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ALGORITHMS FOR BUILDER GUIDELINES

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ABSTRACT

The Builder Guidelines are designed to make simple, appropriate guidelines available to builders for their specific localities. Builders may select from passive solar and conservation strategies with different performance potentials. They can then compare the calculated results for their particular house design with a typical house in the same location.

Algorithms used to develop the Builder Guidelines are described. The main algorithms used are the monthly solar load ratio (SLR) method for winter heating, the diurnal heat capacity (DHC) method for temperature swing, and a new simplified calculation method (McCool) for summer cooling. This paper applies the algorithms to estimate the performance potential of passive solar strategies, and the annual heating and cooling loads of various combinations of conservation and passive solar strategies. The basis of the McCool method is described. All three methods are implemented in a microcomputer program used to generate the guideline numbers.

Guidelines for Denver, Colorado, are used to illustrate the results. The structure of the guidelines and worksheet booklets are also presented.

1. GUIDELINES BOOKLETS STRUCTURE

A procedure has been developed for producing Builder Guidelines booklets for any locality in the United States. These booklets are intended to be disseminated by local homebuilders associations to their members or other local groups. The purpose is to make simple guidelines available to builders that are appropriate to their specific locale. By narrowly defining the location, the worksheet procedures can be greatly simplified.

Builder Guidelines are a three-part package: (1) the Guidelines booklet, which contains information about conservation and solar techniques and how they work and provides specific examples of systems that will save energy; (2) the Worksheets, which offer a simple, fill-in-the-blank method to evaluate the conservation, passive solar, thermal comfort, and cooling performance of a specific design and (3) the Completed Worksheet Example. The issue of cost effectiveness is not discussed in these Guidelines in response to the desires of the National Association of Home Builders (NAHB).

The first part of the package, the Guidelines booklet, is based on more than a decade of experience in construction and monitoring of passive solar houses. It discusses the basic concepts of passive solar design and construction and gives specific advice regarding conservation, the three passive solar strategies, and natural cooling methods. Introducing this booklet is a table that presents the performance potential, in Btu of heating energy saved per square foot of passive solar aperture, for a variety of design approaches.

Starting from a base-case house (defined using conservation measures commonly used in the locality), the Guidelines booklet presents examples of how annual heating energy savings of 20%, 40%, and 60% can be achieved using each of five basic strategies: added insulation only, suntempering, and three approaches to passive solar. The added insulation strategy increases performance by increasing insulation levels without adding solar features. Suntempering involves increasing south-facing glazing from 3% to 7% of the house's total floor area, without adding thermal mass beyond that already in the framing, standard floor coverings, and gypsum wallboard surfaces. Insulation levels are then increased as required to achieve the three levels of savings. The passive solar strategies covered are direct gain, sunspace, and thermal storage wall. Again, insulation levels are increased, if necessary, to obtain the desired energy savings, but the increases are much less than for the previous strategies. Specific guidance is provided for designing each of the passive system types. For example, a simple procedure is given to estimate the required amount and location of mass that must be added to the house when direct gain is used, sunspace design details are discussed, and advice is given on the use of both vents and selective surfaces in Trombe walls.

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The second part of the package, the Worksheet booklet, contains four worksheets and a set of performance tables specially calculated for the locality. The worksheets give a quick and accurate way to estimate how well a design is likely to perform in the following key ways: 1) how well it will conserve heat energy (as given by the annual energy required for heating without the passive solar); 2) how much the solar features will reduce annual heating; 3) whether the house has enough mass to store the direct-gain solar heat and consequently how comfortable the house will be; and 4) how much cooling will be required to maintain comfort in the summer.

The third part of the package, the Completed Worksheet Example, shows how to fill out the worksheets using the example house with a variety of different design features. It illustrates how to handle different situations in the worksheets.

The basis for the creating these tables and the algorithms needed to calculate guidelines and worksheets are described below and in the references.

2. CALCULATIONS PERFORMED

2.1 Base-Case House

Performance estimates are referenced to a base-case house. This is a reasonably energy-efficient house, based on a 1987 NAHB study of housing insulation characteristics, divided into seven heating degree-day zones. Annual heating and cooling estimates are first made for this house, which has no special passive solar features (the glazing area is a nominal 3% of the floor area on each facade). Then the same analysis procedures are used to estimate how much insulation levels would need to be increased to achieve savings in annual heating energy of 20%, 40%, and 60% relative to the base-case house. This is repeated for each of the five strategies. For the passive solar strategies, the solar glazing area is increased as insulation levels are increased up to the maximum recommended area at the 60% savings level.

2.2 Weather Data

The guidelines procedure produces results that are tailored to specific local factors, most important of which is the climate. Weather data for 240 U.S. cities are stored on a microcomputer disk. These include monthly total numbers (divided into daytime and nighttime values) of hours, average outside air dry bulb temperature, average sky radiation temperature, average outside air humidity ratio, wind velocity, average clearness index and other data needed for calculation methods used. Coverage can be extended to approximately 2000 more sites where long term monthly temperature normals have been tabulated by the U.S. Weather Service.

2.3 Calculation Methods Used

The three main methods used to make the calculations are as follows.

The (monthly) Solar Load Ratio (SLR) method (1) is used to estimate annual auxiliary heat consumption, shown in Example tables and also used to estimate yield (the energy saved per square foot of south glazing) in the Performance Potential table. The method uses variable-base degree-days that are required to handle today's better insulated houses and houses with large solar gains (2). The house is assumed to be maintained at 70°F and have an internal heat of 36 Btu/day ft^2. Solar savings fractions are determined from correlations based on the ratio of building net loss coefficient to net projected solar collection area (the solar load ratio). The correlations for various passive systems were developed from a large data base of hour-by-hour simulations made with the PASOLE computer program.

The diurnal heat capacity (DHC) method (3) is used to estimate winter clear-day temperature swings. The limit of temperature swing is set at 13°F, above which the house would be considered uncomfortable and there would be insufficient heat storage for the solar gains. This limits the size of the solar collection area. In practice, the heat storing capacity of a sheetrock house, allowing for furniture, is only sufficient for an area of direct-gain glazing equal to 7% of building floor area. When enough massive floor and other massive elements of the house are available, direct gain glazing percentage can be increased to about 12% of the floor area.

The cooling procedure used, known as the McCool method, is derived from a simplified cooling load calculation method, which estimates monthly auxiliary sensible and latent cooling loads. The method was developed by Robert McFarland at the Los Alamos National Laboratory (4). This procedure includes the effects of internal heat generation, infiltration and ventilation, solar radiation absorbed on the outside of the building, solar radiation transmitted through glazings, and heat gains or losses through exterior walls, glazings, and perimeters due to outside-inside temperature differences. The effects of day-night room-air temperature swings are also included.

The basis of the McCool procedure is a monthly calculation of daytime and nighttime values of the heat gains. The resulting daytime and nighttime room-air heating sources are calculated by using "delay factors" that have been calculated for several walls. Every delay factor is defined as the fraction of a particular daytime or nighttime heat gain that shows up as a room-air heating source during the other period. Variable-base daytime and nighttime monthly cooling "degree hours" are used to calculate the auxiliary cooling from daytime and nighttime monthly average balance points (2). These balance points are the cooling set points less the temperature difference that can be supported by the net room-air heating source.

Since the McCool method itself is too complex to use in a simple worksheet, it is used to calculate sensitivity coefficients related directly to each type of heat gain to the house, including solar gains through windows, roof, and other building elements. These coefficients, called heat gain factors, are determined for the locality and normalized to a reference building. The McCool method is also used to determine shading coefficients for overhangs separately on each facade. All cooling loads are calculated on Worksheet #4 using these heat gain factors and are summed. The final result is then adjusted for thermal mass and ventilation in the last step of the method. This final adjustment includes a constant as required to produce the correct cooling load for the base-case building.

3. AN EXAMPLE

The following example of Builder Guidelines results for Denver, Colorado, area illustrates the procedure (5).

3.1 Guidelines Booklet

The base-case house is a 1500-ft^2, single story building with a basement and 45 ft^2 of south-facing windows.

Table 1 presents the energy performance of several different passive solar systems. The two numbers listed are the Percent Solar Savings (solar savings fraction), which is a measure of how much a 100-ft^2 passive solar system will reduce the house's need for purchased energy. Note that the Percent Solar Savings for the base case is 8.4%, because even in a nonsolar house, the south-facing windows will save some heat. The second number—Yield—is the annual net heating benefit of adding the passive solar system, measured in Btu saved per year per square foot of additional south glazing. Note that the values vary widely between the various passive system options. This variation would be even more pronounced in a less sunny climate, such as the northeast.

An Example table is provided as part of the discussion of each passive solar strategy in part three of the Guidelines. The Examples present the following information about the base-case house:

- Insulation levels (ceilings, walls, floor);
- Tightness (measured in air changes per hour, ACH);
- The amount of glass area on each side (measured as a percentage of floor area);
- The "percent solar savings" (the part of a house's heating energy saved by the solar features);
- Bottom-line numbers corresponding to conservation, auxiliary heating, and auxiliary cooling performance.

TABLE 1

PERFORMANCE POTENTIAL of PASSIVE SOLAR STRATEGIES
in DENVER, COLORADO
1500 ft^2, SINGLE STORY HOUSE

Case	Percent Solar Savings	Yield Btu Saved per Square Foot of South Glazing
Base Case (45 ft^2 of south-facing double glass)	8.4	not applicable
Suntempered (100 ft^2 of south-facing double glass)	17.0	94,675
Direct Gain (145 ft^2 of south glass)		
Double Glass	22.9	89,007
Triple or low-e glass	24.9	106,472
Double glass with R-4 night insulation	28.3	130,741
Double glass with R-9 night insulation	29.1	136,250
Sunspace		
Attached with opaque end walls	22.6	93,140
Attached with glazed end walls	21.8	87,322
Semi-enclosed with vertical glazing	24.0	98,384
Semi-enclosed with 50 deg sloped glazing	29.2	136,633
Thermal Storage Wall - Masonry/Concrete (145 ft^2 of south glass)		
Black surface, double glazing	22.0	87,948
Selective surface, single glazing	29.1	136,934
Selective surface, double glazing	28.4	132,823
Thermal Storage Wall - Water Wall (145 ft^2 of south glass)		
Selective surface, single glazing	33.3	164,901

The Example tables show how the house design could be changed to reduce winter heating energy by 20%, 40%, and 60%, compared to this base case. Table 2 is an example of one of these tables for a sunspace.

3.2 Worksheet Booklet

The four worksheets are presented in a second short booklet. The worksheet calculations are supported by a number of data tables. Most of the numbers in these tables are location specific and are precalculated using weather data from the locality; for example, the heat gain factors values are given in Table 3. They are used in Worksheet #4 to determine the annual cooling load.

3.3 Example Booklet

A completed example is included in the package to show how the worksheets should be filled out for a particular house.

4. GUIDELINES PRODUCTION

Builder Guidelines packages are easily produced. A special microcomputer program has been written that calculates all the required numbers and sets some special flags that determine which of two or more options will be exercised in the particular locality. This program accesses the data disk to read the monthly weather file and then creates a results file. The master Guidelines program is a

TABLE 3

HEAT GAIN FACTORS

Ceilings/Roofs	6.7
Wall and doors	4.4
North glass	14.6
East glass	18.8
West glass	20.5
Skylights	24.3
Direct gain glazing	18.2
Trombe walls and water walls	7.4
Sunspaces	
SSA1	21.1
SSB1	21.1
SSC1	7.4
SSD1	21.1
SSE1	21.1

TABLE 2

EXAMPLES of HEAT ENERGY SAVINGS
PASSIVE SOLAR - SUNSPACE
1500 ft^2 SINGLE STORY HOUSE

	Base Case	20%	40%	60%
R-values				
Ceiling/Roof	30	29	32	35
Walls	18	17	20	21
Floor	5	4	6	6
Glass	1.8	1.8	1.8	1.8
Air changes/hour	0.50	0.42	0.48	0.36
Glass area (percent of total floor area)				
West	3.0	2.0	2.0	2.0
North	3.0	4.0	4.0	4.0
East	3.0	4.0	4.0	4.0
South (windows)	3.0	3.0	3.0	3.0
Sunspace	0.0	5.7	12.4	22.0
Solar system size (ft^2)				
South glass	45	45	45	45
Sunspace glass	0	86	186	331
Sunspace thermal mass	0	258	558	993
Percent solar savings	8	27	42	58
Performance (Btu/yr-ft^2)				
Conservation	45,549	45,795	43,246	40,040
Auxiliary heat	41,729	33,383	25,037	16,691
Cooling	5,265	4,792	4,856	5,926

word-processor file that merges the results file with the guidelines text. Once these files are merged, the text can be customized for the particular locality. The resulting file is then output to a laser printer to produce camera-ready copy of the Guidelines packages. The whole process requires less than one hour.

Guidelines packages are disseminated by the Passive Solar Industries Council to local home builders associations or any individual or group that orders them.

5. CONCLUSIONS

Local targeting of Builder Guidelines makes it feasible to streamline the procedures to a point that permits simple-yet-accurate worksheet computations. It also permits the publication of the performance potentials of various passive design strategies so that informed design decisions can be made based on local weather conditions.

We expect this method of presenting passive solar guidelines to builders will speed the diffusion of passive solar design strategies into U.S. housing.

6. ACKNOWLEDGEMENTS

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