
Ltwt. Concrete Block	110	6-12
Adobe	100	6-12

Water Walls

Water provides about twice the heat storage per unit volume as masonry, so a smaller volume of mass can be used. In "water walls" the water is in light, rigid containers. The containers are shipped empty and easily installed. Manufacturers can provide information about durability, installation, protection against leakage and other characteristics.

At least 30 pounds (3.5 gallons) of water should be provided for each square foot of glazing. This is equivalent to a water container about six inches thick, having the same area as the glazing.

Examples of Heat Energy Savings
Passive Solar—Thermal Storage Wall
1,500 sf Single Story House

	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	21	24	28
Walls	15	9	11	14
Floor	18	12	14	18
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.64	.69	.73
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	3.0%	3.0%	3.0%
Thermal Storage Wall	0.0%	6.4%	10.9%	17.0%
Solar System Size (square feet)				
South Glass	45	45	45	45
Thermal Storage Wall	0	96	163	255
Percent Solar Savings	10%	28%	42%	57%
Performance (Btu/yr-sf)				
Conservation	24,789	25,060	23,072	20,858
Auxiliary Heat	22,413	17,930	13,447	8,965
Cooling	13,721	11,777	10,195	9,886

Summary: In the case of a Thermal Storage Wall, south-facing glazing and thermal mass are incorporated together. The estimates here assume a 12-inch thick concrete Thermal Storage Wall with a selective surface and single glazing.

6. Combined Systems

Although the previous sections have presented separate discussions of four different systems, it isn't necessary to choose one and only one system. In fact, passive solar features work well in combination.

For example, direct gain works very well in conjunction with a sunspace or thermal storage wall. Since thermal storage walls release energy more slowly than direct gain systems, they are useful for supplying heat in the evening and at night, whereas the direct gain system works best during the day. Although using a sunspace, thermal storage wall and direct gain system in the same house may result in excellent performance, such combinations do require a large south-facing area, and careful design to make sure the systems are well-integrated with each other and with the house's mechanical system.

7. Natural Cooling Guidelines

The term "natural cooling" is used here to describe techniques which help a house stay cool in summer but which require little or no energy. Natural cooling techniques work to help reduce air-conditioning, not replace it.

These techniques are useful not only in passive solar houses, but in "conventional" houses as well. The strategies outlined below – attention to the location, size and shading of glazing, using the opportunities on the site for shading and natural ventilation, and using fans – can reduce air conditioning needs and increase comfort even if the house has no passive solar heating features.

But shading is particularly important in passive solar houses, because the same features that collect sunlight so effectively in winter will go right on collecting it in summer – resulting in uncomfortably hot rooms and big air conditioning bills – unless they are shaded and the house is designed to help cool itself.

Fortunately, many of the features that help maintain comfort and reduce energy needs in winter also work well in summer. For instance, additional thermal mass performs well year-round. In effect, masonry materials store coolness as well as heat. If mass surfaces can be exposed to cool night-time temperatures – a technique referred to as "night ventilation" – they will help the house stay cooler the next day. A California utility found during studies of small test buildings that on hot summer days the workmen at the facility always ate lunch in the masonry test building because it stayed much cooler than any of the others. (See Reference 9)

The additional insulation that increases winter performance will also work to improve summer performance by conserving the conditioned air inside the house. And some low-e windows and other glazing with high R-value can help shield against unwanted heat gain in summer.

The potential of some natural and low-energy cooling strategies is shown in in the following table for Cape Hatteras.

Worksheet IV: Cooling Performance Level indicates the total annual cooling load, and so can give an idea of how the passive solar features increast the cooling load and how much reduction is possible when natural cooling techniques are used.

It should be noted that the Cooling Performance numbers presented in the Examples for each passive solar strategy assume that the design also includes the natural cooling techniques recommended in this booklet. This is especially true of the higher percentage reductions; these assume better heating performance, but also better shading and other natural cooling strategies.

Cooling Potential
Basecase 13,721 Btu/yr-sf

Strategy	Energy Savings (Btu/yr-sf)	Percent Savings
No Night Ventilation[1]		
without ceiling fans	0	0%
with ceiling fans	2,480	18%
Night Ventilation[1]		
without ceiling fans	840	6%
with ceiling fans	2,980	22%
High Mass[2]		
without ceiling fans	1,370	10%
with ceiling fans	—	—%

1 With night ventilation, the house is ventilated at night when temperature and humidity conditions are favorable

2 A "high mass" building is one with a thermal mass area at least equal to the house floor area.

Glazing

As mentioned earlier, poorly placed windows can increase air conditioning loads dramatically. It is generally best in terms of energy performance to carefully size non-solar glazing as indicated in the following table.

Recommended Non-south Glass Guidelines

Orientation	Percent of Total Floor Area
East	4%
North	4%
West	2%

As mentioned earlier, west-facing windows present particularly difficult shading problems. If glazing is added above the levels indicated, the need for shading will become even more critical.

Cooling loads increase as window area increases. This relationship for Cape Hatteras is shown in the following table for each of the cardinal window orientations. For instance when a square foot of west area is added or subtracted, the annual cooling load increases or decreases by 101,300 Btu/yr-sf.

Added Window Cooling Load

Orientation	Added Annual Cooling Load (Btu/yr-sf)
North	46,400
East	96,200
South	77,000
West	101,300

These values are based on double glass with a shading coefficient of 0.88. When glazing with a different shading coefficient is used the values may be scaled proportionally.

These numbers can be reduced by shading as described in the next section.

Using special glazing or window films that block solar transmission (low shading coefficient) is an option often used in particularly hot climates, but the more effective they are at blocking sunlight, the less clear they are, as a rule, and so they may interfere with desirable views. It is important to note, however, that some types of low-e windows block solar transmission but also allow clear views. These treatments are not recommended for south windows.

As the table below shows, skylights present a high potential for overheating, and are usually difficult to shade properly. But skylights are very popular features, and they save electricity by providing good natural daylight to the house. In some parts of the country almost every new house has at least one skylight. A good working compromise can usually be achieved if skylight area is limited, and if careful attention is paid to shading, either by trees or by devices such as roller shades or blinds. The manufacturer can usually give guidance on shading options for a particular skylight design.

Added Skylight Cooling Load

Pitch	North	East	South	West
Horizontal	101,300	101,300	101,300	101,300
7:12	—	—	—	—
6:12	—	—	—	—
5:12	—	—	—	—
4:12	—	—	—	—

These values are based on double glass with a shading coefficient of 0.88. When glazing with a different shading coefficient is used the values may be scaled proportionally.

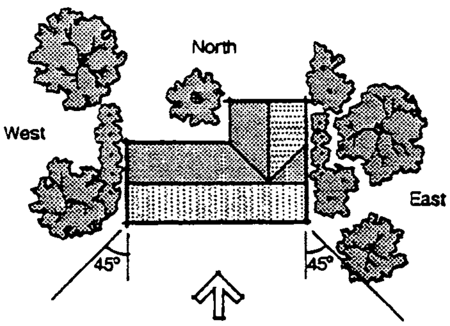
Shading

Shading strategies generally fall into three categories: landscaping, roof overhangs and exterior or interior shading devices.

Landscaping. The ideal site for summer shading has deciduous trees to shade the east and west windows. Even small trees such as fruit trees can help block sun hitting the first story of a house.

Trees on the south side can present a difficult choice. Even deciduous trees will shadow the solar glazing during the winter and interfere with solar gain. In fact, trees on the south side can all but eliminate passive solar performance, unless they are very close to the house and the low branches can be removed, allowing the winter sun to penetrate under the tree canopy. However, in many cases the trees around the house are bigger selling points than the energy efficiency and the builder must make a choice.

If a careful study of the shading patterns is done before construction, it should be possible to accomodate the south-facing glazing while leaving in as many trees as possible (see page 17, Site Planning for Solar Access).



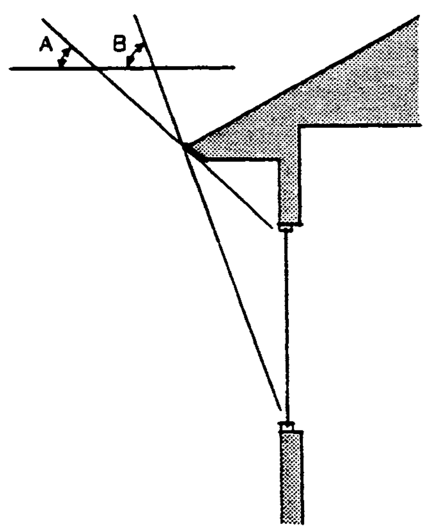
Landscaping for Summer Shade
Trees and other landscaping features may be effectively used to shade east and west windows from summer solar gains.

Other landscaping ideas for summer shade:

- Trellises on east and west covered with vines.
- Shrubbery or other plantings to shade paved areas.
- Use of ground cover to prevent glare and heat absorption.
- Trees, fences, shrubbery or other plantings to "channel" summer breezes into the house.
- Evergreen trees on the east and west sides of the house, as shown above, to balance solar gains in all seasons.

Roof Overhangs. Fixed overhangs are an inexpensive feature, and require no operation by the home owner. They must be carefully designed, however. Otherwise, an overhang that blocks summer sun may also block sun in the spring, when solar heating is desired, and, by the same token, an overhang sized for maximum solar gain in winter will allow solar gain in the fall on hot days. The following figure may be used to determine the optimum overhang size.

In Cape Hatteras, the overhang projection for a four foot high window should be 19 inches and the bottom of the overhang should be 14 inches above the top of the window.



South Overhang Sizing
In Cape Hatteras, an ideally sized south overhang should allow full exposure of the window when the sun has a noon altitude of 36 degrees (angle A) and fully shade the window when the sun has a noon altitude of 73 degrees (angle B).

A combination of carefully sized overhangs on the south windows and shading devices on the other windows will probably be an effective solution. Adjustable overhangs that can be seasonally regulated are another option.

Shading Devices. External shades are the most effective because they stop solar gain *before* the sun hits the building. A wide range of products are available, from canvas awnings to solar screens to roll-down blinds to shutters to vertical louvers. They are adjustable and perform very well, but their limitation is that they require the home owner's cooperation. Usually external screens that can be put up and taken down once a year like storm windows are more acceptable to home owners than those requiring more frequent operation.

Interior shades must be operated, too, and have the further disadvantage of permitting the sun to enter the house and be trapped between the window and the shading device. But highly reflective interior blinds and curtains are relatively low-cost and easy to operate.

Another shading "device" well worth considering is a porch. Especially on the east and west sides, porches add pleasant spaces to houses and are excellent for providing shade to windows. Carports located on the east or west are another option.

Ceiling Fans

Ceiling fans will probably save more energy than any other single cooling strategy. Studies show that air movement can make people feel comfortable at higher temperatures. As a general rule, the thermostat can be set 4 degrees higher without affecting comfort if the air is moving at 100-150 feet per minute. This is enough air movement to greatly improve comfort but not enough to disturb loose papers.

Ceiling Fan Sizes

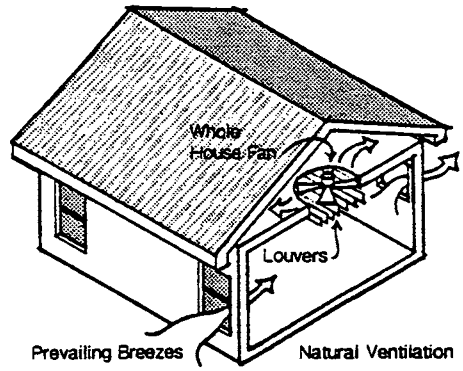
Largest Room Dimension	Minimum Fan Diameter (inches)
12 feet or less	36
12 - 16 feet	48
16 - 17.5 feet	52
17.5 - 18.5 feet	56
18.5 or more feet	2 fans

A ceiling fan should have a minimum clearance of ten inches between ceiling and fan to provide adequate ventilation in a standard room with eight-foot ceilings. In rooms with higher ceilings, fans should be mounted 7.5 to 8.0 feet above the floor.

Ventilation

When possible, the house should be positioned on the site to take advantage of prevailing winds. The prevailing wind in Cape Hatteras varies but is generally from the east or west during the cooling months. Windows, stairwells, transoms and other elements should be located for maximum cross-ventilation in each room. The free vent area (unobstructed openings like open windows) should be between 6-7.5% of total floor area, half located on the leeward and half on the windward side of the building. Insect screens can reduce the effective free vent area by as much as 50%. Casement or awning windows have a 90% open area; double hung windows have only 50%.

Natural ventilation can help keep houses cool and comfortable at the beginning and end of the cooling season and thus shorten the time when air conditioning is required. But natural ventilation can seldom do the entire cooling job, especially for less than ideal sites with little natural air movement.



Ventilation for Summer Cooling
Natural ventilation is often impaired by vegetation and topography. Ventilation fans do not depend on surroundings to be effective.

In cooling climates, a whole-house fan is a good idea for assisting ventilation, especially in houses with sites or designs that make natural ventilation difficult. On the other hand, when the temperature is higher than about 76°F, a whole-house fan will not be very effective, and is probably not necessary if the house has enough operable windows for good cross-ventilation, and the site is not obstructed.

Research indicates that a whole-house fan should pull approximately 10 ACH. A rule of thumb: for rooms with eight foot ceilings, total floor area multiplied by 1.34 will equal the necessary CFM of the fan; for 10 foot ceilings, multiply floor area by 1.67.

For the best possible performance of a whole-house fan, the system should include a timer, a thermostat and a "humidistat", so that the fan would only operate when there is less than 60% relative humidity and a temperature of less than 76°F.

Natural ventilation and whole-house fans are effective at removing heat, but not at moving air. Ceiling fans, on the other hand, can often create enough of a breeze to maintain comfort at higher temperatures, and still use less power than required by air conditioning. By using natural cooling strategies and low-energy fans, the days when air-conditioning is needed can be reduced substantially.

Glossary

Auxiliary Heating System: a term for the system (gas, electric, oil, etc.) which provides the non-solar portion of the house's heating energy needs, referred to as the "auxilary heat."

British Thermal Unit (Btu): a unit used to measure the heat. One Btu is about equal to the heat released from burning one kitchen match.

Conservation: in addition to energy conservation in the general sense, the term is used to refer to the non-solar, energy-saving measures in a house which are primarily involved with improving the building envelope to guard against heat loss -- the insulation, the air infiltration reduction measures, and so forth.

Direct Gain: a passive solar system in which the sunlight falls directly into the space where it is stored and used.

Glazing: often used interchangeably with window or glass, the term actually refers to specifically just to the clear material which admits sunlight, and so can also be plastic. Double and triple glazing refer to two or three panes.

Indirect Gain: a passive solar system in which the sunlight falls onto thermal mass which is positioned between the glazing and the space to be heated, i.e. a Thermal Storage Wall or Trombe Wall.

Low-Emissivity: the term refers to a surface's ability to absorb and re-radiate heat. A material with a low emissivity absorbs and re-radiates relatively small amounts of heat. Low-emissivity or "low-e" glass sandwiches a thin layer of metallic film or coating between two panes of glass. The low-e glass blocks radiant heat, so it will tend to keep heat energy inside the house during the winter, and keep heat energy outside the house during the summer.

Passive Solar: design and construction techniques which help a building make use of solar energy by non-mechanical means, as opposed to active solar techniques which use equipment such as roof-top collectors.

Phase-Change Materials: materials such as salts or waxes which store and release energy by changing "phase"; most store energy when they turn liquid at a certain temperature and release energy when they turn solid at a certain temperature, but some remain solid but undergo chemical changes which store and release energy. Phase change materials can be used as thermal mass but few products are commercially available at this time..

Purchased Energy: although the terms are often used interchangably, a house's "purchased energy" is generally greater than its "auxilary heat" because heating systems are seldom 100% efficient, and more energy is purchased than is actually delivered to the house.

R-Value: a unit that measures the resistance to heat of a given material. the higher the R-value, the better insulating capability the material has. The R-value is the reciprocal of the U-value. (see below)

Radiant Barrier: reflective material used in hot climates to block radiant heat, particularly in a house's roof.

Shading Coefficient: a measure of how much solar heat will be transmitted by a glazing material, as compared to a single pane of clear uncoated glass, which has a shading coefficient (SC) of 1. For example, clear double-pane glass might have an SC in the range of .88. Reflective glass might have SC's of .03-.06. In general, lower shading coefficients are desirable when heat gain is a problem.

Sunspace: passive solar system sometimes also referred to as an isolated gain system, where sunlight is collected and stored in a space separate from the living space, and must be transferred there either by natural convection and\or conduction or by fans.

Suntempering: a modest form of a direct gain passive solar system; suntempered houses increase south-facing glass to about 7 percent of a total floor area, but add no thermal mass beyond the "free" mass already in a typical house -- gypsum board, framing, conventional furnishings and floor coverings.

Temperature Swing: a measure of the number of degrees the temperature in a space will vary during the course of a sunny winter day without the furnace operating; an indicator of the amount of thermal mass in the passive solar system.

Thermal Mass: material that stores energy, although mass will also retain coolness. The thermal storage capacity of a material is a measure of the material's ability to absorb and store heat. Thermal mass in passive solar buildings is usually dense material such as brick or concrete masonry, but can also be tile, water, phase change materials, etc.

Thermal Storage Wall: a passive solar system also sometimes called Trombe Wall or indirect gain system; a south-facing glazed wall, usually made of masonry but can also be made of containers of water.

Trombe Wall: a thermal storage wall, referred to by the name of its inventor, Dr. Felix Trombe.

U-Value: a unit representing the heat loss per square foot of surface area per degree F of temperature difference (see R-value above).

References

General

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3. *The Passive Solar Construction Handbook*, Steven Winter Associates/Northeast Solar Energy Center/National Concrete Masonry Association/Portland Cement Association/Brick Institute of America. Available for 29.95 plus 3.00 handling, from Steven Winter Associates, Attn: Publications, 6100 Empire State Building, New York, N.Y. 10001

4. *Suntempering in the Northeast*, Steven Winter Associates. Available from them at the address above, or from PSIC, for 9.50.

5. *Passive Solar Design Handbook, Volume I, II, III.* Available from National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, Va. 22161, 32.00 each for I and II, 12.00 for III.

6. *Passive Solar Heating Analysis*. J.D. Balcomb et al. This volume supercedes and expands Volume III of the Passive Solar Design Handbook (Ref. 5). Available from ASHRAE, Publications, 1791 Tullie Circle NE, Atlanta, Ga, 30329, 30.00 for ASHRAE members, 60.00 for non-members.

7. *Living With the Sun* (for consumers) and *Building With the Sun* (for builders), PPG Industries, Available from PSIC for 2.00 apiece handling.

8. *The Passive Solar Information Guide*, PSIC. Available from PSIC for 2.00 handling.

9. *Passive Solar Trends*. Technical briefs from PSIC. Package of all issues below for 5.00 handling.
a. Infiltration in Passive Solar Construction
b. The State of the Art in Passive Solar Construction
c. Passive Solar in Factory-Built Housing
d. Radiant Barriers: Top Performers in Hot Climates
e. Glazings: The Design Considerations Aren't As Clear As Glass
f. Ideas for Passive Solar Remodeling
g. Passive Homes in the Marketplace (Class C Studies)
h. Daylighting in Commercial Buildings
i. Human Comfort and Passive Solar Design
j. Passive Design for Commercial Buildings
k. Passive Solar: Principles and Products
l. Increasing Design Flexibility
m. Utilities and Passive: Predicting the Pay-off

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10. *NAHB Insulation Manual*, National Association of Home Builders, National Research Center. Available from NAHB Bookstore, 15th and M Streets N.W., Washington, D.C. 20005. (202) 822-0200.

11. *The Airtight House: Using the Airtight Drywall Approach*, James K. Lischkoff, Iowa State University Research Foundation. Available for 14.95; Attn: Sarah Terrones, EES Building, Iowa State University, Ames, IA. 50011

12. *Radon Reduction in New Construction, Interim Guide*, John Spears, National Association of Home Builders, Environmental Protection Agency OPA 87-009, , August 1987. Available from the EPA or the NAHB Bookstore, 15th and M Streets N.W., Washington, D.C. 20005. (202) 822-0200.

Appliances

13. *Saving Energy and Money with Home Appliances*, Environmental Science Department, Massachusetts Audobon Society/American Council for an Energy Efficient Economy. Available for 2.00 apiece from ACEE, 1001 Connecticut Ave. N.W., Suite 535, Washington D.C. 20036

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16. *Site Planning for Solar Access*, U.S. Department of Housing and Urban Development/American Planning Association. Available for 6.50 from Superintendent of Documents, U.S. Government Printing Office, Washington D.C. 20402

Sunspaces

17. *The Sunspace Primer: A Guide for Passive Solar Heating*, Robert W. Jones and Robert D. McFarland. Available for 32.50 from Van Nostrand Reinhold, 115 5th Avenue, New York, N.Y. 10003

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19. *Concept IV*, from Andersen Corporation, Bayport, MN. 55003, 6.95.

20. *Passive Solar Greenhouse Design and Construction*, Ohio Department of Energy/John Spears, 8821 Silver Spring, Md., 20910.

More Information

Conservation and Renewable Energy Inquiries and Referral Service (CAREIRS) 1-800-523-2929, Renewable Energy Information, Box 8900, Silver Spring, Md. 20907

National Association of Home Builders
Attention: Technical Services
15th & M Streets N.W.
Washington, D.C. 20005

National Concrete Masonry Association
Attention: Energy Engineer
2302 Horse Pen Road
Herndon, Va. 22070

Brick Institute of america
Attention: Energy Engineer
11490 Commerce Park Drive
Suite 300
Reston, Va. 22091

Solar Energy Research Institute
Attention: Solar Buildings
1617 Cole Boulevard
Golden, Co. 80401

Passive Solar Industries Council
2836 Duke Street
Alexandria, Virginia 22314

Cape Hatteras, North Carolina

Examples of Heat Energy Savings Added Insulation

1,500 sf Single Story House

	Base Case	20%	40%	60%
R-values				
Ceiling/Roof	27	28	38	49
Walls	15	14	22	27
Floor	18	17	26	33
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.74	.71	.47
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	3.0%	3.0%	3.0%
Percent Solar Savings	10%	11%	13%	18%
Performance (Btu/yr-sf)				
Conservation	24,789	20,175	15,545	10,986
Auxiliary Heat	22,413	17,930	13,449	8,966
Cooling	13,721	9,935	7,515	6,723

Examples of Heat Energy Savings Suntempered

1,500 sf Single Story House

	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	25	34	45
Walls	15	12	18	25
Floor	18	15	22	30
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.75	.73	.55
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	6.7%	6.7%	6.7%
Solar System Size (square feet)				
South Glass	45	100	100	100
Percent Solar Savings	10%	20%	23%	30%
Performance (Btu/yr-sf)				
Conservation	24,789	22,288	17,536	12,804
Auxiliary Heat	22,413	17,929	13,448	8,965
Cooling	13,721	11,893	9,447	8,267

Summary: Insulation values and tightness of the house (as measured in ACH) have been increased. The window area has been slightly decreased on the west, increased slightly on the east and north, and increased significantly on the south. The performance estimates assume the use of double glazing on all sides.

Examples of Heat Energy Savings Passive Solar—Direct Gain

1,500 sf Single Story House

	Base Case	20%	40%	60%
R-values				
Ceiling/Roof	27	24	31	41
Walls	15	11	16	23
Floor	18	14	20	27
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.69	.74	.65
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	7.5%	9.3%	12.0%
Added Thermal Mass				
Percent of Floor Area	0.0%	26.9%	38.1%	54.0%
Solar System Size (square feet)				
South Glass	45	112	140	180
Added Thermal Mass	0	404	571	810
Percent Solar Savings	10%	21%	29%	40%
Performance (Btu/yr-sf)				
Conservation	24,789	22,741	18,896	15,021
Auxiliary Heat	22,413	17,930	13,448	8,965
Cooling	13,721	12,475	10,970	11,086

Summary: South-facing glazing has been substantially increased, and thermal mass added. These estimates assume double glazing on all sides and adequate added thermal mass. For these examples, added mass area is assumed to be six times the added south glass area.

Examples of Heat Energy Savings
Passive Solar—Sunspace
1,500 sf Single Story House

	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	22	27	35
Walls	15	10	13	19
Floor	18	13	16	23
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.68	.69	.72
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South (windows)	3.0%	3.0%	3.0%	3.0%
Sunspace	3.0%	6.7%	10.6%	16.2%
Solar System Size (square feet)				
South Glass	45	45	45	45
Sunspace Glass	0	100	160	244
Sunspace Thermal Mass	0	301	479	731
Percent Solar Savings	10%	26%	36%	50%
Performance (Btu/yr-sf)				
Conservation	24,789	24,095	21,009	17,805
Auxiliary Heat	22,413	17,930	13,448	8,965
Cooling	13,721	11,894	10,500	10,201

Summary: Insulation (for the 60% case) has been increased. North and east-facing glazing have been increased slightly. The sunspace assumed here is semi-enclosed (surrounded on three sides by conditioned rooms of the house, as in Figure SSC1 of the worksheets), with vertical south glazing. The common wall is a thermal mass wall made of masonry. Sunspace glazing is assumed to be double. Glazing on the house is assumed to be double.

Examples of Heat Energy Savings
Passive Solar—Thermal Storage Wall
1,500 sf Single Story House

	Base Case	20%	40%	60%
R-Values				
Ceiling/Roof	27	21	24	28
Walls	15	9	11	14
Floor	18	12	14	18
Glass	0.9	1.8	1.8	1.8
Air Changes/Hour	.75	.64	.69	.73
Glass Area (percent of total floor area)				
West	3.0%	2.0%	2.0%	2.0%
North	3.0%	4.0%	4.0%	4.0%
East	3.0%	4.0%	4.0%	4.0%
South	3.0%	3.0%	3.0%	3.0%
Thermal Storage Wall	0.0%	6.4%	10.9%	17.0%
Solar System Size (square feet)				
South Glass	45	45	45	45
Thermal Storage Wall	0	96	163	255
Percent Solar Savings	10%	28%	42%	57%
Performance (Btu/yr-sf)				
Conservation	24,789	25,060	23,072	20,858
Auxiliary Heat	22,413	17,930	13,447	8,965
Cooling	13,721	11,777	10,195	9,886

Summary: In the case of a Thermal Storage Wall, south-facing glazing and thermal mass are incorporated together. The estimates here assume a 12-inch thick concrete Thermal Storage Wall with a selective surface and single glazing.

Cooling Potential
Basecase 13,721 Btu/yr-sf

Strategy	Energy Savings (Btu/yr-sf)	Percent Savings
No Night Ventilation[1]		
without ceiling fans	0	0%
with ceiling fans	2,480	18
Night Ventilation[1]		
without ceiling fans	840	6
with ceiling fans	2,980	22
High Mass[2]		
without ceiling fans	1,370	10
with ceiling fans	—	—

1 With night ventilation, the house is ventilated at night when temperature and humidity conditions are favorable.

2 A "high mass" building is one with a thermal mass area at least equal to the house floor area.