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**AUTHOR(S):** William O. Wray and Claudia E. Kosiewicz

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# A SIMPLE PROCEDURE FOR SCHEMATIC DESIGN OF PASSIVE SOLAR BUILDINGS*

by

William O. Wray and Claudia E. Kosiewicz
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

## ABSTRACT

A simple procedure for use during the schematic phase of passive solar building design is presented in this article. The procedure is quantitative and accurate enough to insure that designs based on the provided starting point values of the primary building parameters will be cost effective.

## INTRODUCTION

The appropriate use of passive solar and conservation measures in buildings depends on climate in a manner that is fairly well understood by experienced architects and builders and by researchers whose understanding is based on scientific principles. In this paper, we seek to convey our own scientifically based understanding of the building/climate relationship to interested professionals as well as to provide a step-by-step procedure for schematic design.

The design procedures presented herein were excerpted from "Passive Solar Design Manual for Naval Installations."[1] A second paper dealing with design analysis will appear in a later issue.

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*Development of these simplified design procedures was supported by the Naval Civil Engineering Laboratory at Port Hueneme, California. The Navy project officers who directed the work were Charles Miles and Ed Durlak.

## GENERAL CLIMATIC CONSIDERATIONS

### Important Weather Parameters

The heating degree days (DD) value for a period of 1 day is calculated by summing the difference between the base temperature of interest and the outside ambient temperature for each hour of the day. If an hourly difference happens to be negative, we set DD equal to zero for that particular hour. Using this procedure for determining the daily DD, one can easily obtain the heating degree days for a time period of arbitrary length, say a month or a year, simply by summing the daily contributions that occur during the period. Consequently, the amount of heat required to maintain a building at the base temperature (in the absence of internal sources) for one month is given by

$$Q_L = TLC \cdot DD \text{ (Btu)} \quad , \qquad (1)$$

where TLC (Btu/°F day) is the total load coefficient of the building and DD is the number of degree days occurring during the month. The total load coefficient is defined as the amount of heat required to maintain a 1°F difference between the inside and outside ambient temperatures for a period of 24 hours. The heat load for the entire heating season is obtained simply by adding the monthly loads given by Eq. (1). Thus, DD is an important climate parameter because it is directly proportional to the building heat load. The units of degree days are °F day.

The amount of solar radiation, VT2, that is transmitted through 1 $ft^2$ of a vertical, south-facing, double-glazed aperture during a given month is a second important weather parameter. The parameter VT2 is important because it quantifies the solar resource available for passive space heating. In the following section we will show that various combinations of the parameters VT2 and DD can be used to characterize climates with regard to the relative importance of conservation and passive solar measures for reducing auxiliary heat consumption.

### Climate Regions Based on Importance of Conservation Measures

The fraction of the total monthly heating load of a building that can be met by passive solar strategies depends on certain features of the building design and the weather parameter S/DD, where S is the monthly solar radiation absorbed by the passive system. Depending on the building characteristics and the type of passive heating system involved, S is usually between 0.9 VT2 and 1.0 VT2 for double-glazed systems. We can, therefore, employ the parameter VT2/DD to obtain a rough idea of the passive solar potential of a particular climate during a given month. If we wish to know the passive solar potential of a particular climate for the entire heating season, we take the degree day weighted average of VT2/DD for all the months in the heating season, using the notation $\overline{VT2/DD}$ to indicate the weighted average.

Now, climates with like values of the characteristic parameter $\overline{VT2/DD}$ can be expected to yield like values of the solar heating fraction, SHF (the fraction of the total building load met by solar energy), for identical buildings. High values of $\overline{VT2/DD}$ yield high SHFs and, conversely, low values of $\overline{VT2/DD}$ yield low SHFs. It follows that in climates having low $\overline{VT2/DD}$ ratios, conservation measures (insulation, weather stripping, etc.) will be more important than in climates having higher values. Clearly, if only small fractions of the building load can be met by solar energy, one must seek to reduce that load by appropriate conservation measures to significantly reduce energy consumed for space heating. A map of the continental United States with contours of constant $\overline{VT2/DD}$ is presented in Fig. 1. The uppermost, middle, and lowest contours are given by $\overline{VT2/DD}$ = 30, 50, and 90 Btu/ft$^2$ °F day, respectively. As indicated on the map, the four climate regions defined by the contours are referred to as mild (MI), moderate (MO), harsh (HA), and very harsh (VH). General descriptions of these climate regions and qualitative comments concerning regionally appropriate design are presented in the following four subsections.

*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 this region the winter heating load varies from small to nil and, in any case, there is plenty of sunshine available to meet most of the small loads that arise. In general, the heating loads can be met using less expensive direct gain systems with relatively small solar collection apertures. Summer cooling loads can be quite high in this region, however, sometimes several times larger than the heating load. Thus, it is particularly important to make sure that the small amount of energy saved by passive solar heating is not negated by the associated incremental cooling load. The use of defensive countermeasures is strongly recommended. Because of the high solar heating fractions obtainable in this region, conservation measures are less important than in areas farther north.

Moderate Climates. The moderate region comprises 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.

Both thermal storage wall and direct gain systems are appropriate in this region. More insulation is required and, because of the larger ratio of heating load to cooling load, larger solar collection apertures are the rule.

Harsh Climates. The harsh region embraces 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. Heating loads are appreciable in this region, but it is still necessary to exercise care not to unduly aggravate the summer cooling load. Conservation measures are very important.

Very Harsh Climates. The very harsh region contains 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 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. However, if night insulation is not employed, the direct gain apertures should be kept fairly small. Thermal storage walls are preferred in the very harsh region and the addition of night insulation may be advisable near the northern boundary. Because relatively small solar savings fractions are obtainable in this region, heavy use of conservation measures is critical to achieving energy-efficient performance.

## Climate Regions Based on Solar Availability

To define climate regions on the basis of the availability of solar energy as a space-heating resource, we have calculated the degree day weighted average of the monthly radiation transmitted through vertical, south-facing, double-glazed apertures. The notation $\overline{VT2}$ is used to represent the weighted average. The degree day weighting has been employed because solar radiation is most valuable when the heating load is highest and is of no value (as a space-heating resource) when the heat load is zero (or when DD is zero).

A map with contour lines of constant $\overline{VT2}$, presented in Fig. 2, divides the country into five solar regions that we label as follows:

(1) Most Sunny (MS): $\overline{VT2} = 30 \rightarrow 40$ (KBtu/$ft^2$),
(2) Very Sunny (VS): $\overline{VT2} = 25 \rightarrow 30$ (KBtu/$ft^2$),
(3) Sunny (SU): $\overline{VT2} = 20 \rightarrow 25$ (KBtu/$ft^2$),
(4) Cloudy (CL): $\overline{VT2} = 15 \rightarrow 20$ (KBtu/$ft^2$),
(5) Very Cloudy (VC): $\overline{VT2} = 0 \rightarrow 15$ (KBtu/$ft^2$).

These five regions cut across the four principal climate regions defined in Fig. 1 and form subregions that determine appropriate sizes for solar apertures.

As a general rule, the sunnier subregions of a particular principal climate region should have the larger solar apertures; the largest apertures will occur in the sunnier parts of the moderate and harsh principal climate zones. Apertures will be relatively small in the mild region because the heat load is modest, but also relatively small in the very harsh region because heavy use of conservation measures is the preferred strategy. Some general comments on the solar regions defined in Fig. 2 are presented in the next five subsections.

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 strategies 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.

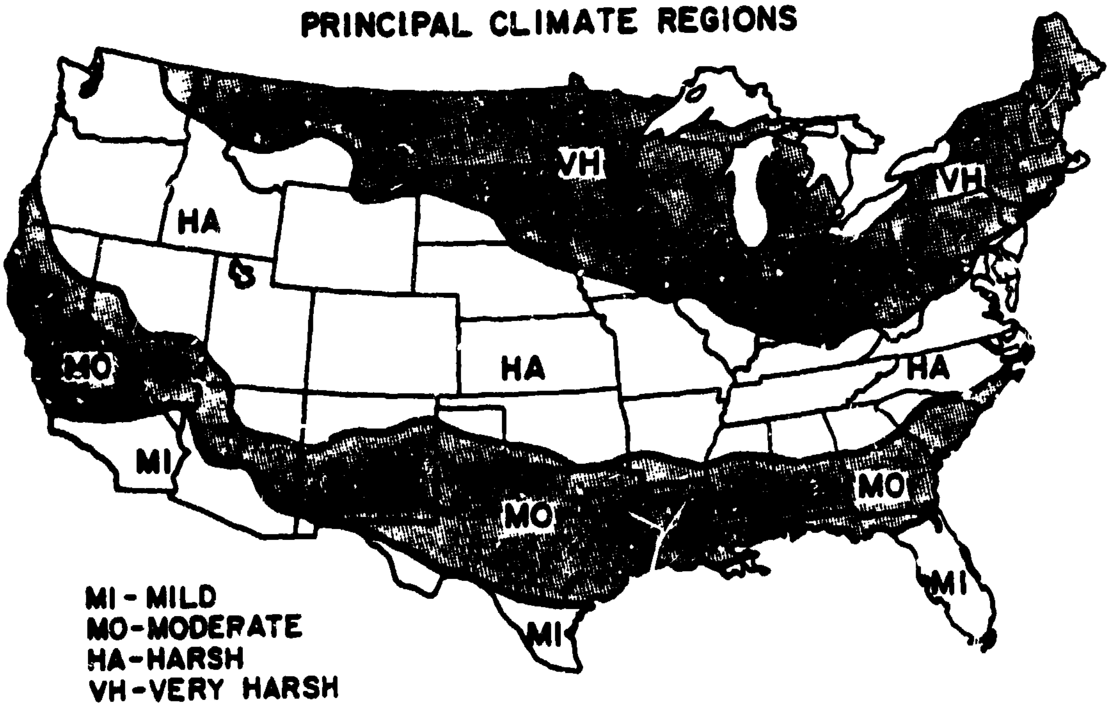

Fig. 1. Principal climate regions in the continental United States for passive solar design.

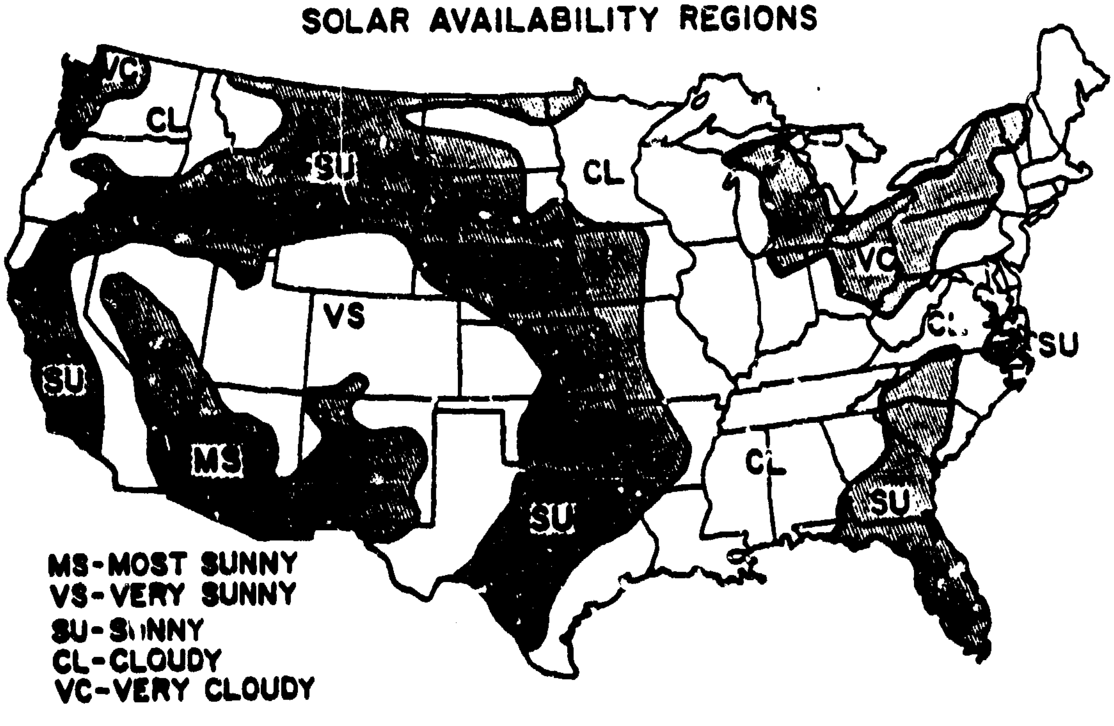

Fig. 2. Climate regions based on solar availability.

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

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 of the principal climate zones. A broad range of passive solar designs is viable across these subregions.

Cloudy 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.

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.

## GUIDELINES FOR SCHEMATIC DESIGN

During the schematic phase of architectural design, one is involved in developing a rather coarse picture of the desired building. At this point in the design process, design-analysis techniques are of little use because the building is not well defined. What is needed during schematic design is a set of rules of thumb to help the designer select starting-point values for the principal design parameters. In the sections that follow, we present climate-specific guidelines for determining the initial design.

### Building Shape and Orientation

Passive solar buildings should be elongated in the east/west direction such that a large south-facing surface is presented to the low winter sun for heat collection, and small east- and west-facing surfaces are presented to the northerly rising and setting summer sun to minimize unwanted heat gains. The aspect ratio (east-west dimension divided by north-south dimension) should generally be at least 1.67, although much larger values would be appropriate for large dormitory-like structures. It is best if passive solar buildings are no more than two zones deep in the north-south direction because overall performance is enhanced if solar heat collected in the southern zone can be transported for use in the zones lacking solar apertures. Multistory buildings are appropriate candidates for passive solar heating, provided the depth in the north/south direction is limited to two principal zones and the aspect ratio is kept above 1.67.

Departures of up to 30° from a true south orientation are permissible; performance penalties will be less than 10%. An easterly bias in orientation is preferred if a more rapid warm-up in the morning is desired, whereas a westerly bias may yield better performance in buildings that will be occupied after working hours, because of the improved phasing of solar resource and heat load.

### East, West, and North Windows

Windows not facing south should be kept small while complying with local building codes. Particularly in cold climates, most of the nonsouth window area should be placed on the east or west side of the building to take advantage of solar gains available during the early morning and late afternoon.

All windows not facing south should have at least two glazing layers and, in the harsh or very harsh regions, it would be wise to consider the use of triple glazing. Movable opaque covers should be provided on east- and west-facing windows to screen out unwanted sun during the summer.

### Type of Passive System

Only two types of passive solar heating systems are currently addressed in this procedure. Thermal storage wall systems are massive south-facing walls covered externally with one or more glazing layers. Solar radiation is transmitted through the glazing and absorbed on the mass surface. The glazing is opaque to infrared (IR) radiation emitted by the hot storage wall so that losses back to the outside are limited. Heat migrates through the storage medium and is introduced to the living space upon reaching the inside surface. Three types of storage media are considered in this manual: (1) concrete or brick, (2) water, and (3) 8-in. concrete building blocks, with cores empty or filled with mortar. Direct gain systems involve ordinary south-facing windows that introduce solar energy directly to the living space. It is generally necessary that direct gain buildings be fairly massive so that heat may be stored in the building elements for nighttime use.

However, low-mass direct gain buildings are viable if the aperture is sized to meet only the daytime heating load.

Thermal storage walls, particularly those without vents, provide more stable indoor environments than do direct gain systems. The mass of the wall exerts a moderating effect on inside temperatures and, consequently, overheating is seldom a problem. Also, because of the thermal-lag effect associated with heat transport through masonry storage walls, solar heat delivery is at a maximum during the evening hours when it is most needed in residential applications. As an additional benefit, the mass wall provides a buffer against high outside ambient temperatures during the cooling season.

Thermal storage wall systems are applicable in all four climate regions defined on the contour map in Fig. 1. In the milder climates, defensive countermeasures may be required to limit solar heat gain during the cooling season. In the harsher winter climates, one may need additional glazing layers or possibly even night insulation to achieve adequate solar gains during the heating season. Bear in mind that winter night insulation that is intended to increase the net diurnal heat gain of the solar aperture can be used in the reverse mode during the summer; that is, one may have the aperture insulated during the day to limit unwanted solar gains and remove the insulation at night to facilitate cooling, if the outside ambient temperature is low enough. Recommended glazing levels for thermal storage walls with or without night insulation are presented in Table I for the four principal climate regions. Defensive strategies for controlling summer heat gains are also suggested. The purpose of external covers is to shade the aperture from direct and diffuse radiation. A fixed overhang provides partial protection from direct radiation; moreover, a seasonal overhang achieves the same objective, but more effectively because of its adjustable feature. In the present context, venting refers to allowing heat built up between the thermal storage-wall surface and the inner glazing to escape from the air gap. A natural circulation pattern will be established if vents to the outside are placed at the top and bottom of the storage wall.

Direct gain systems have the advantages of being less expensive than thermal storage walls, at least for inherently massive structures, and involve less departure from conventional building design. However, they are more sensitive to external conditions and, if not properly designed, may be prone

## TABLE I

## RULES OF THUMB FOR THERMAL STORAGE WALL ELEMENTS

### SYSTEMS WITH NO NIGHT INSULATION

| Climate | No. of Glazings | Defensive Cooling Strategy |
|---|---|---|
| Mild | 1 | External covers |
| Moderate | 1-2 | External covers |
| Harsh | 2 | Seasonal overhang and venting |
| Very Harsh | 2-3 | Fixed overhang and venting |

### SYSTEMS WITH R5 NIGHT INSULATION

| Climate | No. of Glazings | Defensive Cooling Strategy |
|---|---|---|
| Mild | 1 | Seasonal cover |
| Moderate | 1 | Seasonal cover |
| Harsh | 1-2 | Seasonal cover |
| Very Harsh | 2 | Seasonal cover |

## TABLE II

## RULES OF THUMB FOR DIRECT GAIN SYSTEMS

### SYSTEMS WITH NO NIGHT INSULATION

| Climate | No. of Glazings | Defensive Cooling Strategy |
|---|---|---|
| Mild | 2 | External covers |
| Moderate | 2 | Internal shades or blinds |
| Harsh | 2-3 | Drapes and seasonal overhang |
| Very Harsh | 3 | Drapes and fixed overhang |

### SYSTEM WITH R5 NIGHT INSULATION

| Climate | No. of Glazings | Defensive Cooling Strategy |
|---|---|---|
| Mild | 1 | Seasonal cover |
| Moderate | 1-2 | Seasonal cover |
| Harsh | 2 | Seasonal cover |
| Very Harsh | 2-3 | Seasonal cover |

to overheat during the winter, aggravate the cooling load during the summer, or lose so much heat through the aperture during cold winter nights that net heat gains are minimal or even negative. The rules of thumb presented in Table II will enable the designer to avoid these problems.

A mixture of thermal storage wall and direct gain systems on a single building is desirable because one is able to take advantage of the best features of both designs. Thermal storage walls

(1) are thermally stable,
(2) deliver maximum heat in the evening, and
(3) yield relatively high performance.

Direct gain systems

(1) provide quick warm-up in the morning,
(2) allow for a view to the south,
(3) provide daylighting,
(4) are especially easy to control by movable insulation or shades, and
(5) are relatively inexpensive.

Procedures for estimating the performance of direct gain and thermal storage wall systems, individually or in combination, will be presented in a later paper on design analysis.

## Insulation Levels

Recommended levels of insulation depend only on the principal climate region in which the building is located (see Fig. 1) and on the building size. The R-values (thermal resistance) of wall insulation should lie in the following intervals for small (1500 ft$^2$), one-story, single-family detached residences:

(1) Mild Region: $RWALL_o = 10 \rightarrow 15$ (ft$^2$-°F-h/Btu)
(2) Moderate Region: $RWALL_o = 15 \rightarrow 20$ (ft$^2$-°F-h/Btu)
(3) Harsh Region: $RWALL_o = 20 \rightarrow 25$ (ft$^2$-°F-h/Btu)
(4) Very Harsh Region: $RWALL_o = 25 \rightarrow 30$ (ft$^2$-°F-h/Btu)

These recommendations are consistent with the results of a study on the economics of mixing conservation measures and passive solar strategies conducted for the US Department of Energy by the Los Alamos National Laboratory.[2]

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 two-story, single-family residences, townhouses, and dormitories or office buildings, the R-values of the wall insulation should be scaled down from the above recommendations as follows:

$$RWALL = \frac{1}{3}\left(\frac{A_e}{A_f}\right) RWALL_0 \quad ,$$

where RWALL is the scaled R-value, $A_e$ is the exposed or external surface area of the building (common walls between townhouse units, for example, are excluded but ground-level floors are included), and $A_f$ is the heated floor space of the building. This scaling credits larger buildings for their more effective utilization of internal source heating during the winter by allowing reduced levels of wall insulation.

It is common practice to employ higher levels of insulation in the ceiling than in the wall for three reasons:

(1) It is cheaper to insulate the ceiling than the wall;

(2) Stratification causes larger heat-loss rates per $ft^2$ of ceiling than per $ft^2$ of wall; and

(3) Solar gains on roofs during the summer can cause unwanted heating of the living space beyond that caused by high ambient air temperatures alone.

We, therefore, recommend that the total R-value of the roof be scaled directly with the wall R-value as follows:

$$RROOF = 1.5\ RWALL.$$

Heat losses through building perimeters and through fully bermed basement walls are limited by contact with the soil so that insulation levels need not be as high as the values recommended for exposed external walls. The following formulas yield reasonable insulation levels for these surfaces:

$$RPERIM = 0.75\ RWALL, \text{ and}$$
$$RBASE = 0.75\ RWALL \quad .$$

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. However, if there is no problem with pipes freezing, a reasonable level would be

RFLOOR = 0.5 RWALL .

Before leaving this section, we wish to caution the reader that these insulation levels are recommended only as starting-point values. We recommend performance of design-analysis calculations that facilitate fine tuning the values of all important design parameters.

## Solar Collection Area

Our rule of thumb for sizing solar apertures is based on achieving annual productivities that are high enough to yield a payback period of roughly 10 years. Annual productivity is the amount of useful solar heat delivered to the building by 1 $ft^2$ of collection aperture during a full heating season. High productivities are realized with relatively small apertures that are more efficient, whereas large absolute energy savings are achieved with large apertures. By employing productivity in our sizing procedure rather than absolute energy savings, we are assured that our designs will be cost effective at any location in the continental United States.

Four representative passive solar systems were consid[illegible] in the development of our sizing rule. Two of the systems were double-glazed direct gain designs; the first had no night insulation and the second had R9 night insulation. Both direct gain designs employed 4 in. of high-density concrete for thermal storage mass, spread over an area that was 6 times the size of the solar aperture. Two 12-in.-thick, high-density concrete Trombe walls were also considered. Both Trombe walls were double glazed and vented to the inside; one employed R9 night insulation and the second had none. Each of these four systems was assigned a different productivity because of the differences in representative costs per $ft^2$ of aperture. The assigned productivities are as follows:

Direct Gain—No night insulation: P = 58,500 Btu/$ft^2$
Direct Gain—R9 night insulation: P = 76,500 Btu/$ft^2$
Trombe wall—No night insulation: P = 67,500 Btu/$ft^2$
Trombe wall—R9 night insulation: P = 85,500 Btu/$ft^2$

Contour maps of aperture size in percentage of floor area were generated for each of the above systems using the indicated productivities. Differences among the four maps were small. Therefore, a single map was generated by taking the average of the aperture sizes obtained for the four different systems. The average-aperture-size contour map is presented in Fig. 3.

Figure 3 may be used for preliminary sizing of all direct gain and thermal storage wall systems described in this article. Systems that operate at higher efficiencies tend to be more expensive and, therefore, require higher productivities to pay back in about 10 years. The higher productivities are achieved by keeping the aperture size about equal to that recommended for less efficient but cheaper systems. Thus, only a single contour map is required for initial aperture sizing.

The numbers appearing on the map in Fig. 3 give the aperture size in percentage of floor space for a single-family detached residence of 1500 $ft^2$. For larger structures, the ratio of collector area to floor area, $A_c/A_f$, should be scaled according to the following formula:

$$\frac{A_c}{A_f} = \frac{1}{3}\left(\frac{A_e}{A_f}\right)\left(\frac{A_c}{A_f}\right)_0 ,$$

where $A_e$ is the external surface area of the building and $(A_c/A_f)_0$ is the reference value of the collector-area-to-floor-area ratio from the contour map.

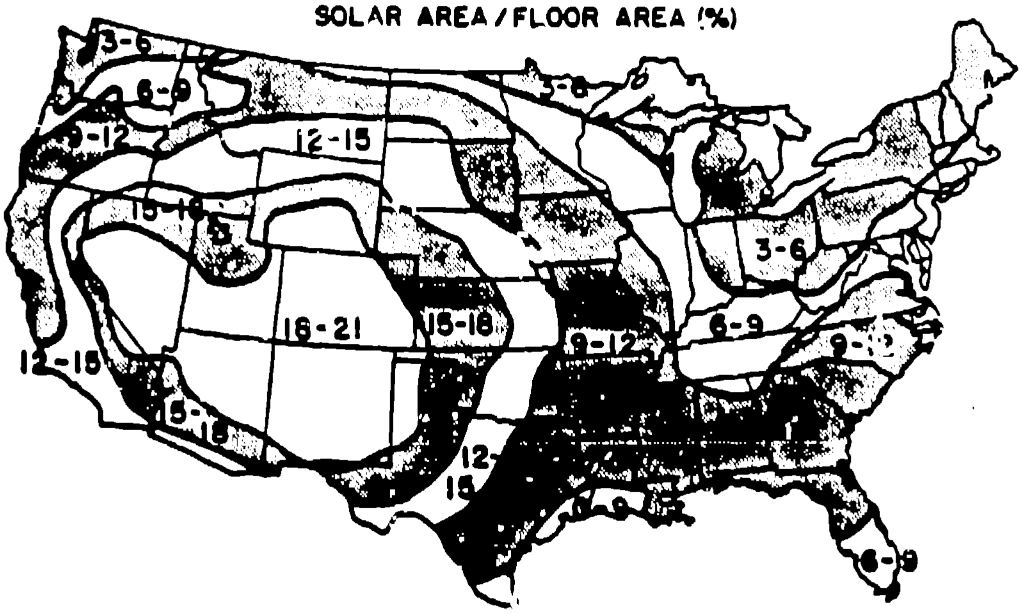

Fig. 3. Solar aperture area/floor area ratio in per cent (initial schematic design values) for direct gain and Trombe wall systems.*

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*Note: 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.

If the solar collection aperture is not oriented due south, the size should be reduced to compensate for the lower productivities that result from off-south orientations. The following formula provides a reasonable correction for departures of up to 60° from due south.

$$\frac{A_c}{A_f} = \left(\frac{A_c}{A_f}\right)_{south} \cos\left(\frac{4}{5}\theta\right) ,$$

where $\theta$ is the azimuth of the collector in degrees. The azimuth is zero for due south and positive to the east.

Thermal Storage Mass

The passive solar systems used to establish a sizing rule in the previous subsection had fixed amounts of thermal storage mass. The direct gain systems had 2 $ft^3$ of high-density concrete per $ft^2$ of aperture. The concrete has a volumetric heat capacity of 30 $Btu/ft^3$, which yields a system heat capacity of 60 $Btu/ft^2$ of solar aperture. The Trombe walls were 1 ft thick and, therefore, have a system heat capacity of 30 $Btu/ft^2$ of solar aperture.

These heat capacities, which represent good intermediate values for both types of systems considered, are most appropriate in the sunny region (see Fig. 2), and values up to 25% lower are acceptable in the cloudy region. In the smaller, very cloudy region, reductions of 25 to 50% are permissible. However, in the very sunny and most sunny regions, one might consider using more thermal storage mass to reduce the incidence of winter overheating. Trombe walls up to 18 in. thick are appropriate in both regions as are direct gain buildings with 3-4 $ft^3$ of concrete per $ft^2$ of aperture. It is best to use thin layers of thermal storage mass with large surface areas in direct gain buildings to facilitate heat transfer to and from storage. Concrete is most effective in thicknesses of 4 in. or less, but layers up to 6 in. thick are permissible.

Schematic Design Worksheet

Worksheet No. 1 is provided to assist the user in organizing and recording the results of the schematic design process discussed in this paper. (Additional worksheets will be presented in a later paper on design analysis.) The worksheet is self-explanatory except that the quantity, $P_t$, has a special definition. $P_t$ is the total external perimeter of the heated floor space, $A_f$, selected for analysis. The floor space may occupy one or more levels in a building, and $P_t$ is defined as the total external perimeter of all levels included in the analysis. Thus, for a two-story building being analyzed as a single unit, the total perimeter is the perimeter of the ground floor plus the perimeter of the upper floor. If the two-story unit is a duplex consisting of two distinct thermal zones separated by a vertical plane, one may choose to analyze the thermal zones separately. In this case, the length of the common wall separating the two zones must be subtracted from the perimeter of each level before summing to obtain $P_t$.

## CONCLUSION

The procedures presented in this article should enable one to rapidly specify appropriate starting-point values for the primary passive solar building parameters. Designs based on these parameters will be comfortable and cost effective. However, it is always wise to follow schematic design with a more detailed analysis before proceeding to construction documents.

## ACKNOWLEDGMENTS

The authors would like to express their appreciation to Charles Miles and Ed Durlak for providing us the opportunity to be involved in the task of improving the energy efficiency of buildings at US Navy installations. We feel quite strongly that the military may provide the proving ground for applied passive solar technology, and thereby lead the commercial sector out of the stagnation that has characterized most building design during the past decade. Mr. Miles and Mr. Durlak are well acquainted with energy-efficient building technology. Their guidance and direction has been most valuable.

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## WORKSHEET NO. 1
## SCHEMATIC DESIGN PARAMETERS

### Building Size

Heated floor space: $A_f$ = ________ $ft^2$

Ceiling height: $h$ = ________ ft

Total external perimeter: $P_t$ = ________ ft

Note: Include external perimeter of each floor.

External surface area: $A_e = 2A_f + h\,P_t$ = ________ $ft^2$

External surface-area-to-floor-area ratio: $A_e/A_f$ = ________

### Insulation Levels

$RWALL_0$ = ________ $ft^2$ °F h/Btu

Note: $RWALL_0$ is obtained from the contour map in Fig. 1 and the insulation levels recommended in the text.

$RWALL = \frac{1}{3}\left(\frac{A_e}{A_f}\right) RWALL_0$ = ________ $ft^2$ °F h/Btu

RROOF = 1.5 RWALL = ________ $ft^2$ °F h/Btu

RPERIM
or
RBASE = 0.75 RWALL = ________ $ft^2$ °F h/Btu

### Solar Aperture Size (Due south orientation)

$\left(\frac{A_c}{A_f}\right)_0$ = ________

Note: $\left(\frac{A_c}{A_f}\right)_0$ is obtained from the contour map in Fig. 3. Remember to convert from per cent to the fractional value before recording the quantity.

$A_c = A_f\left(\frac{A_c}{A_f}\right)_0 \left(\frac{A_e}{A_f}\right) \Big/ 3$ = ________ $ft^2$

### Building Orientation (Azimuth)

$\theta$ = ________ degrees

Note: Azimuth is zero for due south and positive to the east

### Solar Aperture Size (Corrected for Off-South Orientation)

$A_c = \left(A_c\right)_{south} \cos\left(\frac{4}{5}\,\theta\right)$ = ________ $ft^2$