# Advances in Passive Solar Design Tools

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## ABSTRACT

*Since the early 1980s, an industry-based federally funded technology transfer organization in Washington, DC, has worked to improve the delivery of energy-efficient buildings designed to include architecturally based passive solar design techniques. This paper reviews the basis for these simplified and accurate design techniques, as they have been established through research and development undertaken by national laboratories, industry trade groups, and other nonprofit entities. Work is now under way to improve these design techniques and accelerate the integration of the passive solar approach into the broader context of energy efficiency in buildings.*

## INTRODUCTION

An estimated 250,000 to 300,000 passive solar buildings have been constructed in the United States, and numerous others have been built in other countries. The techniques are applicable to all building types, provided climatically responsive analysis is performed to ensure effective designs. Problems with first-generation passive solar structures have been thoroughly explored and significant strides made in new simplified design techniques to reduce or eliminate difficulties of overheating (excess temperature swings), proper air circulation, and inadvertent summer cooling load increases.

What is passive solar design? The concepts of passive solar design are fairly simple. It operates on physical principles that have been found to be efficient due to operating temperatures near optimal human comfort levels. A properly sized and constructed array of insulating windows on the south-facing side of a building can admit significant quantities of energy, as can skylights and specially designed roof apertures for daylighting building interiors. Simple design tool calculations can help builders and architects interested in energy efficiency integrate proper levels of wall, ceiling, and foundation insulation; thermal storage materials; light admittance controls; interior floor plans that improve air circulation; provisions for natural ventilation; and methods for seasonal exclusion of solar gains to avoid increased air-conditioning needs.

A key concept in passive solar design is consideration of the climate-specific outdoor environmental conditions and the systematic selection of energy efficiency levels, glazing properties and sizes, and interior characteristics (surface properties, heat storage capacity, floor plans, circulation, etc.) that work with the local environment to provide improvements to indoor comfort at reduced levels of conventional energy consumption.

### History of Passive Design

Thomas Jefferson used energy-efficient designs such as window shutters, an "orangery" or sunspace, and below-grade cooling tunnels in his Monticello home in Virginia. The earliest solar houses of the modern era (not including designs by the Greeks, Romans, Koreans, and Native Americans that could be considered passive solar) were constructed in the 1940s during the post-World War II housing boom.

Little engineering design went into these homes, which used darkly painted walls and larger expanses of glass, but occupant accounts did indicate they provided lower energy bills. However, the cheap and plentiful energy in the 1950s and 1960s acted to depress interest in solar building design.

In the late 1960s, a French researcher, Felix Trombe, designed and constructed a thermal storage wall house and conducted extensive testing of its heat storage and air circulation characteristics. The modern thermal storage wall designs evolved from this early work. Parallel efforts were under way in the United States.

In the southwestern United States, alternative dwellings were being constructed using recycled materials and adobe or masonry walls along with bigger glazed areas, solar "greenhouses," sloped collectors, and other concepts. These design elements have become part of an evolving architectural style. Early passive homes were frequently part of an alternative life-style that elected to live "off the grid." As early as 1974, entire residential developments of solar homes were being proposed in areas of New Mexico.

Through the late 1960s and early 1970s, what is now known as passive solar design developed to the degree that the scientific community became interested in its physics of operation. Work on design and analytical approaches for passive solar buildings evolved in this more technically based direction. A better understanding of basic building science resulted. During the heyday following the first oil embargo, this same evolution was simultaneously encompassing other building science and design areas, such as airtight superinsulated construction, residential ventilation systems, indoor environment and air quality concerns, earth shelters, log homes, and geodesic domes.

A key event was the development of the National Energy Act of 1974, which began demonstration programs at both the United States Department of Housing and Urban Development and the United States Energy Research and

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Development Administration—now the United States Department of Energy (DOE). A large number of active and passive designs were reviewed, selected for construction, and monitored for their performance and energy savings.

Some of these buildings were of passive solar design, and data exist on the performance and occupant reactions to more than 400 of them, including the buildings in the National Solar Data Network (NSDN), the Class-B and Class-C programs (DOE 1980), and a program conducted by the state of California (Mahajan 1983).

The Energy Act also initiated research funding to support the development of design and engineering capabilities (guidelines, manuals, computer programs, etc.) intended to support the needs of builders, developers, architects, and engineers for incorporating energy efficiency and passive solar design strategies into more buildings to save energy. This was termed a "technology transfer" effort, and it has been under way since the late 1970s with various degrees of success and penetration.

## Principal Design Approaches

There are four principal types of passive solar design for buildings. The *direct gain* system is the simplest. It consists of south-facing windows of appropriately enlarged size, interior surfaces that may contain materials with extra heat storage capacity (concrete, clay, or stone masonry, concrete water containers, ceramic tile, concrete or clay pavers, or special chemical materials). The sunlight is directly admitted to and stored in the indoor spaces for later use in comfort heating.

The second most prevalent type is the indirect gain or *mass-wall* system. It is designed to place a heat storage component such as a wall of concrete, clay, or stone masonry; concrete; or water behind south-facing insulating glass. The sunlight is transmitted through the glazing and heats the absorptive surfaces of the mass wall, which both transfers warmth through its thickness and stores heat for later use. Considerable information exists for designers to use when selecting the wall thickness and material properties for best performance and economy. Coatings or membranes having selective surfaces to maximize absorption and minimize emissivity are often used on mass walls. Mass walls are typically designed together with windows so natural light is provided to rooms located behind them.

The third passive solar form is the *sunspace*, or "solar greenhouse." These may be either fitted to the building's exterior or integrated into the design as a room or zone in the building. A well-designed sunspace will have sufficient heat storage mass to reduce overheating and provide for freeze resistance so plants may be kept year-round in all but the most severe climates. The solar heat is often transferred through a mass wall separating the sunspace from the rest of the building. In colder climates, an insulated wall can be used, and mass is provided in an insulated floor slab or concrete or clay pavers. Windows and doors in the separation wall are provided for natural light from, and access to, the sunspace.

The fourth common passive solar form is a category of design approaches called *daylighting*. Most widely used in commercial buildings, the concept of reducing electric lighting demand by admitting controlled quantities of daylight may be applied to virtually any building. Rooftop apertures have been designed to admit light without irritating glare or excess solar heat. A principal benefit of daylighting is a significant reduction in the mechanical cooling demand from the byproduct heat of electric lighting. Daylighting, used together with energy-efficient electric lighting strategies, can reduce electric power consumption in buildings by up to 90%, according to recent studies. Properly sized and positioned skylights admit light to interior zones lacking exterior walls (hence, windows) in homes, warehouses, schools, and strip retail buildings. Operable skylights providing fresh air are available and can boost whole-building ventilation levels to reduce air-conditioning bills.

The reduction of excessive cooling loads in mild and hot climates can be achieved by passive architectural design. Emphasis is placed on fixed or movable shading devices on windows (gain avoidance); sufficient thermal mass to store heat gains, which may be combined with ventilation to outdoors (night-flush cooling); and thermal envelope treatments such as insulation or radiant barrier reflective materials, light color finishes, and slab-on-grade construction. Daylighting is very important in passive cooling design since it reduces the electric power used for illumination, hence lowering air conditioner demand. A building using a passive architectural cooling design can frequently be fitted with a smaller-capacity HVAC system, which saves energy and lessens the release of CFC and HCFC gases into the atmosphere.

Good passive solar designs may involve any of these strategies, but often several solar architecture strategies are combined to maximize performance and comfort. In all cases, good passive solar design results from proper integration of energy conservation measures for the building envelope, use of energy-efficient equipment and appliances, daylighting, and solar architecture.

## Review of Measured Performance Results

Numerous passive solar buildings have been monitored since the mid-1970s. The monitoring results and methods used to gather performance data are discussed in Howard and Saunders (1989). Passive solar residential buildings have been observed to perform in a wide range—when the building thermal load coefficient is compared to auxiliary load requirements. This range exists due to the first generation of passive solar buildings being designed and constructed without access to verified and accurate design assistance. Early passive designs frequently did not properly combine conservation—improved thermal protection and air-leakage reduction measures—with solar design strategies to serve the indoor space-conditioning loads through natural means integrated into the whole-building context.

Measured results indicate that heating requirements for new buildings can be reduced without adding significantly to first costs by using very rudimentary passive solar design, such as orientation of windows, better insulation levels, and proper shading. According to the United States Department of Energy (DOE), passive solar homes on average have been found to save 40% of heating energy requirements of typical homes (DOE 1992). Data from individual monitored buildings have often shown even higher savings.

A study in Frederick, Maryland, demonstrated that just reorienting existing windows in a typical new tract wood-frame home resulted in 18% to 22% solar heating, without undue additive effects on the air-conditioning load (Spears 1982). Results from detailed DOE-funded monitoring of an architect-designed home located in Reston, Virginia, indicated the 2,300-square-foot home had a 56% heating fraction and was more than 95% cooled by architectural methods—increased insulation, concrete masonry thermal storage walls, and a special flow-through ventilation design (Howard 1983).

In commercial buildings, several monitored structures using daylighting have reported excellent results. A public service center located in cool high desert at Taos, New Mexico, not only cut its lighting load in half compared to a conventional office building but provided more than 30% of the heat needed (Howard and Pollock 1982). A library in North Carolina significantly reduced both cooling loads and electric lighting by using simple baffled roof apertures for daylighting. Since each commercial design is different, generalized performance statistics are less meaningful. However, computer studies have indicated that up to 90% of the electric load of many commercial buildings could be reduced by including passive solar design combined with other good design practices (Lovins 1990).

## TECHNICAL BASIS FOR PASSIVE DESIGN METHODS

The passive solar design guidelines are a result of the distillation and refinement of work conducted by the United States federal laboratory system under funding from the DOE Solar Buildings Program. Thermal simulations and test-cell evaluations of numerous types of passive and hybrid solar collection, storage and control, and gains avoidance devices and systems were undertaken at laboratories in Maryland, New Mexico, California, Colorado, and Florida.

### Estimation Methods—Heating

The first generation of rule-of-thumb passive designs was replaced in the early 1980s by the advent of the solar load ratio (SLR) method (Balcomb et al. 1980a, 1980b). These studies contained complete technical information for designers of low-rise residential buildings and small commercial structures (less than 10,000 $ft^2$ [939 $m^2$] in floor area) that allowed actual prediction of solar savings and estimation of a design's particular auxiliary fuel requirements. Comparisons with measured results indicate that buildings designed with calculation-based (engineering) methods can provide better comfort due to reduced indoor temperature swings and deliver energy savings that more closely meet design expectations.

The estimation methods were derived by national laboratory scientists from correlation analysis of numerous main-frame computer simulations conducted under the Solar Buildings Program. The researchers used a federal domain computer simulation program that had been verified by detailed comparisons of parametric runs against thermal data from test cells located in New Mexico (Balcomb 1977).

These methods were further expanded (Jones et al. 1982) to the point where private consulting firms began to package and market microcomputer programs based on the SLR methods. Several packages of computer software exist today that involve the same SLR calculation and correlation methods developed by the national laboratories. But none was produced with extensive simplified documentation, worked examples, and other valuable support information useful to the less technical nonengineering audiences—builders and developers.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Technical Committee on Solar Utilization (TC 6.7) and the ASHRAE Research and Technical Committee conducted a research project culminating in the complete review, technical rewrite, and effective packaging of the DOE-developed SLR method, associated economic analysis tools, and supporting design guidelines. This volume (Balcomb et al. 1984) with its supplement (Balcomb and Wray 1986) remains one of the most important design documentation standards in the industry.

These technologies have now been published in a format designed to accommodate the needs of builders in the United States (PSIC and SERI 1988a). This design and analysis tool is also available in a computer spreadsheet format further enhancing usability (PSIC and SERI 1988b).

### Estimation Methods—Cooling

Very similar computer simulation correlation procedures were later used to develop a cooling load estimation method thought to be accurate for evaluating sensible heat gain avoidance strategies in passive solar buildings (MacFarland and Lazarus 1987). These cooling analysis methods address various cooling gain avoidance strategies to reduce or eliminate the negative summer season impact of otherwise beneficial heating designs upon air-conditioning loads. These cooling analysis methods do not include latent heat (moisture) terms at this time but leave this to the mechanical engineer who includes such estimates in equipment-sizing procedures, outside the current scope of these simplified energy estimation procedures.

These sensible cooling analysis techniques were first applied in a national laboratory project for a United States Department of Defense client who needed an incremental cooling load determination worksheet method for evaluating the passive architectural processes most likely to save energy for the types of buildings common to military bases. Cooling is a problem at many United States military installations here and abroad. Measures that specifically save heating fuels needed to be reviewed so they would not boost air-conditioning loads.

A calculation-based optimization process was developed in three parts:

- passive cooling guidelines for effective designs based on research from a Florida university (Chandra and Fairey 1986);
- a simple correlation-based calculation to evaluate the effect of a passive solar-heating component (direct gain window, thermal storage wall, sunspace, etc.) upon the space-cooling requirement of the candidate building (McFarland and Lazarus 1987);
- a detailed method to analyze monthly and annual cooling energy requirements of the building (MacFarland and Lazarus 1987).

The application of these simplified cooling methods results in a calculation-based approach to quantify the reduction of unwanted byproduct heat gains, usually beneficial during the heating season. Shading elements, thermal mass, insulation, and window optical qualities can all be varied to optimize heating performance and minimize cooling impacts.

The designer is also furnished with fundamental design concepts to permit design for natural cooling with ventilation when local weather conditions permit. The worksheet in Figure 1 illustrates the cooling method (PSIC and SERI 1988a). The same technical approach is used in the supporting software (PSIC and SERI 1988b) developed under contract with DOE.

## GUIDELINES FOR HOME BUILDERS

### History of the Guidelines Program

The term passive *solar design* was coined at a 1976 energy conference in Albuquerque, New Mexico, concerning energy and housing design for the southwestern United States. These conferences have continued in an annual series of 18 such national meetings, providing a forum for presentation of new solar building research, development, demonstration, and design results. These meetings have provided a forum for the continual refinement of passive solar and energy-efficient designs, technologies, systems, components, and analytical methods.

Planned workshops for home builders on passive solar design began in earnest at the 1980 National Passive Solar Conference in Amherst, Massachusetts. The workshops there were based on SLR methods and were oriented toward reducing heating fuel use. They were targeted to early adopters of passive solar and energy-efficient building design in the Northeast, where there was concern about excessive dependence on fuel oil for home heating. Several hundred builders, engineers, designers, and energy specialists turned out, and the stage was set for development of a successful technology transfer program.

An industry-based nonprofit group funded by DOE was organized in 1981 specifically to function as a technology transfer and industry consensus building body. It quickly seized upon the idea of replicating such workshops on a national scale. Under the auspices of the principal professional association in the solar field, a national workshop series was begun in 1983 at the Eighth National Passive Solar Conference. These first industry-sponsored national workshops included design information for two microclimates, Santa Fe and Albuquerque, New Mexico, and concluded with a full-day solar home tour for inspection of newly constructed residences designed using the SLR-based prototype guidelines. Appropriately for the location, this pioneering workshop was based on simulations and test-cell research done in New Mexico. At the same conference, a residential buildings cooling design seminar was presented for the first time, though it was not yet officially linked to the passive solar builder guidelines workshop program.

Subsequently, DOE funded a national laboratory to work with the nonprofit passive solar group to develop a truly national builder passive solar technology transfer program to include technical guidelines, software tools and support, and education mechanisms such as workshops and certified presenters. From 1984 through the present, the nonprofit group and the supporting national laboratories have worked with DOE to develop simplified and accurate energy efficiency guidelines for home builders. To suit the builders' needs, a key emphasis of the guidelines is cost-effective passive solar designs.

### Developing the Guidelines

The passive solar builder guidelines (PSIC and SERI 1988a) were developed based on the research described in a rich literature, including the DOE Solar Documentation Project, and numerous papers from the federal laboratory system and other support contractors. They include means to analyze and estimate both the sensible heating and cooling loads of low-rise residential buildings but are currently being extensively modified to provide analytical capabilities and a computer design aid for small commercial structures.

A group of technically competent industry representatives extensively reviewed the literature on technology transfer practices and consulted with national representatives

# Worksheet IV: Summer Cooling Performance Level

## A. Opaque Surfaces

| Description | Heat Loss [Worksheet I] | | Radiant Barrier Factor [Table J] | | Absorp-tance [Table K] | | Heat Gain Factor [Table L] | | Load |
|---|---|---|---|---|---|---|---|---|---|
| Ceilings/roofs | | × | | × | | × | | = | |
| | | × | | × | | × | | = | |
| | | × | | × | | × | | = | |
| Walls | | × | na | | | × | | = | |
| | | × | na | | | × | | = | |
| Doors | | × | na | | | × | | = | |
| | | | | | | | | | Total kBtu/yr |

## B. Non-solar Glazing

| Description | Rough Frame Area | | Net Area Factor | | Shade Factor [Table M] | | Heat Gain Factor [Table L] | | Load |
|---|---|---|---|---|---|---|---|---|---|
| North Glass | | × | 0.80 | × | | × | | = | |
| East Glass | | × | 0.80 | × | | × | | = | |
| West Glass | | × | 0.80 | × | | × | | = | |
| Skylights | | × | 0.80 | × | | × | | = | |
| | | | | | | | | | Total kBtu/yr |

## C. Solar Glazing

| Solar System Description | Rough Frame Area | | Net Area Factor | | Shade Factor [Table M] | | Heat Gain Factor [Table L] | | Load |
|---|---|---|---|---|---|---|---|---|---|
| Direct Gain | | × | 0.80 | × | | × | | = | |
| Storage Walls | | × | 0.80 | × | | × | | = | |
| Sunspace | | × | 0.80 | × | | × | | = | |
| | | × | 0.80 | × | | × | | = | |
| | | | | | | | | | Total kBtu/yr |

## D. Internal Gain

_____ Constant Component [Table N] + ( _____ Variable Component [Table N] × _____ Number of Bedrooms ) = _____ kBtu/yr

## E. Cooling Load per Square Foot

1,000 × _____ (A+B+C+D) ÷ _____ Floor Area = _____ Btu/yr-sf

## F. Adjustment for Thermal Mass and Ventilation

_____ [Table O] Btu/yr-sf

## G. Cooling Performance Level

_____ (E - F) Btu/yr-sf

## H. Cooling Performance Target

_____ [Table P] Btu/yr-sf

**Line G should be less than Line H**

*Figure 1*

of the home building industry to determine just the right mix of simplification to boost usability and technical content to ensure credibility. The technical group responsible for the development of the guidelines, consisting of prominent solar researchers, computer scientists, building technologists, environmental engineers, and architects, concluded that both calculational worksheets and a computer-diskette-based design tool would be necessary to effectively complement the transfer mechanism for regional or local programs.

The worksheets were developed to allow builders and designers to walk through the analytical process with actual house plan take-offs—thermal envelope insulation values, surface areas, window layouts and thermal resistances, heat storage material descriptions, etc. The worksheets provide climate-specific pre-calculated design values derived from the SLR methods of analysis for passive solar heating and envelope-based cooling.

A special word-processing feature embedded in the guidelines operating program by the national laboratory developers integrates the climate-specific values into appropriate places in the worksheet forms—into supporting data tables and into a workbook text that supports the guidelines and is the workshop's instructional syllabus.

Figures 1 and 2 are direct reproductions of location-specific worksheets and supporting tables of precalculated data used in the guidelines derived for Raleigh, North Carolina, a site of several builders' workshops since 1985.

## GUIDELINES FOR REMODELERS

The builder guidelines for new construction were modified in a special DOE-funded project in 1990-1991 to specifically support the somewhat different technical and business requirements of the remodeling component of the construction community.

Identical technical and calculational bases were utilized for the remodelers' version of the guidelines (PSIC and SERI 1991). Revisions concerned the considerable differences in how remodeling professionals confront the implementation of energy efficiency in additions, remodels, or gut rehabilitation work.

The remodelers confront existing structures and often have little flexibility over building orientation, existing levels of thermal protection, installed mechanical system capacity and efficiency, and floor plans. The guidelines were modified accordingly, including lower ranges of "current" thermal protection levels and serving as an intermediate step for using utility or energy service company audit data in the calculations. The remodeler can go through the calculations and modify the design to be more energy efficient using passive solar techniques where applicable. The workshop syllabus was also rewritten in somewhat less technical terms and includes sections specifically relevant to the remodelers' work-planning needs. A section on why energy efficiency matters and what some of the marketing considerations are was also prepared.

The job is provided with needed documentation showing estimated energy savings, which can then be extrapolated to determine aspects of cost-effectiveness and affordability for the homeowner. This additional information can provide good arguments that the proposed energy features are a good value. The worksheets and results may be acceptable in the energy efficiency mortgage process. However, more work is needed to refine the remodeling guidelines as a method of energy efficiency rating and producing acceptable construction documentation for real estate professionals and lenders.

## GUIDELINES FOR SMALL COMMERCIAL BUILDINGS

The newest extension of the guideline programs is the development of guidelines for thermal envelope (skin) dominated light commercial construction. Results from DOE monitoring of smaller commercial passive solar applications indicates savings from energy-efficient design are provided in the range of 45% to 60% depending upon the energy use of the comparison building and its age (DOE 1990). This level of savings means that such buildings can begin to provide better demand-side characteristics to the utility grid and can significantly lessen the energy-related emissions of air pollutants implicated in possible global climatic change.

These buildings are typically less than 10,000 $ft^2$ (929 $m^2$) of floor area and represent more than three-fourths of all commercial buildings and 22% of the floor space of buildings in the United States. In many locations, these buildings are designed to building codes based on 15-year-old standards and can use up to $2.00 per square foot more energy than a building employing cost-effective energy-efficiency and passive solar designs (Howard 1991). Candidate buildings include small offices, retail stores, fast-food outlets, motels, libraries, schools and school additions, banks, and warehousing.

The commercial building guidelines and the computer design tool under development by contractors to DOE will include 16 specific energy-efficiency measures in a knowledge-based system that will allow comparison and selection of the most cost-effective and energy-efficient attribute combinations for a specific building in a climate.

The design tool is being developed to run using a popular graphics-based personal computer operating system. It will be fast to operate and will allow users to build up from a very basic design typical of the program planning or schematic design phase to a completed design that reflects the optimal choices of energy-efficient and passive solar features to meet the designers' objectives. The outputs are being developed to be graphically clear and concise enough for prompt decision making and should allow easy interpretation of results that in other energy simulation tools require extensive engineering expertise to evaluate. The output will not only be the heating, cooling, and lighting loads of the

F3—Water Walls

| Load Collector Ratio | WWA3 No Night Insulation | WWB4 Night Insulation | WWC2 Selective Surface |
|---|---|---|---|
| 200 | 0.12 | 0.13 | 0.13 |
| 150 | 0.16 | 0.18 | 0.18 |
| 100 | 0.23 | 0.28 | 0.28 |
| 80 | 0.27 | 0.35 | 0.34 |
| 60 | 0.33 | 0.44 | 0.43 |
| 50 | 0.38 | 0.50 | 0.49 |
| 45 | 0.41 | 0.53 | 0.52 |
| 40 | 0.44 | 0.57 | 0.56 |
| 35 | 0.48 | 0.62 | 0.61 |
| 30 | 0.52 | 0.67 | 0.66 |
| 25 | 0.58 | 0.73 | 0.72 |
| 20 | 0.64 | 0.80 | 0.79 |
| 15 | 0.73 | 0.88 | 0.86 |

This table should be used only when the air space between the water tank and the solar glazing is sealed.

F4—Sunspaces

| Load Collector Ratio | Sunspace Type SSA1 | SSB1 | SSC1 | SSE1 |
|---|---|---|---|---|
| 200 | 0.17 | 0.15 | 0.11 | 0.16 |
| 150 | 0.21 | 0.17 | 0.14 | 0.20 |
| 100 | 0.27 | 0.22 | 0.20 | 0.26 |
| 80 | 0.30 | 0.26 | 0.24 | 0.31 |
| 60 | 0.36 | 0.31 | 0.29 | 0.37 |
| 50 | 0.40 | 0.35 | 0.33 | 0.41 |
| 45 | 0.42 | 0.37 | 0.36 | 0.44 |
| 40 | 0.45 | 0.39 | 0.39 | 0.47 |
| 35 | 0.48 | 0.43 | 0.42 | 0.50 |
| 30 | 0.52 | 0.46 | 0.46 | 0.55 |
| 25 | 0.57 | 0.51 | 0.52 | 0.60 |
| 20 | 0.63 | 0.57 | 0.58 | 0.66 |
| 15 | 0.71 | 0.65 | 0.66 | 0.74 |

### Table G—Auxiliary Heat Performance Targets (Btu/yr-sf)

| Performance Level | Passive Solar | Sun-tempered | Insulation |
|---|---|---|---|
| ★ | — | — | 41,300 |
| ★★ | 14,900 | 16,500 | 18,800 |
| ★★★ | 10,700 | 12,300 | 15,000 |

### Table H—Unit Heat Capacities (Btu/F-sf)

H1—Mass Surfaces Enclosing Direct Gain Spaces

| Material | Thickness (inches) 1 | 2 | 3 | 4 | 6 | 8 | 12 |
|---|---|---|---|---|---|---|---|
| Poured Conc. | 1.8 | 4.3 | 6.7 | 8.8 | 11.3 | 11.5 | 10.3 |
| Conc. Masonry | 1.8 | 4.2 | 6.5 | 8.4 | 10.2 | 10.0 | 9.0 |
| Face Brick | 2.0 | 4.7 | 7.1 | 9.0 | 10.4 | 9.9 | 9.0 |
| Flag Stone | 2.1 | 4.8 | 7.1 | 8.5 | 8.6 | 8.0 | 7.6 |
| Builder Brick | 1.5 | 3.7 | 5.4 | 6.5 | 6.6 | 6.0 | 5.8 |
| Adobe | 1.3 | 3.2 | 4.8 | 5.5 | 5.4 | 4.9 | 4.8 |
| Hardwood | 0.4 | 1.4 | 1.8 | 1.7 | 1.5 | 1.5 | 1.5 |
| Water | 5.2 | 10.4 | 15.6 | 20.8 | 31.2 | 41.6 | 62.4 |

H2—Rooms with no Direct Solar Gain

| Material | Thickness (inches) 1 | 2 | 3 | 4 | 6 | 8 | 12 |
|---|---|---|---|---|---|---|---|
| Poured Conc. | 1.7 | 3.0 | 3.6 | 3.8 | 3.7 | 3.6 | 3.4 |
| Conc. Masonry | 1.6 | 2.9 | 3.5 | 3.6 | 3.6 | 3.4 | 3.2 |
| Face Brick | 1.8 | 3.1 | 3.6 | 3.7 | 3.5 | 3.4 | 3.2 |
| Flag Stone | 1.9 | 3.1 | 3.4 | 3.4 | 3.2 | 3.1 | 3.0 |
| Builder Brick | 1.4 | 2.6 | 3.0 | 3.1 | 2.9 | 2.7 | 2.7 |
| Adobe | 1.2 | 2.4 | 2.8 | 2.8 | 2.6 | 2.4 | 2.4 |
| Hardwood | 0.5 | 1.1 | 1.3 | 1.2 | 1.1 | 1.0 | 1.1 |

### Table I—Comfort Factors (Btu/sf)

| | |
|---|---|
| Direct Gain | 881 |
| Sunspaces and Unvented Trombe Walls | 294 |

### Table J—Radiant Barrier Factors

| | |
|---|---|
| Radiant Barrier | 0.75 |
| No Radiant Barrier | 1.00 |

### Table K—Solar Absorptances

| Color | Absorptance |
|---|---|
| Gloss White | 0.25 |
| Semi-gloss White | 0.30 |
| Light Green | 0.47 |
| Kelly Green | 0.51 |
| Medium Blue | 0.51 |
| Medium Yellow | 0.57 |
| Medium Orange | 0.58 |
| Medium Green | 0.59 |
| Light Buff Brick | 0.60 |
| Bare Concrete | 0.65 |
| Red Brick | 0.70 |
| Medium Red | 0.80 |
| Medium Brown | 0.84 |
| Dark Blue-Grey | 0.88 |
| Dark Brown | 0.88 |

### Table L—Heat Gain Factors (Btu/sf-yr)

| | |
|---|---|
| Ceiling/roofs | 47.0 |
| Walls and Doors | 26.3 |
| North Glass | 37.0 |
| East Glass | 68.9 |
| West Glass | 73.2 |
| Skylights | 134.2 |
| Direct Gain Glazing | 55.0 |
| Trombe Walls and Water Walls | 12.2 |
| Sunspaces | |
| SSA1 | 39.3 |
| SSB1 | 39.3 |
| SSC1 | 12.2 |
| SSE1 | 39.3 |

### Table M—Shading Factors

| Projection Factor | South | East | North | West |
|---|---|---|---|---|
| 0.2 | 0.77 | 0.92 | 0.92 | 0.91 |
| 0.4 | 0.66 | 0.80 | 0.81 | 0.80 |
| 0.6 | 0.54 | 0.69 | 0.71 | 0.68 |
| 0.8 | 0.42 | 0.58 | 0.60 | 0.56 |
| 1.0 | 0.30 | 0.47 | 0.50 | 0.44 |
| 1.2 | 0.19 | 0.35 | 0.40 | 0.32 |

### Table N—Internal Gain Factors

| | | |
|---|---|---|
| Constant Component | 2,250 | kBtu/yr |
| Variable Component | 940 | kBtu/yr-BR |

### Table O—Thermal Mass and Ventilation Adjustment (Btu/yr-sf)

| Total Heat Capacity per SF | Night Vent w/ Ceil. Fan | Night Vent w/ No Ceil. Fan | No Night Vent w/ Ceil. Fan | No Night Vent w/ No Ceil. Fan |
|---|---|---|---|---|
| 0 | 4,248 | 401 | 2,317 | -1,601 |
| 1 | 5,553 | 1,484 | 3,622 | -518 |
| 2 | 6,245 | 2,084 | 4,314 | 82 |
| 3 | 6,611 | 2,416 | 4,680 | 415 |
| 4 | 6,805 | 2,601 | 4,874 | 599 |
| 6 | 6,962 | 2,759 | 5,031 | 758 |
| 8 | 7,006 | 2,808 | 5,076 | 806 |
| 10 or more | 7,019 | 2,823 | 5,088 | 821 |

Total heat capacity per square foot is calculated on Worksheet III, Step E.

### Table P—Cooling Performance Targets

| Performance Level | Target |
|---|---|
| ★ | — |
| ★★ | 13,100 |
| ★★★ | 9,100 |

*Figure 2*

building but will also provide a profile of the energy use, daily, seasonally, or annually.

## IMPLEMENTATION

Market acceptance of passive solar buildings is well under way. The DOE-led National Collaborative Council on Home Energy Rating Systems (HERS) and Energy Efficient Mortgages (EEMs) intends to provide for passive solar design as an acceptable program feature in its uniform recommended HERS and EEMs guidelines (National Renewable Energy Laboratory 1992).

Workshops for builders are being provided nationwide on how to integrate energy efficiency and passive design into new homes. Nearly 50 workshops on proper passive design have been delivered since the program began in the early 1980s. Projects are under way now to expand these tools to assist remodelers in providing affordable, energy-efficient, passive solar features to owners of existing homes that do energy remodeling.

The latest effort hinges on the development of completely new computer-based guidelines and a personal computer design tool for builders, developers, architects, and engineers of light commercial and institutional and residential construction. Thousands of these buildings are erected each year, to date with little focus on improving their energy efficiency. These latest passive solar design guidelines will be available in 1993 for the design and building community to put into practice. The technology transfer efforts are intended to be focused on utility demand-side management programs. Passive solar designs not only provide reductions in the use of generated energy for heating, cooling, and lighting but also tend to use energy at off-peak times, reducing the need for more electric power generation. These energy-efficient, environmentally sound building design and construction strategies are increasing in popularity. Increased participation in the development and implementation by the entire building community, especially utilities and mechanical equipment industries, is needed to maximize these benefits for building owners and operators and the nation in a timely manner.

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