PDHonline Course G259 (2 PDH)

An Introduction to Passive Solar Buildings

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1. INTRODUCTION

This course is intended as an introduction to principles and concepts underlying the design of buildings to *passively* utilize solar energy for heating. Here are some points for you to keep in mind as you go through the course material:

- This is an introduction to the *passive* solar technology that may be used to heat buildings. It is not about *active* technologies. Usually an optimal solution for a specific building and locale involves *passive* technology supplemented by *active* technologies. Active technologies are not part of this course. Passive technologies are. This will be discussed further.

- Utilization of passive solar energy to heat buildings is fundamentally an exercise requiring an understanding of (a) the fact that heat is transferred from outside to inside a building by conduction, convection and radiation, and (b) the concept of heat sinks as a reservoir for heat storage.

- Procedures for design of buildings to passively use solar energy for heating buildings may typically involve (a) use of shading devices to reduce heating by radiant (solar) energy in the summer and allow it in winter, (b) utilize thermal convection (i.e. hot air rises) to maximize heating by convection in winter, and (c) utilize thermal storage (mass-effect) to transfer excess heating capacity from daylight to nighttime hours.

- This is an introductory course intended to tell you about basic systems and climate considerations underlying the passive utilization of solar energy to heat buildings. It is not intended to be a definitive design manual that can be used for feasibility studies, design analyses and building design.

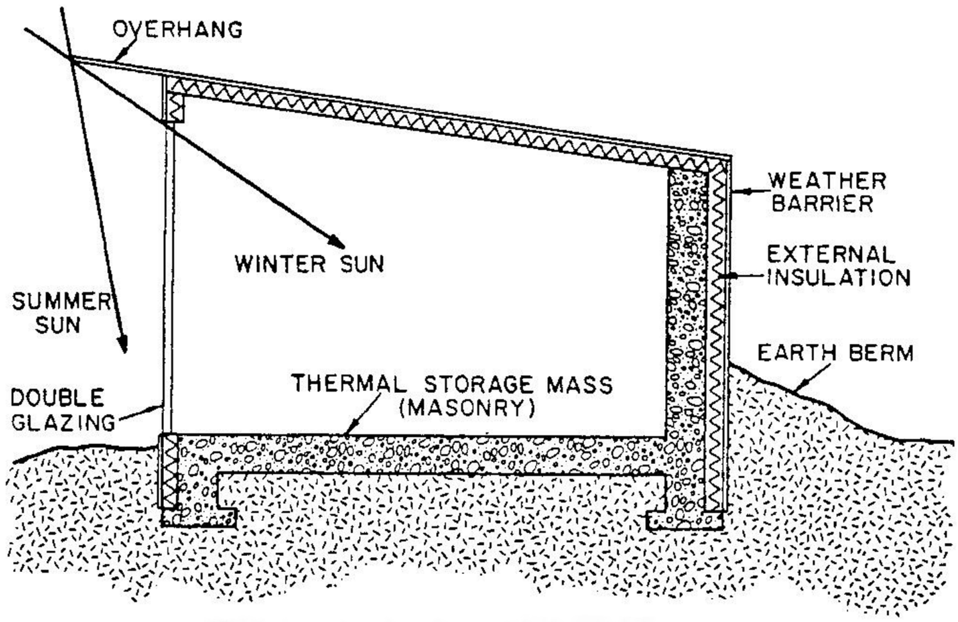
2. SYSTEMS

2.1 Direct Gain Heating. Direct gain buildings are passive solar heating systems in which sunlight is introduced directly to the living space through windows or other glazed apertures as indicated schematically in Figure 1. As with all passive solar systems, it is important that the apertures face south or near south in order to achieve high solar gains during the winter heating season and low solar gains during the summer cooling season.

Thermal storage mass is essential to the performance and comfort of direct gain buildings. A building that has inadequate mass will overheat and require ventilation, which entails a loss of heat that might otherwise have been stored for night time use. Generally, it is desirable to employ structural mass as a storage medium in order to take advantage of the improved economics associated with multiple use. Insulation should always be placed on the outside of massive elements of the building shell rather than on the inside in order to reduce heat Losses without isolating the mass from the living space. Concrete floor slabs can contribute to the heat capacity of a building provided they are not isolated by carpets and cushioning pads. Heat losses from the slab can be limited by placing perimeter insulation on the outside of the foundation walls. If the structure is fairly light, the heat capacity can be effectively increased by placing water containers in the interior. A variety of attractive containers are available commercially.

An overhang, illustrated in Figure 1, is used to shade the solar aperture from the high summer sun while permitting rays from the low winter sun to penetrate and warn the inside of the building. In climates having particularly warm and sunny summers, an overhang may not be sufficient to prevent significant aggravation of the summer cooling load. Sky diffuse and ground reflected radiation enter the living space despite the presence of an overhang and must be blocked by external covers or internal shades. Using movable insulation on direct gain apertures has the advantage of reducing night time heat losses during the winter-as well as eliminating unwanted solar gains during the summer.

FIGURE 1
DIRECT GAIN HEATING SYSTEM



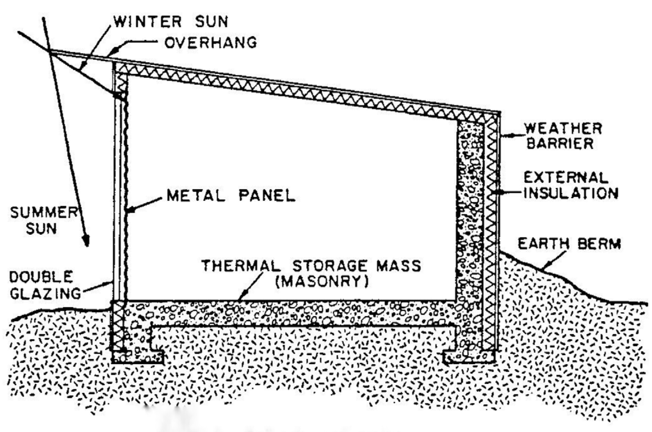
Direct gain buildings involve less departure from conventional construction than other types of passive solar systems and are therefore cheaper and more readily accepted by most occupants. However, they are subject to overheating, glare, and fabric degradation if not carefully designed; these problems can be minimized by distributing the sunlight admitted to the building as uniformly as possible through appropriate window placement and the use of diffusive blinds or glazing materials. When properly designed for their location, direct gain buildings provide an effective means of reducing energy consumption for space heating without sacrifice of comfort or aesthetic values.

2.2 Daylighting. The daylight delivered to the interior of direct gain buildings is an additional resource that is available year-round. Pleasing uniform illumination can be achieved by using blinds that reflect sunlight toward white diffusive ceilings. The artificial lighting system in many buildings imposes a significant load on the cooling system that may be reduced by daylighting because the fraction of visible light in the solar spectrum is greater than the visible fraction of incandescent or fluorescent lighting.

2.3 Radiant Panels. Radiant panels are simple passive solar systems that are inexpensive and well suited as retrofits to metal buildings. A sketch of a radiant panel system is presented in Figure 2. Note that the solar aperture consists of one or more layers of glazing material placed over an uninsulated metal panel. The metal panel would ordinarily be a part of the building shell so that a retrofit is constructed by simply glazing an appropriate area on the south side of the structure. Any insulation or other poorly conducting material should be removed from the inner surface of the glazed portion of the metal panel to facilitate heat transfer to the interior.

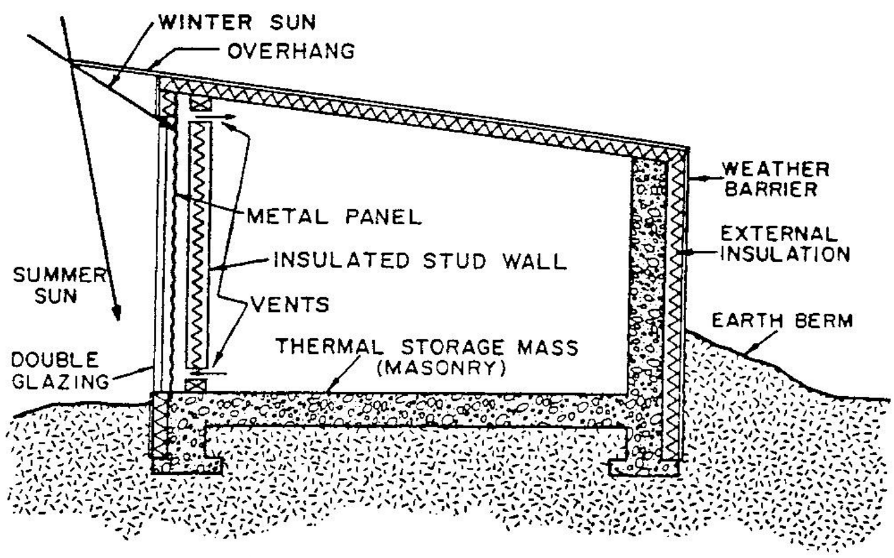
Solar radiation is absorbed on the outer surface of the metal panel after passing through the glazings. The panel becomes hot and gives up heat to the interior by radiation and convection. Thermal mass must be included inside the building shell as with direct gain systems. Usually, only a concrete slab will be available before retrofitting a metal building and it may sometimes be necessary to add water containers to achieve the desired thermal capacitance. Radiant panels perform on a par with direct gain buildings and are likely to be less expensive when used as retrofits to metal buildings.

FIGURE 2
RADIANT PANEL SYSTEM



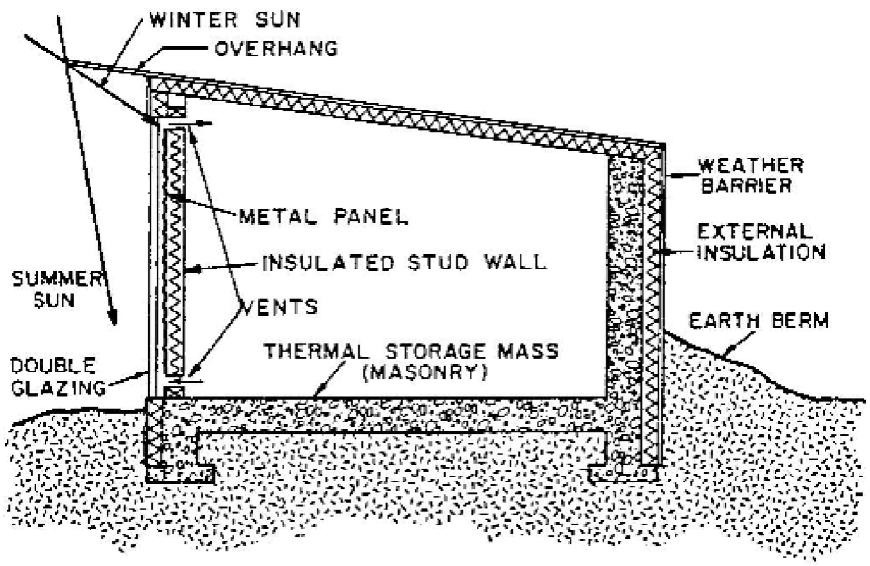
2.4 Thermosiphoning Air Panels. Thermosiphoning air panels (TAPs) are also appropriate for use on metal buildings either as retrofits or in new construction. Two configurations occur in practice and the first, which is referred to as a frontflow system, is illustrated in Figure 3. Again there are one or more glazing layers over an absorbing metal surface but, in this case, the metal panel is insulated on the back side. Heat transfer to the interior occurs via circulation vents cut through the metal panel and its insulation at the upper and lower extremes. Solar radiation absorbed on the the outer surface of the panel is converted to heat and convected to the adjacent air which then rises due to buoyancy forces and passes through the upper vent into the living space. The warm air leaving the gap between the inner glazings and the absorber is replaced by cooler air from the building interior that enters through the lower vents. In this manner, a buoyancy driven loop is established and sustained as long as the temperature in the air gap exceeds that in the living space. Passive backdraft dampers or manually operated vent closures must be employed to prevent reverse circulation at night. Backdraft dampers are usually made of a lightweight plastic material suspended above a metal grid such that air flows freely in one direction but is blocked should the flow attempt to reverse.

FIGURE 3
FRONTFLOW TAP SYSTEM



The second type of TAP configuration, illustrated in Figure 4, is called a backflow system. In a backflow system, the flow channel is behind the absorber plate rather than in front of it. An insulated stud wall is constructed a few inches behind the metal panel and vents are then cut at the top and bottom of the wall. Air in the flow channel thus formed is heated by convection from the back of the absorber panel and a circulation loop is established in the same manner as in a frontflow system.

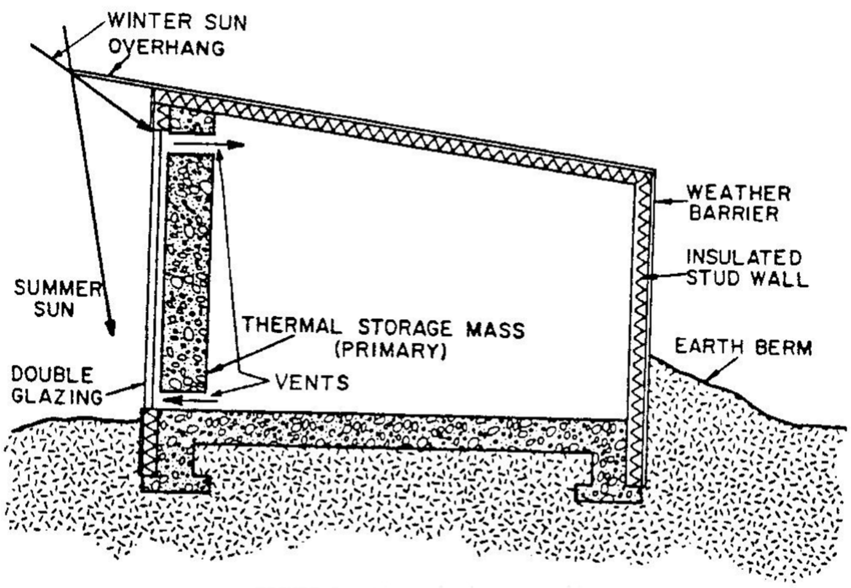
FIGURE 4
BACKFLOW TAP SYSTEM



TAPs have thermal storage requirements similar to those of direct gain and radiant panel systems. Generally speaking, the best performance will be obtained from passive solar systems associated with high heat capacity structures. Although a backflow TAP performs slightly better than a comparable system in the frontflow configuration, the difference is not significant and construction costs should govern any choice between the two. Both TAP configurations outperform radiant panels and direct gain systems with comparable glazings and thermal storage mass. This performance edge is due to the low aperture conductance of TAPs, which can be insulated to arbitrary levels, thereby limiting night time heat loss.

2.5 Thermal Storage Walls. A thermal storage wall is a passive solar heating system in which the primary thermal storage medium is placed directly behind the glazings of the solar aperture, as illustrated in Figure 5. The outer surface of the massive wall is painted a dark color or coated with a selective surface to promote absorption of solar radiation. Solar radiation absorbed on the outer surface of the wall is converted to heat and conducted (or convected in the case of the water walls) to the inner surface where it is radiated and convected to the living space. Heat transfer to the living space is sometimes augmented by the addition of circulation vents placed at the top and bottom of the mass wall. These vents function in the same manner as the vents in a TAP system except that only a portion of the solar heat delivered by the system passes through the vents.

FIGURE 5
THERMAL STORAGE WALL



A thermal storage wall provides an effective buffer between outside ambient conditions and the building interior; night time heat losses are reduced during the cold winter months, and during the summer, unwanted heat gains are limited. This moderating effect generally enables thermal storage walls to outperform direct gain systems. There are many types of thermal storage walls distinguished by the type of storage medium employed.

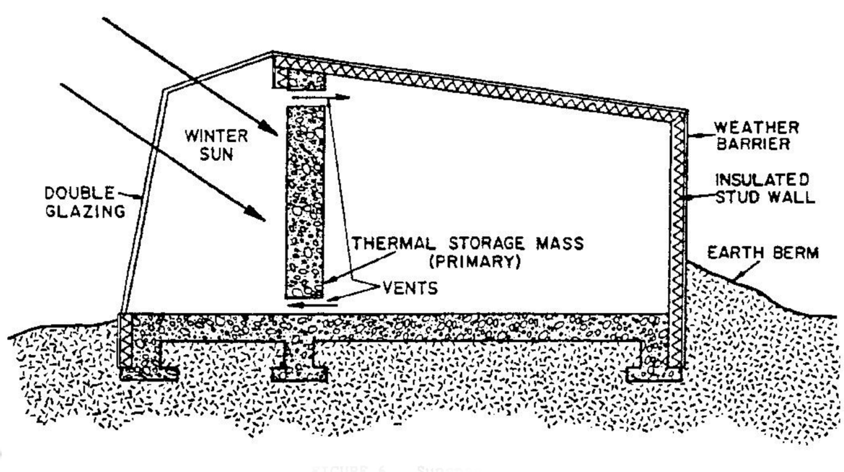
2.5.1 Trombe Wall. A Trombe wall is a thermal storage wall that employs solid, high density masonry as the primary thermal storage medium. Appropriate thicknesses range from 6 to 18 inches depending on the solar availability at the building site. Sunny climates require relatively thicker walls due to the increased thermal storage requirements. The wall may be vented or unvented. A vented wall is slightly more efficient and provides a quicker warm up in the morning but may overheat buildings containing little secondary thermal storage mass in the living space.

2.5.2 Concrete Block Wall. Ordinarily, a thermal storage wall would not be constructed of concrete building blocks, because solid masonry walls have a higher heat capacity and yield better performance. However, where concrete block buildings are very common they may offer opportunities for passive solar retrofits. The south facing wall of a concrete block building can be converted to a thermal storage wall by simply painting the block a dark color and covering it with one or more layers of glazing. Walls receiving this treatment yield a net heat gain to the building that usually covers the retrofit costs rather quickly. The relatively low heat capacity of concrete block walls is offset somewhat by the large amount of secondary thermal storage mass usually available in these buildings. Concrete floor slabs and massive partitions between zones help prevent overheating and otherwise improve the performance of concrete block thermal storage walls. Concrete block thermal storage walls may also be introduced during the construction of new buildings. For new construction, however, it is advisable to take advantage of the superior performance of solid masonry walls by filling the cores of the block in the thermal storage wall with mortar as it is erected. This process is inexpensive and the resulting performance increment covers the increased cost. The design procedures developed herein are applicable to 8-inch concrete block thermal storage walls with filled or unfilled cores.

2.5.3 Water Wall. Water walls are thermal storage walls that use containers of water placed directly behind the aperture glazings as the thermal storage medium. The advantage over masonry walls is that water has a volumetric heat capacity about twice that of high density concrete; it is therefore possible to achieve the same heat capacity available in a Trombe wall while using only half the space. Furthermore, a water wall can be effective at much higher heat capacities than a Trombe wall because natural convection within the container leads to an nearly isothermal condition that utilizes all of the water regardless of the wall thickness. The high thermal storage capacity of water walls makes them especially appropriate in climates that have a lot of sunshine.

2.6 Sunspaces. There are many possible configurations for a sunspace but all of them share certain basic characteristics; a representative schematic is presented in Figure 6. Sunlight enters the sunspace through south facing glazing that may be vertical or inclined or a combination of the two and is absorbed primarily on mass surfaces within the enclosure; the mass may be masonry or water in appropriate containers and is generally located along the north wall and in the floor. The massive elements provide thermal storage that moderates the temperature in the enclosure and the rate of heat delivery to the living space located behind the north wall. Operable windows and circulation vents in the north wall provide for heat transfer by thermal convection from the sunspace to the living space. The north wall may be an insulated stud wall placed behind containers of water or a masonry wall through which some of the heat in the sunspace is delivered to the building interior by thermal conduction as occurs in a Trombe wall. A sunspace may be semi-enclosed by the main structure such that only the south facing aperture is exposed to ambient air, or may be simply attached to the main structure along the north wall of the sunroom, leaving the end walls exposed.

FIGURE 6
SUNSPACE



The temperature in a sunspace is not thermostatically controlled but is generally moderate enough for human habitation during most of the day and appropriate for growing plants year round. Amenities are thus provided that compensate for the somewhat higher cost of sunspaces relative to other types of passive solar heating systems.

2.7 Incremental Cooling Load. Unfortunately, not all of the heat delivered to the living space by a passive solar heating system is useful to the occupants. During the winter heating season, part of the delivered solar energy will cause the building to overheat unless ventilation is employed to limit the indoor temperature. It is to be expected that some overheating will occur in most passive solar buildings, but too much excess heat is indicative of a poor design: it may be that the solar aperture is too large or that inadequate thermal storage mass has been provided. During the summer cooling season, a passive solar heating system continues to function although the increased solar elevation angle reduces the radiation flux transmitted through the glazings, particularly if an overhang is employed. However, all heat delivered to the building during the cooling season is unwanted and must be removed either by ventilation or by evaporative or vapor compression cooling systems. A poorly designed passive heating system can significantly aggravate the summer cooling load of a building. The sum of all unwanted heat delivered to a building by the passive heating system is referred to as the incremental cooling load. This is clearly an important parameter because it represents the cooling penalty associated with various passive solar designs.

3. CLIMATIC CONSIDERATIONS

3.1 Characteristic Weather Parameters. This discussion is based on two weather parameters that, in certain combinations, may be used to characterize climates with respect to the potential effectiveness of conservation and passive solar measures in reducing energy consumption for space heating.

The first of these important parameters is the heating degree days, which is represented by the symbol DD and has units of deg.F-day. DD is calculated by summing the difference between the base temperature and the outside ambient temperature over each hour in the time period of interest and dividing the result by 24 hr/day; all negative terms are omitted from the sum. The base temperature is the thermostat setpoint adjusted to account for the presence of internal heat sources; the time period of interest is usually one month or one year. This method of calculating DD differs from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) approach and is recommended because it yields better accuracy when applied to the analysis of passive solar buildings. Furthermore, the hourly data required for such a calculation is available in the Typical Meteorological Year (TMY) data base. The heating degree days is an important weather parameter because the amount of heat lost from a building during a particular time period is directly proportional to DD, i.e., if a building is moved from one location to another having twice as many degree days, the heat loss from the building will double.

The second important weather parameter is VT2, the amount of solar energy transmitted through a vertical, south facing, double glazed aperture during a specific time period. The V in VT2 stands for vertical, the T indicates transmitted radiation, and the 2 represents the two glazing layers. The parameter VT2 is important because it quantifies the solar resource available for passive space heating.

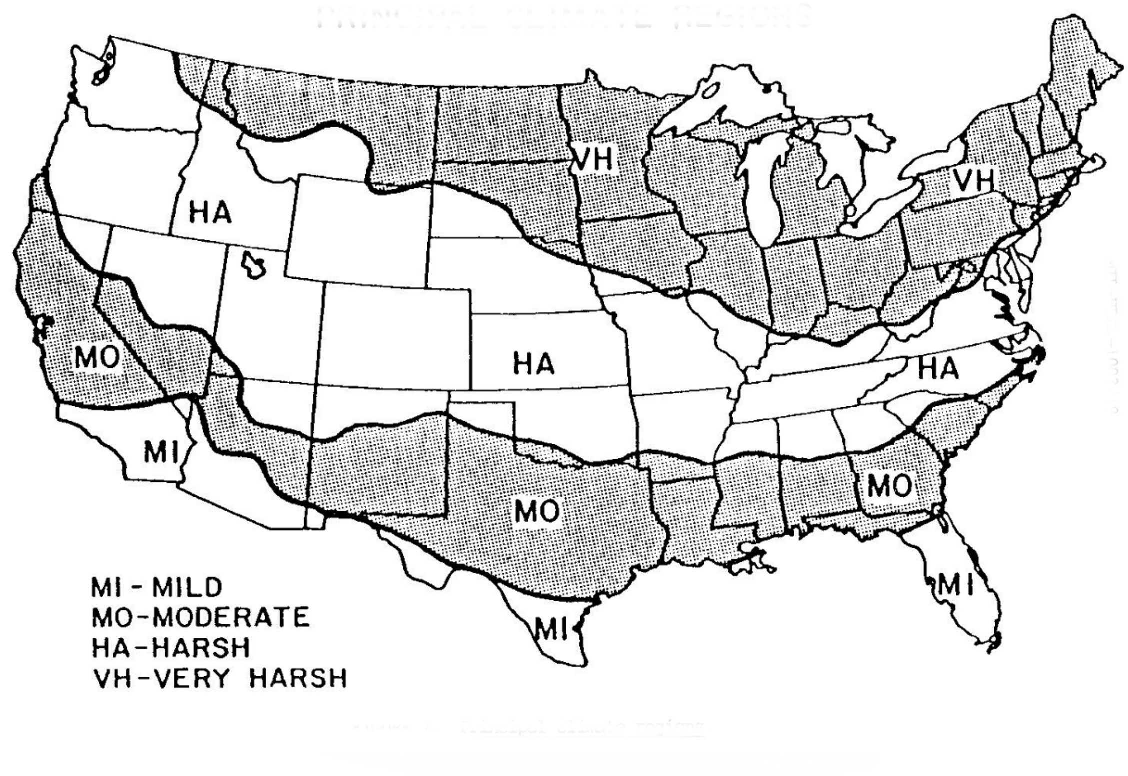
In the following discussion, combinations of VT2 and DD are used to characterize climates with regard to the relative importance of conservation and passive solar measures for reducing auxiliary heat consumption in buildings.

3.2 Climate and Conservation Measures. The fraction of the monthly heating load of a building that can be met by passive solar strategies depends on certain characteristics of the building design, and for double glazed systems, which are by far the most common, on the ratio VT2/DD. For this discussion, it is sufficient to know that the parameter VT2/DD provides an accurate measure of the passive solar potential of a given climate during any selected month. It follows that by considering the value of VT2/DD for each month in the heating season, it is possible to assess the passive solar potential of the climate-for the full annual cycle. One way to do this might be to average VT2/DD over all months in the heating season, but that approach would ignore the fact that it is more important to have high solar heating fractions in cold months with high values of DD than it is in warm months with low values of DD. The solution to this dilemma is to determine the degree day weighted average of VT2/DD.
It follows that in climates having low values of weighted average of VT2/DD conservation measures such as insulation, storm windows, weather stripping, etc., will be more important than in climates having high values. If only a small portion of the building load can be displaced with solar energy, then reduction of that load through the use of conservation measures clearly becomes a top priority. A map of the continental United States with contours of constant weighted average of (VT2/DD) is presented in Figure 7. The three contour lines divide the map into four climate regions that are referred to as mild (MI), moderate (MO), harsh (HA), and very harsh (VH). General descriptions of these climate regions and qualitative comments regarding regionally appropriate design are presented in the next four subsections.

3.2.1 Mild Climates. The mild climate region includes the southern third of California and Arizona, small parts of the southern extremes of New Mexico, Texas, and Louisiana, and most of the Florida peninsula.

in the mild region the winter heating load varies from small to nil and in any case, there is plenty of sunshine available to meet whatever loads do arise. Generally, the small heat loads can be displaced with inexpensive radiant panels or direct gain systems having relatively small solar collection apertures. However, summer cooling loads in this region can be quite high, usually exceeding the winter heating load several times over.

FIGURE 7
PRINCIPAL CLIMATE REGIONS



It is therefore particularly important to assure that the incremental cooling load associated with the passive heating system does not negate the small savings realized during the winter heating season. The use of defensive countermeasures such as adjustable shades and shutters that shield the solar aperture from direct and diffuse sunlight during the cooling season is essential. The term defensive cooling refers to strategies or devices that prevent excess heat from entering a building, in contrast to procedures for removing such heat with air conditioning equipment after it has gained entry. Because of the high SHFs obtainable in the mild region, conservation measures are not as important as in regions further north.

3.2.2 Moderate Climates. The moderate region includes most of California, the southern half of Nevada, the central third of Arizona, and most of New Mexico, Texas, Louisiana, Mississippi, Alabama, Georgia, and South Carolina. The Florida panhandle and most of the North Carolina coast are also included.

Thermal storage walls, sunspaces, thermosiphoning air panels, and direct gain systems are all appropriate in this region. The solar apertures will be larger than in the mild region and more thermal insulation will be required. Defensive cooling strategies are also important to overall performance.

3.2.3 Harsh Climates. The harsh region includes most of Washington, Oregon, Idaho, Nevada, Wyoming, Utah, Colorado, Nebraska, Kansas, Oklahoma, Missouri, Arkansas, Kentucky, Tennessee, Virginia, and North Carolina. Northern parts of Arizona, New Mexico, Texas, Mississippi, Alabama, Georgia, and South Carolina are also included as well as southern parts of Montana, South Dakota, Iowa, Illinois, Indiana, and West Virginia. Finally, the harsh region includes coastal areas in Massachusetts, Rhode Island, New York, New Jersey, Maryland, and all of Delaware.

At the northern extremes of the harsh region, night insulation should be considered on direct gain apertures. Otherwise, all passive systems may be adequate in this region; heating loads are substantial making conservation measures very important. Despite the large heating loads, defensive cooling strategies are still required to assure positive net energy savings.

3.2.4 Very Harsh Climates. The very harsh region includes all of North Dakota, Minnesota, Wisconsin, Michigan, Ohio, Vermont, New Hampshire, and Maine; most of Montana, South Dakota, Iowa, Illinois, Indiana, West Virginia, Connecticut, Pennsylvania, and Massachusetts; and parts of Washington, Idaho, Wyoming, Nebraska, Kentucky, Virginia, Maryland, New Jersey, and Rhode Island.

Near the boundary between the harsh and very harsh regions or in areas with greater than average sunshine, direct gain systems without night insulation may still be viable provided the aperture is kept fairly small. Thermal storage walls and sunspaces will function well in this region although night insulation may be desirable near the northern boundary; TAPs are a good choice because arbitrarily high levels of fixed insulation can be placed between the collector surface and the living space. Heavy use of conservation measures is critical to performance in the very harsh region. Defensive cooling strategies, though less of a concern than in regions with milder winter climates, should not be ignored.

3.3 Solar Availability. As previously discussed, the parameter VT2 provides a measure of the availability of solar radiation as a space heating resource during a specified time period. If VT2 were evaluated for the duration of the winter heating season the result would provide some indication of the potential of the site for passive solar heating applications. However, it is more important to have high solar availability during the colder months of the heating season than during the warmer months, and the straight summation involved in evaluation of VT2 does not reflect this fact. A better measure of the effective solar availability is obtained by taking the degree day weighted average of the monthly VT2s that occur during the heating season.

A map of the continental United States with contours of constant weighted average of VT2 is presented in Figure 8. The four contours divide the map into five regions that are labeled most sunny (MS), very sunny (VS), sunny (SU), cloudy (CL), and very cloudy (VC). These five regions cut across the four principal climate regions defined in Figure 7 and form subregions that are related to the appropriate size of solar apertures. As a general rule, the sunnier subregions of a particular principal climate region should have the larger solar apertures.

The ideal climate for passive solar applications is one in which high solar availability coincides with a large heat load; large apertures are appropriate in such a climate. In the continental United States, the best climates for passive solar design lie in the subregion formed by the most sunny and harsh climate regions. Solar apertures should be relatively small in the mild climate region because the heat load is small, and relatively small in the very harsh region because solar availability is low. Some general comments on the solar regions defined in Figure 8 are presented below.

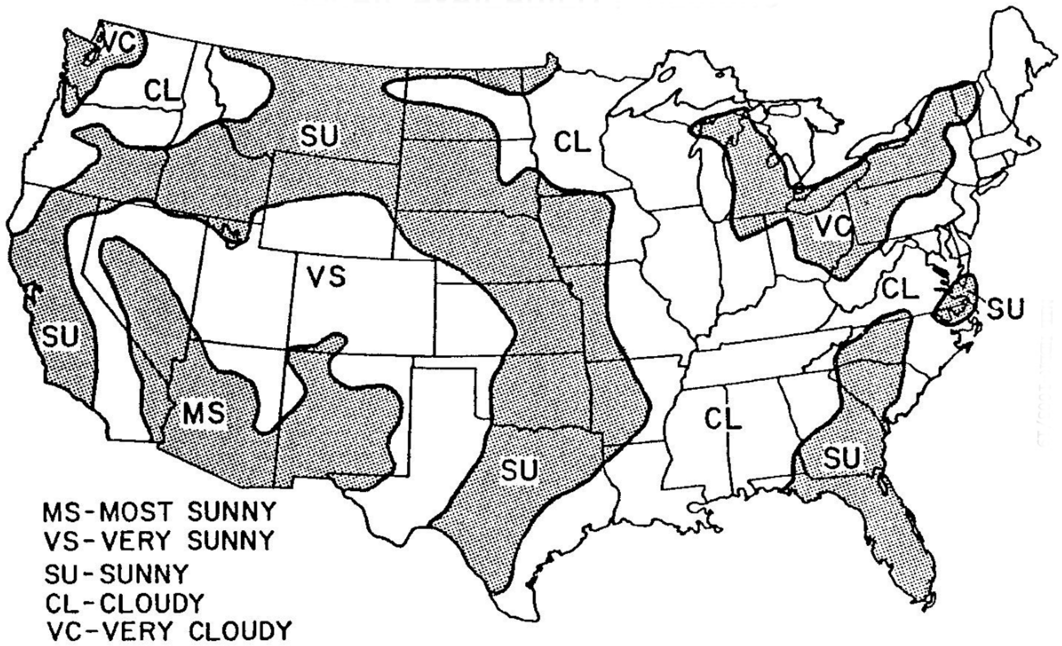
3.3.1 Most Sunny Region. This region is limited to the desert southwest and includes major parts of Nevada, Arizona, and New Mexico. Subregions in which the most sunny region overlaps the harsh region are ideal for passive solar heating because of the coincidence of a substantial heating load and excellent solar availability. The most sunny/moderate subregion is also quite good for passive solar heating.

3.3.2 Very Sunny Region. The very sunny region forms a complex crescent that bounds the most sunny region. It forms a large, verysunny/harsh subregion in which passive solar applications are very beneficial.

3.3.3 Sunny Region. The sunny region forms a still larger crescent about the very sunny region, and includes parts of Florida, Alabama,Georgia, South Carolina, North Carolina, and Virginia. The sunny area cuts completely across the country from North to South and forms subregions with all four principal climate zones. A broad range of passive solar designs is viable across these subregions.

3.3.4 Clouds Region. The cloudy region also traverses the country from north to south and forms four types of subregions among which many passive designs are feasible. Parts of the Pacific northwest, the Midwest, and the eastern seaboard are included in the cloudy region.

FIGURE 8
SOLAR AVAILABILITY REGIONS



3.3.5 Very Cloudy Region. The very cloudy region includes only the extreme Pacific Northwest and the central to eastern Great Lakes area. The Great Lakes area, where the very cloudy region overlaps the very harsh region, is the poorest location in the continental United States for passive solar heating. The Pacific northwest area overlaps the Harsh climate region and is slightly better suited for passive solar applications. Schematic design guidelines that are related to the climate regions appearing in figures 7 and 8 are discussed below.

3.4 Guidelines for Schematic Design. The objective during schematic design is to develop a rough idea of what the final building will be like. The designer is not concerned with detail at this point but seeks only to establish the basic shape, dimensions, materials, window areas, and insulation levels that will characterize the design; in these procedures, the characteristics of the passive solar heating system are added to the list of more traditional architectural concerns.

3.3.1 Building Shape and Orientation. Passive solar buildings are usually elongated in the east-west direction so that a large south-facing surface is presented to the low winter sun for solar heating, and small east and west-facing surfaces are presented to the northerly rising and setting summer sun to reduce unwanted solar gains. The aspect ratio (east-west dimension divided by north-south dimension) should be at least 5/3.

Ideally, passive solar buildings should be no more than two zones deep in the north-south direction. The two zone limit on depth generally allows solar heat collected on the south side of the building to be transported for use to the north side, thereby improving thermal performance. Multi-story buildings are well suited to passive solar design, particularly if the above recommendations on aspect ratio and depth are observed, because of the large vertical surface that may be presented to the winter sun for solar absorption.

Orientations that depart from true south by up to 30 degrees are permissible; performance penalties will usually be less than 10 percent. An easterly bias is preferred in applications that require a rapid warm up in the morning, whereas a westerly bias will sometimes improve the performance of buildings that are occupied in the evening because of the improved phasing of heat source and heat load.

3.3.2 East, West, and North Windows. Windows not facing south should be kept small while complying with local building codes. Particularly in the colder climates, it is best to place most of the non-south window area on the east or west side of the building to take advantage of winter solar gains available during the early morning and late afternoon.

All windows, including those facing south, should have at least two glazing layers, and in the harsh and very harsh regions, triple or even quadruple glazing should be considered. Especially in the warmer climates, drapes or better still, movable opaque covers or shades, as described in Thermal shutters and shades, are recommended as means to prevent unwanted sunlight from entering the windows during the summer.

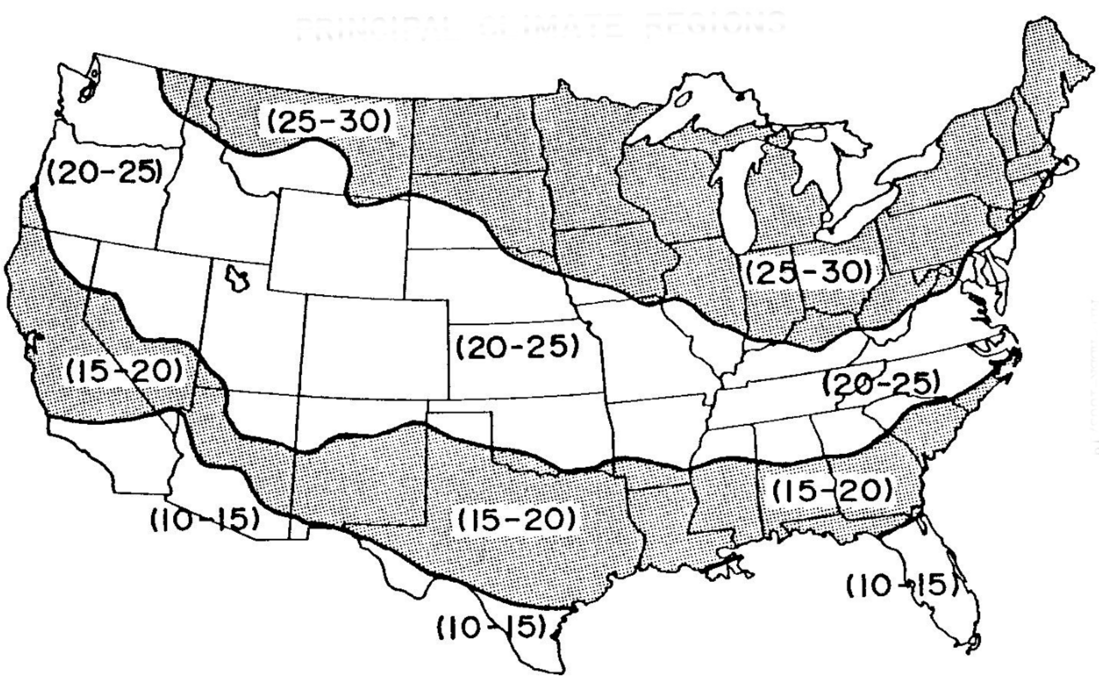
3.3.3 Passive Heating System Characteristics. The interaction between a passive heating system and its environment is a complex process that involves many subtle phenomena. The complexity of the interaction makes it difficult to determine exactly what type of passive system will perform best in a given climate. Ultimately, detailed design analysis calculations of the type to be described later in these procedures may be required to make the final decision. However, a few generalizations may be cited that are useful for selecting candidate systems during the schematic phase of design.

The general rules for system selection are based on the steady state conductance of the passive solar aperture. The aperture conductance is the amount of heat that would be lost through the solar aperture if the outside ambient temperature were maintained at 1deg.F below the indoor temperature for a period of one hour. It is generally true that systems with low values of steady state conductance are better suited for use in areas having relatively severe winter climates than are systems with larger aperture conductances. The climate regions based on the importance of conservation measures that are illustrated in Figure 7 provide a convenient measure of winter severity. The selection process based on aperture conductance may be further refined by the observation that it is also more important to have a small steady state conductance in regions that receive relatively little sun; the solar availability contour map in Figure 8 is useful in making this secondary assessment. In summary, passive solar systems having low aperture conductances are recommended for use in regions having severe winter climates with little sunshine.

3.3.4 Sizing Overhangs. The purpose of a fixed overhang is to reduce unwanted solar gains during the summer while allowing the low winter sun to illuminate the solar aperture and provide heat to the building interior. Sizing an overhang is a difficult problem because the heating season is not symmetrical about the winter solstice, but tends to be displaced toward the new year. Therefore, a design that provides adequate protection from overheating in the fall may tend to reduce the amount of solar energy available for needed space heating in late winter or spring. Since an overhang does not provide protection from sky diffuse or ground reflected radiation, it is often necessary to provide additional countermeasures to prevent overheating during the cooling season. For this reason, the currently accepted design practice is to size an overhang such that the performance of the passive heating system is minimally affected, and employ additional countermeasures against overheating as required.

3.3.5 Insulation Levels. Starting point values for thermal insulation are recommended on the basis of principal climate region and building size, and geometry. The R-values (thermal resistance) of walls, including installed insulation and other layers, should lie in the intervals consistent with the intervals indicated in Figure 9.

FIGURE 9
PRINCIPAL CLIMATE REGIONS, R VALUES



Larger buildings derive a greater benefit from incidental heating by internal sources because of the reduced external surface area relative to the heated floor area

For three reasons, it is common practice to employ higher levels of insulation in the ceiling than the wall:

a. It is cheaper to insulate the ceiling than the wall.

b. Stratification causes larger heat loss rates per unit area of ceiling than per unit wall area.

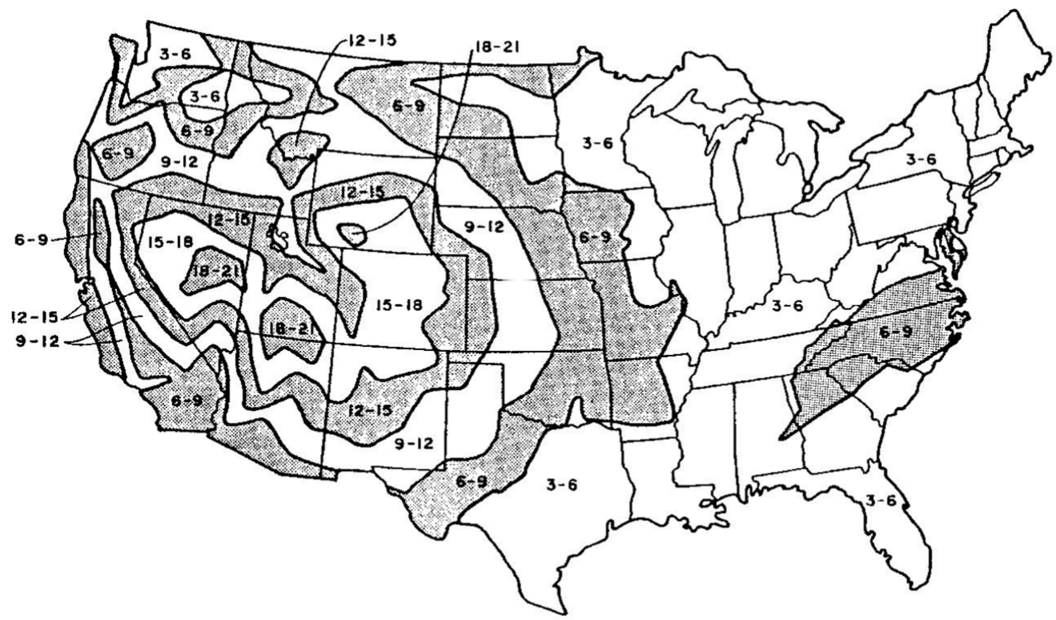
c. Solar gains on roofs during the summer can cause unwanted heating of the living space beyond that caused by high ambient air temperature.

Heat losses through building perimeters and fully bermed basement walls are limited by contact with the soil so that insulation levels need not be so high as for exposed external walls. Ordinarily, floors are not insulated so as to assure that pipes located below do not freeze. Because of widely varying conditions beneath ground level floors, it is difficult to recommend specific insulation levels. The insulation levels recommended above are intended only as starting point values. Design analysis calculations described in later sections should be performed before fixing any important design variables.

3.3.6 Infiltration. Many older buildings have infiltration rates as high as 1.5 air changes per hour (ACH). A reduction to 1.0 ACH may be achieved by employing a plastic vapor barrier; taking care to seal all joints and foam any cracks will generally further reduce the infiltration rate to 0.5 ACH. It is strongly recommended that the infiltration rate be limited to 0.5 ACH for both new construction and retrofits whenever possible. Since extremely low rates may be hazardous to the occupants' health due to the accumulation of indoor pollutants, further reductions in infiltration heat loss should be attempted only through the use of window heat recovery units. Extensive use of these units can yield effective infiltration rates as low as 0.187 and under certain circumstances, the additional expense involved may be justifiable.

3.3.7 Solar Collection Area. The solar collection areas indicated here are intended to illustrate starting point values for a design analysis procedure. Figure 10 is an example of solar aperture area in percent of floor space. Remember, this is only for illustration purposes. Large apertures occur where high solar availability coincides with a large heat load. Small apertures occur where the solar availability is low or the heat load is small.) These aperture sizes, used in conjunction with the recommended insulation and infiltration levels, will yield a payback period of ten years for some systems.

FIGURE 10
SOLAR APERTURE AREA IN PERCENT OF FLOOR SPACE
(ILLUSTRATIVE EXAMPLE FOR ONE TYPE OF SYSTEM)



3.3.8 Thermal Storage Mass. The amount of thermal storage mass required per square foot of solar aperture depends primarily on the solar availability at the building site. The relative solar availability in the continental United States is given by the contour map in Figure 8.

Masonry thermal storage walls and sunspaces with masonry common walls generally employ a wall thickness of about 12 inches of high density material. This thickness is quite appropriate in the sunny region and to a large extent, in the adjacent cloudy and very sunny regions. However, in the most sunny region a wall thickness of 18 inches should be employed to protect against overheating and fully utilize the available resource. In the very sunny region, wall thicknesses may range from 12 inches to 18 inches depending on which boundary the building site is nearest. At the other extreme, mass walls in the very cloudy region need only be 6 inches thick and in the adjacent cloudy region, thicknesses may range from 6 inches to 12 inches depending on position relative to the boundaries. When water containers are used for thermal storage, either in sunspaces or thermal storage walls, equivalent thicknesses comparable to those recommended for masonry walls are appropriate in all solar availability regions; however, because the heat capacity of water is roughly twice that of high density masonry, significant downward revisions may be permissible.

Direct gain apertures, radiant panels, and TAPs all use interior mass for heat storage. Ideally, the interior mass should have a high density and be distributed in thicknesses of 2 inches to 6 inches. Appropriate area ratios are 3 in the very cloudy region, 3 to 6 in the cloudy region, 6 in the sunny region, 6 to 9 in the very sunny region and 9 in the most sunny region. Equivalent or somewhat smaller volumes of water may be used instead of masonry in lightly constructed buildings.

4. CONCLUSION

This brief discussion has been intended to introduce you to basic types of passive systems that may be used to heat buildings and thereby conserve energy, the roles of climate and solar availability in determining the feasibility of passive solar systems, and some guidelines that may be useful in undertaking feasibility studies and preliminary designs. This will give you a foundation for learning about and utilizing more technically rigorous methods that are available in the engineering literature.