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# The Determination of Energy Savings for Passive Solar Buildings

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# THE DETERMINATION OF ENERGY SAVINGS FOR PASSIVE SOLAR BUILDINGS

Brandt Andersson
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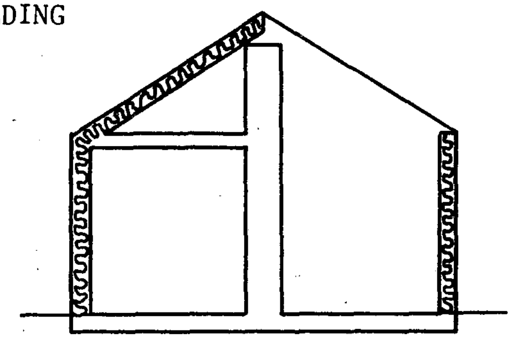
Ronald Kammerud

## ABSTRACT

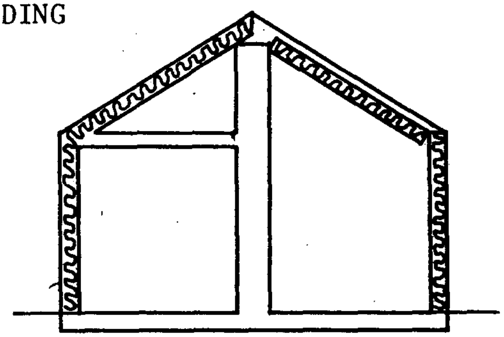
As part of a larger effort to define a series of performance indices for passive buildings, this report presents a method for calculating the energy saved by any specific passive design. The energy use of a passive building is measured. A conventional building counterpart to the passive structure is defined and its energy use is modeled by computer. The results for the conventional building are adjusted, using a correction factor obtained for a building which can be both measured and computer-modeled. Such a building is obtained by crippling the passive components of the passive solar building so that the crippled building can be modeled as well as measured. The crippled buiding provides a method of calibrating building measurements to building simulations. The procedure is illustrated on page vi. The success and limitations of the methods are discussed. Two applications are described in the Appendix.

INSTRUMENTED
AND
MONITORED
BUILDINGS

PASSIVE
SOLAR
BUILDING
(MEASURED)



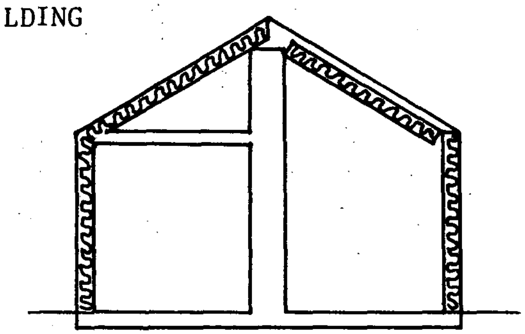
CRIPPLED
PASSIVE
BUILDING
(MEASURED)



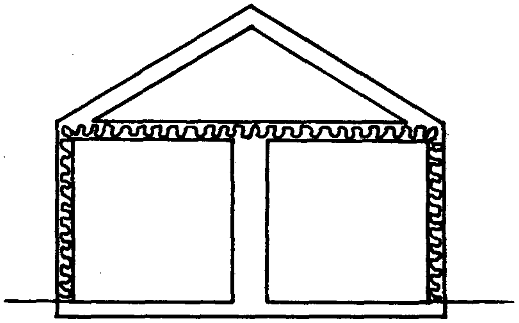
$$\textbf{ENERGY SAVED} = E_{\text{Measured Passive}} - \frac{E_{\text{Measured Crippled Passive}}}{E_{\text{Predicted Crippled Passive}}} \times E_{\text{Predicted Conventional}}$$

COMPUTER
SIMULATED
HYPOTHETICAL
BUILDINGS

CRIPPLED
PASSIVE
BUILDING
(SIMULATED)



CONVENTIONAL
BUILDING
(SIMULATED)



# I. INTRODUCTION

Passive solar design concepts are receiving increased attention as viable solar heating and cooling systems. There is a strong suspicion that passive solar systems are advantageous from a first cost point of view and that their thermal performance will approach and perhaps exceed that of active solar systems in a variety of climates; these conjectures have not been substantiated in a general way. There is, in fact, no general methodology for comparing the performance of an active and a passive system nor, more importantly, are there ways to compare the performance of two different passive systems in the same climatic region or to objectively gauge the thermal and economic performance of a particular passive system. In order to perform these comparisons and/or evaluations, relevant and determinable performance indices must be defined and applied in a standardized manner.

The calculation of performance factors is an attempt to isolate individual aspects of passive building performance which can be more easily calculated and interpreted than a single, inclusive performance index. We focus here on one of the available parameters which might be used in evaluating the performance of a passive building -- the "energy saved" by incorporating passive design features in the structure. Therefore, we will not be concerned directly with important related but separate factors such as collection efficiency, personal comfort, etc. These will be determined separately,[1] and all factors, together or individually, will be used to evaluate different aspects of different designs in different situations.

The objective of this report is to describe a general procedure by which the energy-saved performance factor can be obtained for any given passive solar building. This parameter can then be utilized for comparing passive designs and for assessing the impact of passive solar designs on energy consumption. In addition, the appendix to this report presents the results obtained by applying the procedure to two existing passive solar buildings. These examples point out both the strengths and the weaknesses of the method defined here.

This project was carried out at Lawrence Berkeley Laboratory as a supplement to a Department of Energy effort to develop and document a full range of performance factors and instrumentation requirements and techniques for passive solar buildings. The remainder of the work was performed by the National Bureau of Standards; a brief description of the methodology described in this report is included in the NBS document[1] resulting from the project.

## II. THE ENERGY SAVED CONCEPT

### A. Motivation

A passive solar building is designed to maximize utilization of the environmental resource while minimizing consumption of the conventional fuels used for heating, cooling and energy distribution/management. This typically results in a reduction of the user's dependence on mechanical and/or electrical equipment.

More specifically, a passive solar space heating (cooling) system contains the following elements:

- A space to be heated (cooled)
- A collector where solar radiation is converted to heat (a dissipator where heat is discharged to an environmental sink)
- Thermal storage

Possible energy flows exist between:

- Collector (environmental sink) and storage
- Collector (environmental sink) and space
- Storage and space

The energy flows in both space heating and space cooling systems will fall into one of two broad categories:

- Forced (using fans or pumps)
- Natural (involving conduction, convection, and/or radiation)

A passive solar system is defined as one in which the thermal energy flow is by natural means. In an active system, thermal energy flow is forced; the flow is dominated by mechanical devices such as fans or pumps. A hybrid system is one in which both natural and forced flow of thermal energy are significant to the successful operation of the system. The distinction being made is based on the driving influence causing the energy flow and not on the degree of regulation. The term, "natural energy flow", is not synonymous with "unregulated energy flow". Natural energy flow can, in fact, be regulated by mechanically actuated controls such as dampers or movable insulation. The important point is that the flow motivation derives from non-mechanical sources.

In order to motivate the purchaser of a building to consider passive design features, the thermal (and therefore economic) performance advantages of the design over its alternatives must be quantified; in order to motivate the designer to select the most appropriate design concept for a particular region, these same performance parameters must be available. The basic issues are aesthetics, first cost, occupant comfort, and the magnitude of the reduction in consumption of conventional fuel resources that are utilized in heating and cooling the occupied space - the energy savings. Technically, the expected energy savings, coupled with an adequate data base on the first costs associated with all of the various design options (different passive solar concepts, active solar, conventional design), provides the potential designer and user with a basis for judgement and selection.

The energy saved is defined as the difference in conventional energy used to provide auxiliary heat to a passive solar structure and to provide all of the heating energy required by an "identical", non-passive structure. For this comparison to be meaningful, the comfort conditions, use patterns, internal load profiles and infiltration levels must be identical between the design alternatives.

The most basic issues in determining the energy-saved parameter are (1) the selection of the physical characteristics of the non-passive structure to which the passive solar building is to be compared and (2) the selection of a suitable procedure for determining the amount of conventional fuel used to heat and/or cool the two structures. This report outlines a procedure for addressing each of these issues.

## B. Rationale

Implementation of passive solar concepts in a building typically produces basic changes in the building architecture. Large expanses of south glazing, movable glazing insulation, buffer zones and thermally massive construction materials are common. These features can result in substantially different thermal loads and load profiles for the passive solar building than would be realized in a "similar" conventional design. Often, the total load for the passive solar building (before the solar gain is accounted for) will be considerably larger than for a conventional building. This typically results from thermal losses through the expanse of glazing; these losses are larger than in the conventional building where at least a portion of the glazing is replaced by opaque, insulating building materials. In a well-designed passive solar building, this increased load is more than offset by the solar contribution.

In attempting to determine the energy savings which result from application of passive solar design criteria, two major topics must be addressed. First, the extent to which the passive concepts alter the building configuration must be determined; that is, the configuration of the conventional counterpart to the passive structure must be defined. Second, the energy consumption of the conventional building must be determined assuming the user- and construction-associated variables are identical between the two buildings. These two issues cannot be considered independently; a general strategy for selecting the comparison methodology is described below.

The choice of the conventional building to which a particular passive structure is to be compared presents several options. It might be typical of the existing stock of structures in the region; energy consumption data for this average building could then be based on local utility experience. The energy savings would be determined by subtracting the consumption of the passive building under consideration from the average consumption. This procedure would indicate the effectiveness of the passive design in comparison to the selected period of building history, the selected range of building type and size, etc. The major disadvantage of this approach lies in the broad range of energy use that would be obtained from the existing building stock. Evidence suggests that even in a single building variations in energy consumption of a factor of two or more are experienced due to user influences.[2] Combining this uncertainty over many different buildings of different styles, ages and floor areas would produce an unacceptably large range of data to which the single passive building would be compared. This approach, though simplest, would be useful only if there were a sufficiently large number of passive structures to allow a statistical comparison of passive and conventional structures.

Several other characteristics of this average comparison also would dilute the effectiveness:

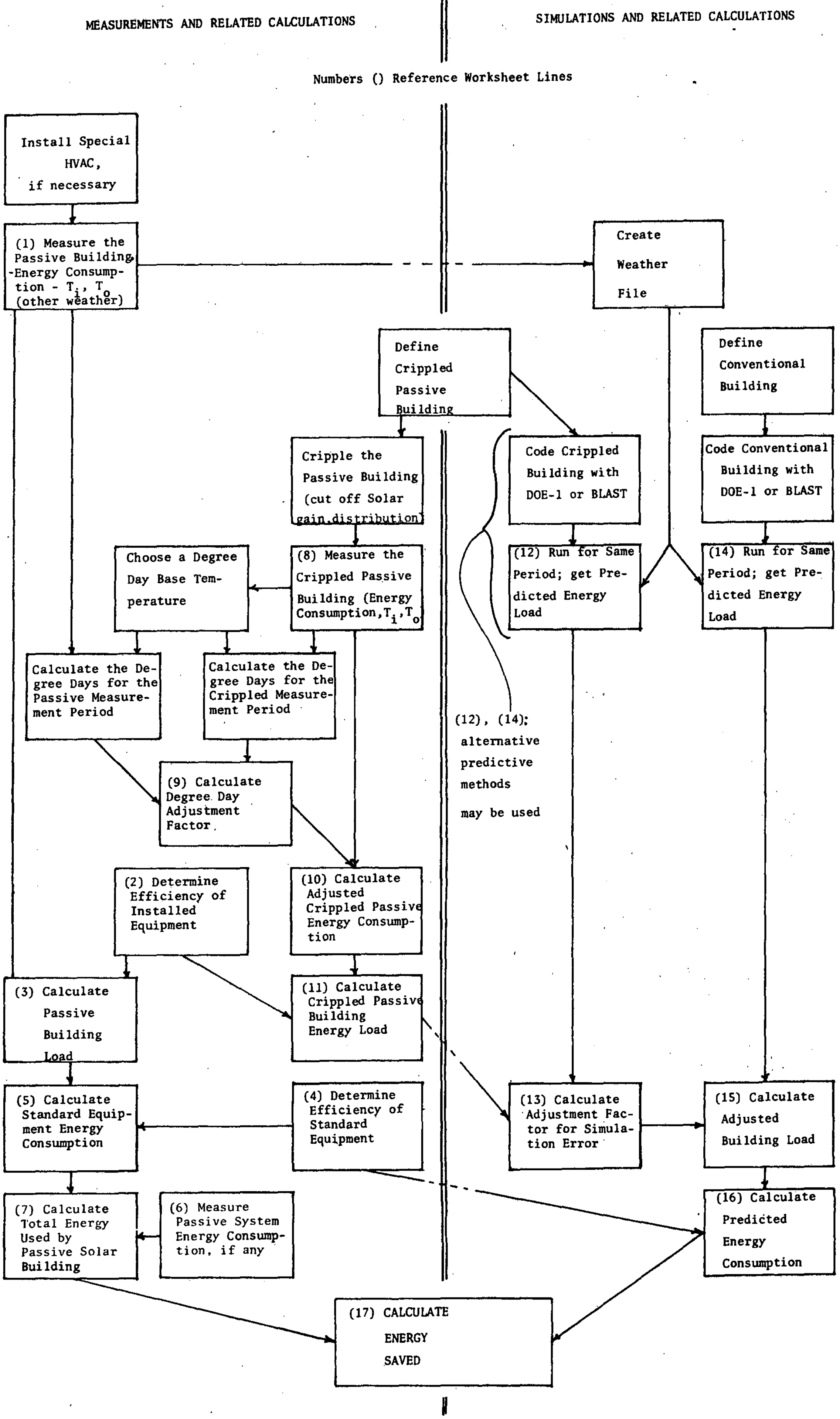
- o Passive solar buildings typically are occupied by energy-aware segments of the community. This user bias would produce an overestimate of the true energy savings that result from the passive solar design itself.
- o Passive solar designs often utilize back-up heating systems such as wood burning stoves, that are not utility based and whose consumption is difficult to monitor and quantify.
- o Passive solar designs typically utilize energy conservation techniques which are not standard practice for the average new (or old) building. This, too, will lead to an overestimate of the effectiveness of the solar design.

The difficulties outlined above suggest that a significantly more thoroughly controlled comparison is required in order to provide meaningful results.

## C. Technical Approach

The flow chart on the following page diagrams the technique for producing the Energy-saved parameter. It can be used as a reference throughout this paper.

1. Conventional Building Selection: The ultimate goal of the comparison is to evaluate a specific passive solar structure. The most appropriate comparison, therefore, is with a building which is designed for the same site, which has the same functional floor plan, and which is designed, constructed and used with an emphasis on energy conservation that is consistent with the non-passive features of the passive solar building. Such a building would be the most probable alternative to the passive structure. Ideally, the energy savings would be determined by physically constructing the conventional


MEASUREMENTS AND RELATED CALCULATIONS
SIMULATIONS AND RELATED CALCULATIONS
Numbers () Reference Worksheet Lines
Install Special HVAC, if necessary
(1) Measure the Passive Building Energy Consumption - $T_i$, $T_o$ (other weather)
Create Weather File
Define Crippled Passive Building
Define Conventional Building
Cripple the Passive Building (cut off Solar gain distribution)
Code Crippled Building with DOE-1 or BLAST
Code Conventional Building with DOE-1 or BLAST
Choose a Degree Day Base Temperature
(8) Measure the Crippled Passive Building (Energy Consumption, $T_i$, $T_o$
(12) Run for Same Period; get Predicted Energy Load
(14) Run for Same Period; get Predicted Energy Load
Calculate the Degree Days for the Passive Measurement Period
Calculate the Degree Days for the Crippled Measurement Period
(12), (14): alternative predictive methods may be used
(9) Calculate Degree Day Adjustment Factor
(2) Determine Efficiency of Installed Equipment
(10) Calculate Adjusted Crippled Passive Energy Consumption
(3) Calculate Passive Building Load
(11) Calculate Crippled Passive Building Energy Load
(5) Calculate Standard Equipment Energy Consumption
(4) Determine Efficiency of Standard Equipment
(13) Calculate Adjustment Factor for Simulation Error
(15) Calculate Adjusted Building Load
(7) Calculate Total Energy Used by Passive Solar Building
(6) Measure Passive System Energy Consumption, if any
(16) Calculate Predicted Energy Consumption
(17) CALCULATE ENERGY SAVED

counterpart beside the passive structure and monitoring the utility consumption in the two buildings under identical use and comfort conditions. This direct comparison will seldom be possible. The logical alternative is to calculate the consumption of the conventional counterpart; the physical characteristics of the counterpart are defined by the specific passive solar structure being evaluated.

2. Energy Saved Calculation Procedure: The energy saved is determined by comparing the measured energy consumption of the passive solar structure and the calculated consumption of the conventional structure. The major difficulties with this approach are in (a) the selection of an acceptable building energy calculation procedure, (b) properly calibrating the energy consumption model to reproduce the user effects observed in the passive solar buildings, (c) adequately accounting for the construction detail effects in the model (that is, calibrating the model to account for the infiltration experienced in the passive solar building), and (d) accounting for the many minor approximations and inaccuracies present in any complex model.

For the purposes of this report, it is assumed that the energy calculation is performed using a public domain computer program such as BLAST[3] or DOE-1.[4] Other calculation procedures or computer programs are appropriate; the two computer codes noted have the advantage of wide public availability, very general energy analysis capabilities, and user flexibility and user convenience. The two calibration steps present a more difficult problem. User influences and infiltration are sufficiently important that the calibration step is the key to a viable comparison.

3. Calibration: Existing publicly available energy analysis computer programs and hand calculation methods are unable to accurately model the complex natural heat flow patterns in passive solar buildings. The programs, therefore, cannot be calibrated directly using thermal data from the passive structure. For the calibration, a building must be selected a) which is similar to the conventional building, b) which is identical to the passive structure with respect to user and infiltration influences, c) whose energy consumption can be monitored, and d) which can be modeled. If the passive solar features of the actual passive solar structure are disabled by covering the solar collecting surfaces, the resulting building will generally be within current analysis capabilities and will meet the other three criteria. Thermal data from this "crippled passive" structure can then be used to calibrate the computer model; the crippled passive structure will properly reflect user effects and actual infiltration levels.

The crippling of the passive structure is a physical experiment which not only produces calibration data but also allows the experimenter to directly measure the effects of solar gain on the building performance. Assuming that the data from both the operating and the crippled passive solar structure can be corrected to the same weather conditions, the experiment allows a direct measurement of a meaningful percent solar for the passive structure.

4. Basis for the Energy Savings Calculation: Metering of the passive building will provide the energy used. The computer or hand calculation model can provide either usage or load, but to find the

energy use it must model the heating or cooling system equipment in the passive building. This may be difficult (heat pumps, active solar) or nearly impossible (wood-burners). Additionally, the Energy-Saved performance factor would then depend to a large degree on the performance of the auxiliary equipment; this should be separated from the passive performance. It is more desirable to determine energy loads for both situations, and then apply identical efficiencies (for standard equipment) to both sets of data to find the energy use for both versions. During the experimental data collection period the passive solar loads can be determined from measured energy usage by using equipment (temporarily installed, if necessary) for which the efficiencies are known and dependable (e.g. electric resistance heaters), and multiplying the energy use by the efficiency.

## III. THE ENERGY SAVED CALCULATION

### A. Describing the Conventional Building

The rules for describing the physical characteristics of the conventional building which is to be modeled are described below. These rules are applied to the existing passive solar structure:

1) On the passive solar building, the collecting/radiating surface is redefined to make it similar to the adjacent surfaces of the structure. For example, large expanses of south-facing glass are replaced with walls whose construction materials and details are compatible with the walls in the remainder of the building envelope. The glazing area on the south side of the building is reduced to the same average glass area per unit wall area as is used on the north, east and west facing walls. In this way, the most important distinction between a passive and conventional building - the collection system - is replaced with opaque insulating walls which are typical of the non-passive parts of the structure. Also, the conventional building will reflect the same level of conservation awareness as the passive solar structure.

2) Any heat distribution system used by the passive system is disabled (unless it is also part of the conventional heating or cooling distribution system). Without the solar heat source, the distribution system would be inappropriate.

3) If any extraordinary construction was involved in the passive system which would be obviously inappropriate to conventional buildings, it should be modified to remove its extraordinary aspects. This would include unusual collection surfaces and sunspaces. The basic form of the passive solar structure should be changed as little as possible in describing the conventional counterpart. For example, an external, south wall sunspace should be removed from the structure; an internal sunspace with a roof aperture should be treated as an internal unconditioned space whose roof and attic configuration is compatible with the remainder of the passive solar structure.

4) The thermal storage mass in the passive solar structure is removed if it is physically separable from the building (e.g. free standing water-filled tubes) or if it is integral with the collection/dissipation surfaces replaced in step 1) above. Distributed storage mass and/or additional floor slab mass typically do not substantially influence thermal performance if the solar collection system is removed. (See Section IV-B-1 for a discussion of mass effects.) In these cases, the removal of the thermal mass is not necessary in defining the conventional structure.

The building thus described is modeled by any appropriate technique. Its performance is simulated under conditions which are identical to those measured during the experiments with the passive solar structure.

## B. Describing the Crippled Building

The physical features of the crippled passive structure are also defined by the passive solar building. The following two rules apply:

1) If there is moving insulation for the collecting/radiating surface, it should be closed for the crippled-passive building. If not, the surface(s) should be covered with a suitable insulation which will make the surface similar in thermal resistance to nearby surfaces of the building.
2) As in the conventional/conserving version, heat distribution systems used exclusively for passive operation should be closed off.

The crippled passive building thus described provides a connection between the physical passive solar building and the modeled conventional building; this intermediate step allows the conventional model to be calibrated to the unique and specific features of the passive structure. Thermal data is collected from the actual disabled passive solar building and compared to a model prediction for the same building. The comparison yields a correction factor which is used to scale the predictions of the conventional building model. This correction is applied prior to subtracting the passive solar consumption data from the model predictions for the conventional building.

## C. Measurements and Weather Adjustments

Two sets of thermal measurements must be made, one for the working passive solar building, and the other for the crippled passive version of that building. Ideally, one year of measurements for each would be made. However, that will not normally be possible or practical so an alternative method is suggested. Alternating periods of passive and crippled passive measurements can be arranged. The periods should be sufficiently long that the transition period (time required for the building to reach some level of thermal stability) is not a significant factor. They should not be so long that the weather will change appreciably during the period. Perhaps two to four weeks is reasonable. (Midsummer and midwinter periods might be longer than spring and fall, because the weather changes more slowly.) For convenience, the examples in the appendix assume full-year measurements.

No matter how the two sets of measurements are made, the weather should be similar, but generally will not be the same. A degree day or other appropriate adjustment must be made. Because the crippled passive building is likely to respond more directly to degree day changes, <u>its</u> measurements should be adjusted. The base temperature from which the degree days are figured should be determined from the data for the crippled passive building. It is likely to be lower than most buildings because of the energy conserving features expected to be found in the construction. Investigation of the measured energy-use vs. outside-temperature for the period will suffice to choose a reasonable base temperature. Degree days for both passive and crippled passive measurement periods can then be found. In this way the two sets of measurements (passive building and crippled passive building) reflect the "same" weather conditions. The weather used in the simulation of the thermal performance of the conventional building models will be the same as that of the passive solar measurement period.

The specific data that is measured depends upon the level of detail used in simulating the conventional and crippled passive building models. At a minimum, the measurements must include interior and exterior drybulb temperatures, auxiliary conventional fuel consumption for heating or cooling the passive solar building and some information on solar irradiance. More detailed modeling may also require the collection of data on additional weather variables and interior comfort conditions. Multiple metering of the utility supply may also be required.

## D. Comfort Conditions

Fundamental to the energy use comparison being suggested here is maintenance of the same comfort conditions in the monitored buildings (passive solar and crippled passive) and the modeled buildings (conventional and crippled passive). By their nature, passive solar buildings will experience temperature swings which are larger than in the typical, conventionally heated building. In the simulations of the conventional and crippled passive performance, the comfort conditions cannot easily be made to track those measured for the passive structure. The simulation should permit the modeled structure to vary over the same comfort range as experienced in the passive building; the thermostat set-points in the model should therefore be set at the minima and maxima of the temperatures measured. The instantaneous comfort conditions in the modeled and actual buildings then will generally be different but the acceptable comfort range will be the same.

## E. Energy Use - Passive Solar Building

It is assumed that during the measurement period, back-up energy is provided to conventional heating and/or cooling equipment rather than, for example, to fireplaces or wood-burning stoves. In order to determine the energy consumption used in the comparison, the measured usage is converted to a building load using the efficiency of the installed equipment (and of the plant if electricity is used as the auxiliary during the monitoring period). The resulting load is then converted back to energy use using the efficiency of standard equipment (.80 for a gas furnace at high demand).

Many "passive" systems have pump or fan assists; these energy consumptions must be included in the passive solar energy use. They should be metered separately since they are an integral part of the passive system. The energy consumed by these devices can be added directly to the figure calculated above. If the system has only manual controls for passive heating, nothing is added. For cooling, on the other hand, pumps might be used to move water through water columns or fans might blow cool air through a rock bed; a significant addition might be made to the energy use during the summer.

## F. Energy Use - Crippled Passive Building

The measurements outlined in Section E above are repeated with the collection surfaces shaded or otherwise protected from solar gains, and preferably, with the collector glazing insulated. This provides energy consumption data for the crippled passive building. This data is corrected to the same weather base as the actual passive solar data using a degree day correction or other appropriate procedure.

The crippled passive building is modeled using best estimates for the infiltration, user schedules and internal loads for the passive solar structure. Weather data gathered during the passive solar operation is used; this calculation produces a predicted building load for the crippled passive building; the load is converted to an energy consumption using the standard equipment efficiency identified in Section E above.

The ratio of the predicted to measured energy consumption for the crippled passive building is a correction factor that is used to normalize the predicted energy consumption for the conventional building which is determined in section G below. This factor accounts for basic uncertainties and inaccuracies in the conventional building model such as infiltration and user effects. This adjustment factor is most responsible for the validity of the entire calculation.

## G. Energy Use - Conventional Building

The conventional building is defined according to the rules specified in Section II above. The building is simulated using weather data collected during the passive solar operation. User schedules, infiltration and internal loads identical to those used in the simulation of the crippled passive structure are included in the simulation. The predicted load is normalized using the crippled passive correction factor and the standard equipment efficiency. The result is a predicted energy consumption for a conventional building that is specifically normalized to the load characteristics of the passive solar structure.

## H. Energy Savings

The energy savings is the difference between the predicted energy consumption for a conventional building (Section G above) and the measured energy consumption for the passive solar structure (Section E above).

## IV. LIMITATIONS OF THE METHOD

### A. Adjustments - Their Effect on Reliability

Several adjustments are necessary in the course of the calculation. They account for differences and unknowns in the auxiliary heating and cooling systems, the weather, and the computer models. It is worthwhile to explain their necessity and their effects on the reliability of the results.

### 1. Auxiliary System Efficiencies

Because this is a comparison between a building in which the data measured is energy use, and a model in which the primary data produced is energy load, some conversion is necessary to relate the building load to the energy used. The bridge is the auxiliary system efficiency. A model of the auxiliary system can be used to obtain the energy consumed in the building on a dynamic basis; this type of model is seldom available for the specific equipment used in the passive solar structure. Even a 5 or 10% difference in the efficiencies could seriously degrade the quality of the comparisons if the energy savings is relatively small. Complicating this further is the occurrence of equipment in many innovative designs for which no good model is available.

A more acceptable approach consists of converting the measured energy use to the building load by application of the efficiencies of the equipment with known and dependable performance (such as electric resistance heaters). Then both the measured and the modeled loads can be divided by identical efficiencies (for typical conventional equipment) to determine the energy use. Because both the passive and conventional loads are changed by the identical efficiency, if it is incorrect by 5-10%, the result will be in error by only that amount. It will not have the multiplicative effect it would have if different efficiencies are used for the two cases.

### 2. Degree Day Adjustments

Obviously, weather plays a large part in any heating and cooling load problem. The same weather cannot be used for different measurements unless nature cooperates more than one has a right to expect. Therefore, <u>similar</u> weather is used and adjusted according to the number of degree days. Degree day calculations[5] are dependable <u>if</u> a) a proper base temperature is used and b) the range of weather in the period being studied is limited. By adjusting the data over short time periods and choosing a base temperature from the measured data, one can be confident that this correction is not adding appreciably to the error in the calculation.

### 3. Crippled Passive Normalization

This important adjustment is meant to minimize the error in the application of the particular energy analysis technique being used and to account for thermal effects which are not or cannot be modeled in sufficient detail. The accuracy of the correction is determined by the ability of the energy calculation technique being used to analyze the specific features of the crippled passive structure. Its effectiveness can be insured by taking care that: a) the crippled passive model reflects the measured crippled passive building characteristics as closely as possible; this will minimize the adjustment, and b) the crippled passive model and the conventional building are defined and modeled to be as physically similar to each other as possible; the closer they are, the more relevance the normalization factor holds for the conventional building.

## B. Further Study

### 1. Mass Effects

Because passive buildings are normally high mass structures, it is desirable to determine the effect of thermal mass in a more conventional structure. A limited series of parametric studies were performed using BLAST and DOE-1 to simulate conventional buildings; the following initial conclusions were reached:

a) In a temperate U.S. climate, the energy use is relatively insensitive to the thermal mass for masses greater than those associated with current building practices.

b) In a semi-desert U.S. climate ideal for the use of mass, the first 50 pounds/sq ft of floor area causes significant improvement in performance. Beyond that point, the returns diminish rapidly.

These assumptions have been used to define the conventional/conserving buildings; clearly more investigation is necessary to confirm and refine these results.

### 2. Infiltration Estimates

Infiltration must be estimated, in one way or another, for the models. While one can estimate the air exchange rate for a room, or the tightness of the building, they are little more than guesses. Air leakage represents a large portion of heat gain or loss of a building and, unfortunately, there is no easy way to gauge it. This is one of the biggest potentials for error in the method described here or in any other building energy analysis calculation. Infiltration is one of the major motivations for the crippled passive calibration step in the procedure. It would be possible and very desirable to measure infiltration[6] in the crippled passive building at various times. A wind- and temperature-dependent infiltration formula could be determined and used in the energy consumption models.

### 3. Slab Heat Losses

The models also require analysis of floor slab heat losses; even the ASHRAE recommendations[7] are no more than rules of thumb. In a passive building, the slab losses can be a far more significant portion of the load than in conventional buildings. More detailed analyses are required in order to improve the understanding of the way in which the ground behaves as a heat sink. These studies should be used to produce better rules of thumb or actual calculation methods for thermal losses to the ground.

## C. Improvements to the Calculation Procedure

Both of the programs utilized in the testing (Appendix I) of the procedure described in this report - DOE-1 and BLAST - have serious deficiencies in the analysis of passive solar buildings. Some are general, and some are of particular importance in high mass, well-insulated structures. Many of these problems can be eliminated without developing any new basic analytical models.

### 1. DOE-1

DOE-1 first does a load analysis assuming a constant inside air temperature; it then perturbs the results according to the magnitude of environmental and user excitations and calculates the inside air temperature fluctuations using perturbation techniques. For the constant temperature calculations a set temperature must be chosen for each space; this temperature must be near the center of the expected temperature range of the space. As the actual temperatures diverge from the set point, the perturbations become less reliable. This procedure works well for conditioned or tempered spaces; buffer spaces, however, can vary by well over 100°F in a year if insulated from the occupied space. Any set point for that buffer space will result in unreliable results. Such a situation might be improved by instituting seasonal set points, so that a smaller temperature range could be dealt with for each season.

DOE-1 models internal mass in a relatively simplistic manner. All of the mass is lumped into a "pounds/sq ft" specification. Coefficients are chosen from a predetermined table according to which weight class the building falls into - light, medium, or heavy. A great deal more flexibility could be attained by calculating coefficients from continuous functions based on the weight of the specific structure being analyzed.

DOE-1 uses a correction factor based on actual wind speed to modify the user specified infiltration rate. Two improvements could be made. First, the correction function is linear, starting at windspeed = 0 (x specified infiltration). Since infiltration does not altogether disappear in the absence of measurable wind velocities, the intercept should be at some higher value. Second, no correction is made for inside-outside temperature differences; these can have large effects on the infiltration rate.

### 2. BLAST

BLAST has scheduling limitations; although weekdays and weekends can be specified separately, no distinctions can be made in a schedule for different months or seasons. Thermostat settings, ventilation rates, and lighting schedules, for example, cannot change during the year. Addition of a seasonal scheduling capability would greatly expand the modeling capabilities for both conventional and passive buildings. BLAST also has a severe limitation in the thermal coupling between adjacent zones. Thermal transfer from one zone to another can only be modeled for the single surface between an attic and the occupied space or between a crawl space and the occupied space. This is a serious problem where buffer zones and the flow of energy between them and the occupied space are important. Although such an improvement might require significant changes to the program, it would be worthwhile.

### 3. Both Programs

Both programs lack the capability to schedule changes to the primary envelope configuration. "Window management" is an important passive solar technique. The inability to even crudely model thermal shutters, shades or bead walls seriously restricts the modeling capabilities.

## V. APPENDIX: TWO APPLICATIONS OF THE ENERGY-SAVED CALCULATION PROCEDURE

Two existing residential buildings were chosen for testing the Energy-Saved Calculation Procedure. Because no passive solar buildings were immediately available with the appropriate measurement data and supporting information, all "measurements" in the examples are performance estimates. They are essentially fictitious data. However, the accuracy of the measurements, although necessary for the actual determination of the Energy-Saved performance index, is not crucial in terms of the demonstration of the technique.

### A. Pacific Gas and Electric Demonstration House - Stockton, California

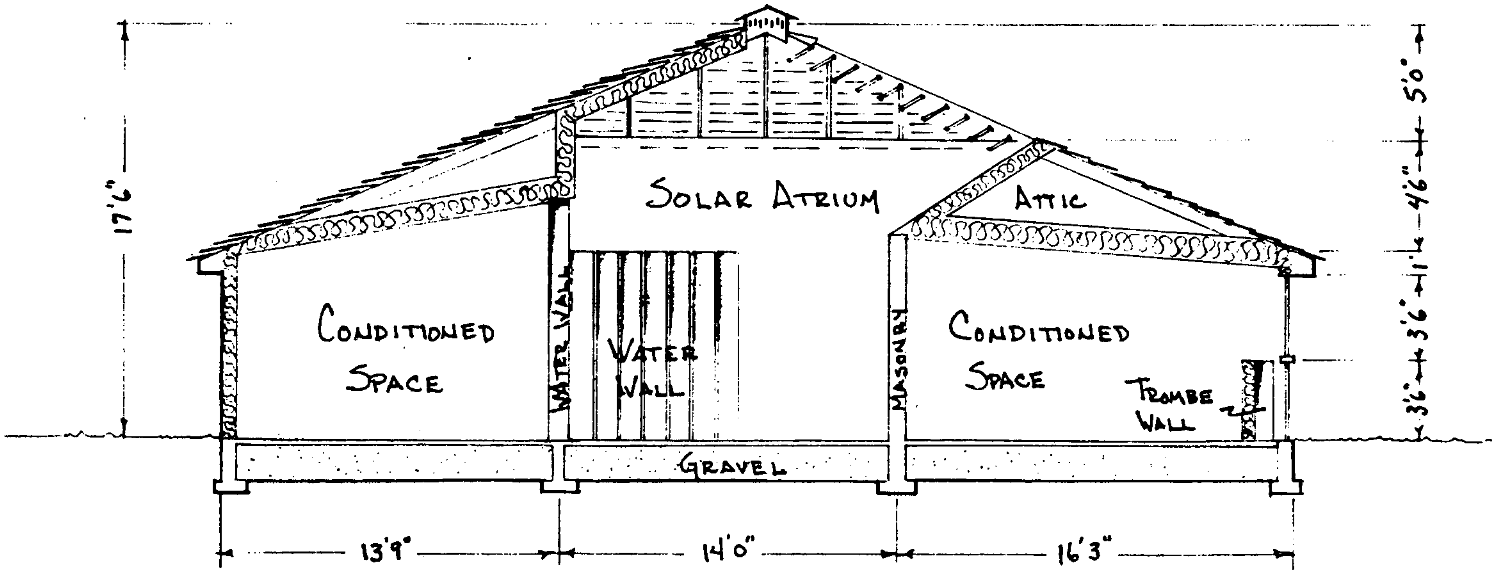
### 1. Building Description

The first building is shown schematically in Figure 1a. It is a residence in Stockton, California, built for Pacific Gas and Electric as a demonstration of passive and conservation features.[8] It is a simple square building, with a central atrium (1600 sq ft + 240 sq ft in the atrium). The roof over the atrium is glazed (south, east, and west) to allow sunlight to penetrate to water columns which form the north, east, and west walls of the atrium. The glazing is equipped with thermal shutters. In addition, there is a short mass storage wall (using water columns) across the south wall under the livingroom windows. For auxiliary heating, the house is equipped with a fireplace with heat ducted throughout the house, and a heat pump. Cooling is achieved using three environmental sources; a) the atrium can be used to transmit heat to the atmosphere at night, b) ventilation air can be drawn through a rock bed under the slab which is cooled by

# PACIFIC GAS & ELECTRIC DEMONSTRATION BUILDING

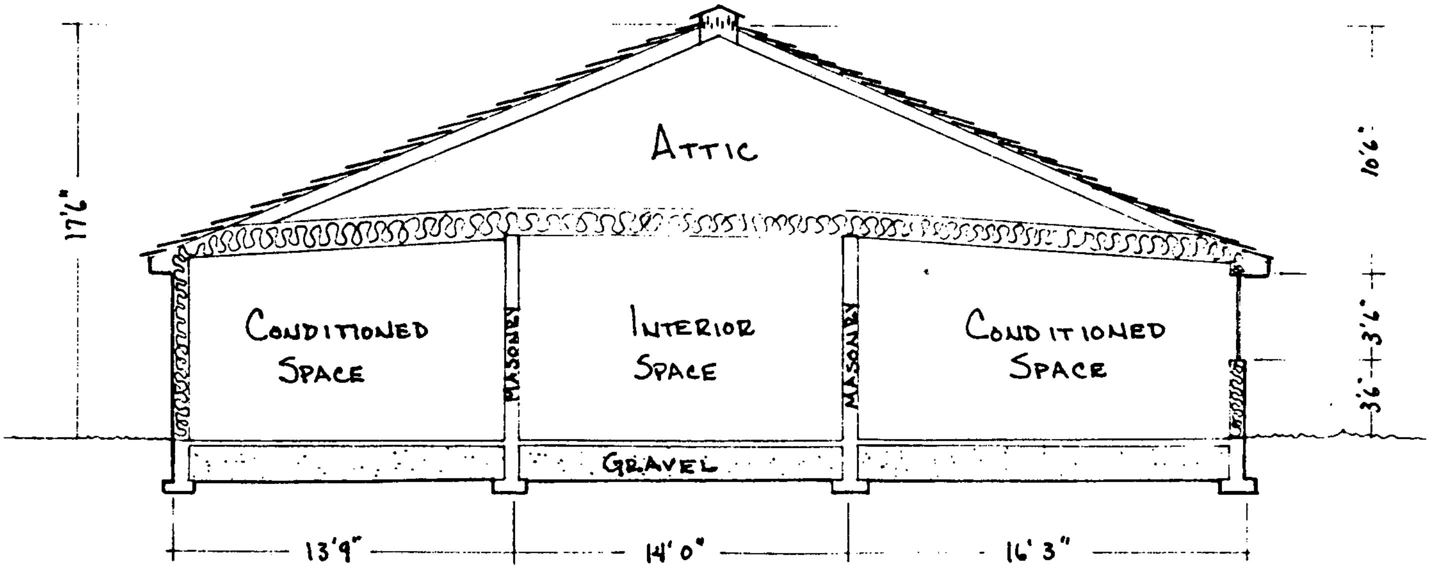
FIGURE 1a - PASSIVE SOLAR BUILDING

FOR CRIPPLED-PASSIVE VERSION:
CLOSE THERMAL SHUTTERS AND TROMBE WALLS, DRAIN WATER WALLS.



N ←—|—→ S

FIGURE 1b - CONVENTIONAL BUILDING



XBL 7812-13644

ground contact or night ventilation, and c) ground water can be pumped into the water columns where it will absorb heat from the rooms. The heat pump acts as an auxiliary cooler.

The calculations are summarized in Table 1. Note that lines 12-17 are repeated with different figures. This reflects the two sets of calculations made with the two computer programs, DOE-1 and BLAST. Calculations are done by the month because the degree day adjustments are more reliable over limited time periods with similar weather. They also allow separate evaluation of passive performance in the primary heating and cooling seasons, as well as in marginal periods. The table is divided into three sections - passive solar (lines 1-7), crippled passive (lines 8-13), and conventional (lines 14-17). Graphs of the most important values - the passive solar energy consumption and the predicted conventional energy consumption are provided in Figure 3. Figure 1b shows the building configuration used for the conventional building calculations. The crippled passive configuration is a variation of Figure 1a.

## 2. Passive Solar Building Load Calculation

Line 1 is the measured (metered) energy used during each month (in this case, a guess). Because of the interest in actual source fuel use, any "processed" fuel, such as electricity or steam, is divided by the efficiency of its production. In this case, both heating and cooling equipment use electricity, so the meter reading (in KBTU) has been divided by .33 to produce line 1.

Line 2 is the efficiency of the installed auxiliary system. For the PG&E building, electric resistance heating and room air conditioners were assumed. Electric heat is 100% efficient at the point of use, but a factor of .33 is necessary to account for the efficiency of production and transmission. Therefore, a monthly efficiency of .33 is used for the entire heating season. The efficiency of the air conditioner, however, varies with the outside temperature. A COP of 6-10 has been assumed. This translates to an efficiency of ~2.00-3.25. Accounting for the electrical production, the total efficiency during the space cooling season would vary from ~.60 when it is hot outside to 1.10 during the marginal cooling periods. The efficiency could be monitored by measuring the outside temperature when the air conditioner is on.

Line 3 is the load, the product of the energy use and the efficiency of the equipment using it. This represents the energy delivered to the spaces.

Line 4 is the efficiency of the conventional systems which are the basis of the actual energy use in both the passive solar and conventional buildings. For this building, a gas furnace and room air conditioners were chosen. An efficient furnace will vary between .75 and .80; the higher figure is appropriate during periods when its on-time is large during each on-off cycle. During the colder months, therefore, the efficiency is expected to be higher. The air conditioner will have the same efficiency as line 2.

Line 5 is the energy that would be used by conventional auxiliary equipment in the passive building. It is the product of the auxiliary load and the efficiency of the conventional equipment.

Line 6 is the energy used to assist the passive systems. In this case, the controls for heating are strictly manual (the shutters) and the heat flow is natural. The passive cooling, however, is assisted by pumps and fans. The energy measured for these (divided by .33 because it is electricity) is entered here.

Line 7 is the Energy Used by the passive building, the sum of the energy used by the passive (line 6) and auxiliary (line 5) systems.

As a specific example of these calculations, hypothetical measurements during January yielded a metered auxiliary heating energy consumption of 4542 KBTU (line 1) by the assumed electric resistance heaters. (This includes a factor of .33 because the electricity was generated off-site.) In order to find the energy used with conventional heating equipment (in this case, a gas furnace), the measured usage must be converted to an energy load, then re-converted to energy use with the standard conventional equipment efficiencies. In this example, the measured energy use is multiplied by the efficiency of the installed equipment (1.00 at the building * .33 at the plant - line 2), giving 4542 * .33 = 1499 KBTU = building heating load (line 3). The load is then divided by the efficiency of the furnace (.80 - line 4 - for an efficient one, at high demand) to calculate the energy used for auxiliary heat in the passive solar building, with a conventional plant: 1499/.80 = 1874 KBTU (line 5). No additional energy was consumed to operate the passive system (line 6) and the total energy used (line 7) is identical to line 5.

### 3. Crippled Passive Building Load Calculation

The crippled passive version of the Stockton house is relatively easy to define. The shutters are closed, and the trombe wall is isolated to prevent passive solar gain. The pumps and fans are shut off to eliminate passive cooling.

Line 8 is analogous to line 1. It is the measured energy divided by .33 to account for electrical generation.

Line 9 is an adjustment to account for weather differences between the two measurement periods (which are hypothetical periods in this example). This adjustment is described in detail in Section III-E. Line 10 is the energy use of the crippled passive buiding, modified to reflect the weather during the passive measurement period. It is the product of the measured energy use and the degree day adjustment.

Line 11 is analogous to line 3. It is the auxiliary energy delivered to the space, determined by multiplying the energy use (line 10) and the efficiency of the installed equipment (line 2). Again, as a concrete example the following calculation details are included; hypothetical measurements of the crippled building for a period similar to the passive solar period shows an energy use of 27,061 KBTU for January (line 8). During this month, for the weather data used in the calculation, and assuming a 57°F base, there were 507 degree days of passive solar operation and 480 for the crippled passive measurements. Therefore, the energy use for the crippled passive building is adjusted upward by 507/480 = 1.06 (line 9). This adjustment draws the crippled passive data into line with the slightly more severe weather experienced during the passive solar measurement period: 27,061 * 1.06 = 28,685 KBTU (line 10). This figure is converted to a heating load in the same way that the passive energy use was converted: 28,685 * .33 = 9466 KBTU (line 11).

The crippled passive building model was simulated using both DOE-1 and BLAST.

Lines 12 are the building load calculated by each program.

Lines 13 are the differences between the loads calculated by the programs and the measured crippled passive loads, expressed as a ratio. This ratio is used to correct for modeling inaccuracies as described in Section III-F. Arbitrary limits of .500 and 2.00 have been set to prevent runaway adjustment. The April heating and May cooling figures reflect this limit. When the building loads are near zero, the ratio can become unreliable simply because of the procedure in which small numbers (with inherent errors) are being subtracted and divided. It is therefore desirable to calculate the energy saving during the deep-heating or deep-cooling seasons.

In the example (using the DOE-1 model) the load calculated by the model for January is 8450 KBTU (line 12). That is about 1000 KBTU lower than the load for the identical situation calculated from measurements. The model is apparently low by a factor of 9466/8450 = 1.120 (line 13). <u>This adjustment factor is most responsible for the validity of the entire calculation</u>.

### 4. Conventional Building Load Calculation

The conventional version of this building is shown in Figure 1b. The pumps and fans are disabled to eliminate the passive cooling. The atrium glazing and the water walls are replaced (in the model) with the construction of the surrounding areas. Finally, because the atrium and the roof are now an extraordinary configuration, the insulated ceiling is carried across the atrium to create an interior room from the lower atrium with an insulated attic over the room. The conventional/conserving model was simulated, using both BLAST and DOE-1. Lines 14 are the loads calculated by the programs, analogous to lines 12 for the crippled passive building. Lines 15 are the loads adjusted by the correction factor determined from the comparison of the crippled passive versions of the building. The modification is made by multiplying the load (line 14) by the adjustment factor from the previous section (line 13).

Lines 16 are the <u>Energy Used</u> by the conventional building, the quotient of the load (line 15) and the same conventional equipment efficiency used in the passive solar calculation (line 4). Specifically, the January load is 7375 KBTU (line 14). That figure is then adjusted because the model had been found to be low: 7375 * 1.120 = 8262 KTBU (line 15). The standard efficiency (line 4) is used to convert the load to energy use with conventional equipment 8262/.80 = 10,327 KBTU (line 16).

Lines 17 are the <u>Energy-Saved</u> by the passive solar building: the difference in energy use of the passive solar and conventional/conserving buildings (lines 7 and 16). For January, the energy saved is 10,327 KBTU - 1874 KBTU = 8453 KBTU.

## B. Greenmoss HUD Demonstration House - Waitsfield, Vermont

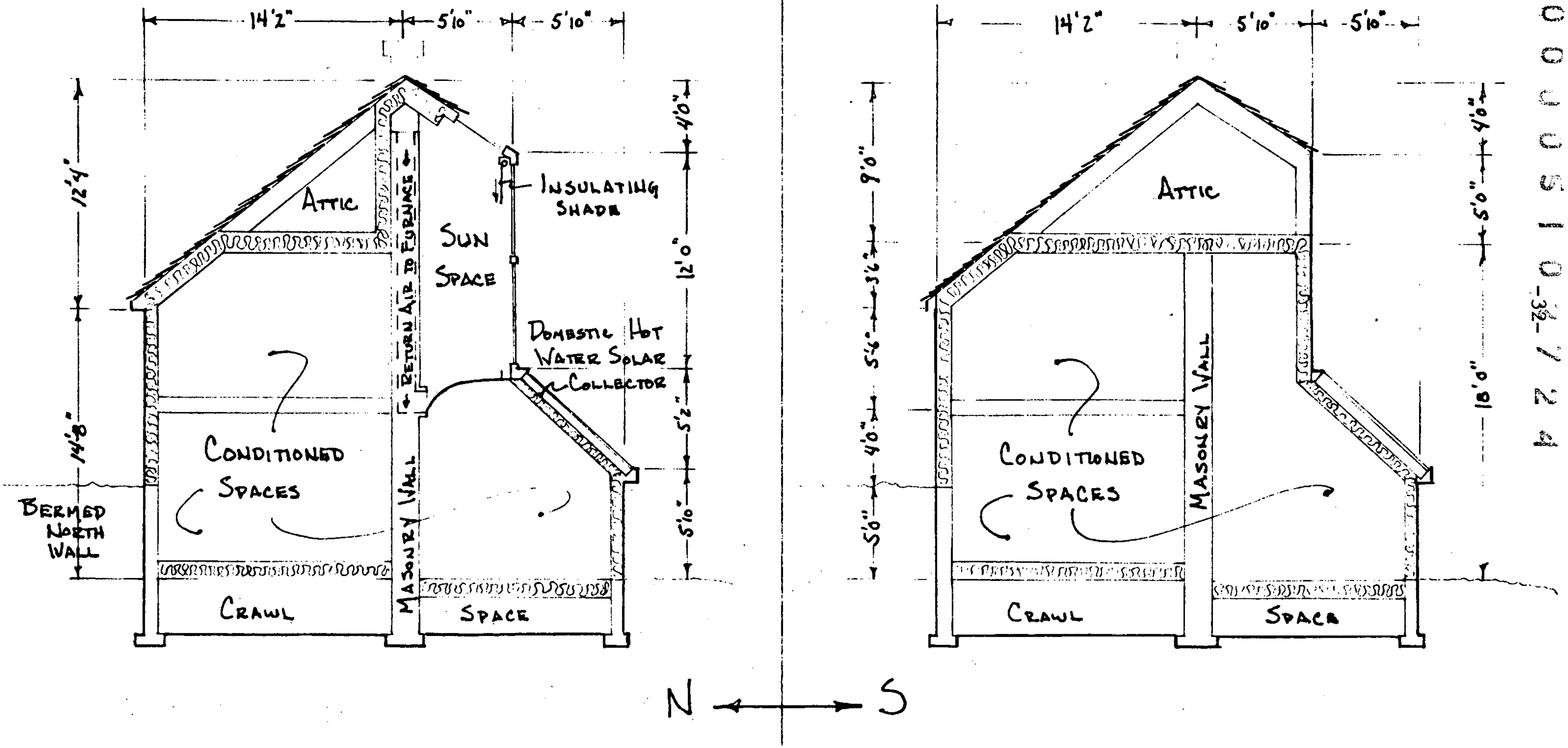
### 1. Building Description

The second building to which the calculation procedure has been applied is a residence in Vermont which was built as a HUD demonstration

Figure 2a - Passive Solar

Figure 2b - Conventional

For Crippled-Passive Version:
Close Insulating Shade,
Close Ducts in Wall.



Greenmoss H.U.D. Demonstration Building

XBL 7812-13643

of a specific passive heating configuration.[9] The drawings show that building is about the same size as the PG&E house, but it has only one major passive feature, a large southern sunspace on the upper floor and attic levels. The glazing is equipped with reflective shades. Behind it is a concrete block wall with ducts which circulate air through the wall and sunspace, and deliver warmed air to the furnace. The furnace is the primary auxiliary heater. Like most buildings in Vermont, there is no provision for cooling.

For this example only those steps in the calculation which differ from the PG&E building are described.

## 2. Passive Solar Building Load Calculation

Line 4 shows that the conventional heating system (the furnace) is operating at peak efficiency for a longer period of the year than in Stockton. Because of the longer winter, the furnace is operating at peak efficiency in late fall and early spring as well as the winter.

## 3. Crippled Passive Building Load Calculation

To define the crippled passive building, two changes are needed. The reflective shades are drawn over the sunspace windows, and the ducts through the concrete wall are closed.

The adjustment factors (line 13) for both programs are much closer to 1.000 than in the first example. This is because both BLAST and DOE-1 gave results which were close to the (estimated) measured results and were also very close to each other.

## 4. Conventional Building Load Calculation

The conventional building requires the replacement of the sunspace glazing with the wall construction of the nearby walls and the closing of the ducts. As in the Stockton building, the extended sunspace is divided into interior and attic by extending the insulated ceiling through the sunspace. The conventional building configuration is shown in Figure 2b.

The Energy-Saved totals calculated by the two programs (line 17) are considerably different, despite good agreement on the conventional loads. This results from the difference in the way in which DOE-1 and BLAST treat the <u>changes</u> to the sunspace from conventional to crippled versions. As a result, the adjustments cause a 20% difference in the energy savings as calculated by the two computer programs. Though this is undesirable, the difference is relatively small in comparison to the potential errors in utilizing a less building-specific utility data base in the comparison.

This example of the energy saved calculation procedure demonstrates a potential limitation in applying the procedure. The user of the procedure must be intimately familiar with the type of building energy analysis technique being used to calculate the conventional and crippled passive building loads. The specific limitations of that calculation will be reflected in the energy savings which are determined.

## FOOTNOTES

1. Thermal Data Requirements and Performance Evaluation Procedures for Passive Buildings; National Bureau of Standards.

2. Movers and Stayers: The Residents Contribution to Variation Across Houses in Energy Consumption for Space Heating: Robert Sonderegger, Lawrence Berkeley Laboratory.

3. Building Loads Analysis and System Thermodynamics Program; Construction Engineering Research Laboratory. A set of subprograms for predicting energy consumption in buildings.

4. DOE-1; Lawrence Berkeley Laboratory. A set of programs capable of rapid and detailed analysis of energy consumption in buildings.

5. Degree days are calculated each day by finding the difference between the average temperature and a base temperature (at which the heating or cooling load will presumably disappear). Degree days can be used to find a rough approximation of heating and cooling demands in a given climate, but much depends on the specific building and the way it responds to the weather. With the precautions taken in the energy-saved calculations, we can be confident of a relatively direct relationship between degree days and heating or cooling loads.

6. Various methods of infiltration measurement have been tested and documented. See Section A4 (Air Infiltration) of the IHVE Guide Book (1970) or Chapter 21 (Infiltration and Natural Ventilation) of the ASHRAE Handbook of Fundamentals (1977) for discussions and references.

7. ASHRAE Handbook of Fundamentals (1977), pages 24.3-24.5.

8. The Stockton House was designed by Glen Mortensen, a Stockton architect, in cooperation with Pacific Gas and Electric. The climate in the San Joaquin Valley has cool winters and very warm, sometimes hot, summers. Summer nights, however, are usually cool, due to a large diurnal temperature swing.

9. The Vermont house was built with a grant (#2708) from the Department of Housing and Urban Development, in Waitsfield, near Burlington. The Vermont climate is very cold in winter with snow cover for about three months. Summers are mild, only occasionally becoming uncomfortably warm.

# PACIFIC GAS & ELECTRIC DEMONSTRATION BUILDING

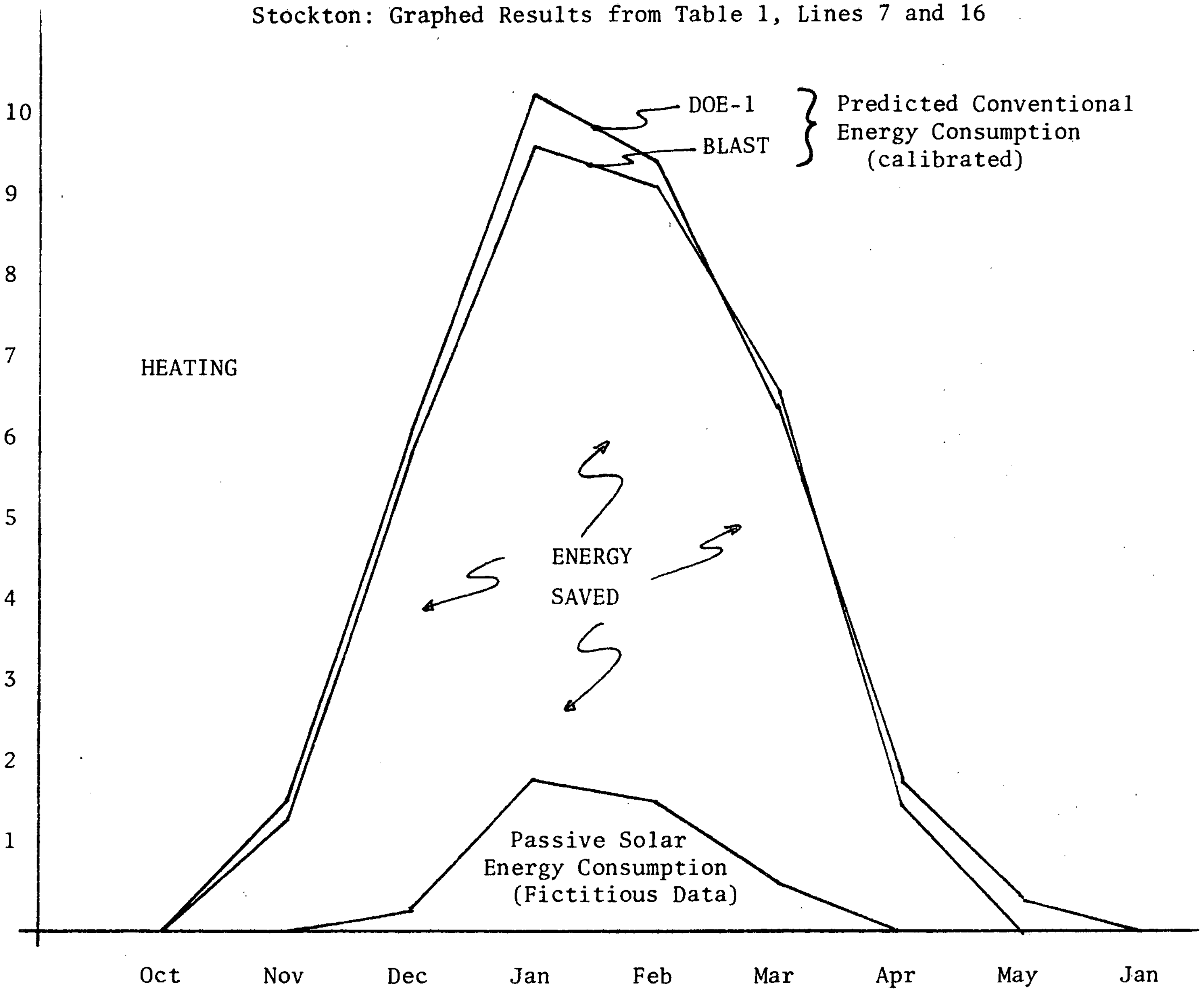
| | | | | HEATING | | | | | | | | | COOLING | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Total | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Total | |
| Building Measurements | Passive Solar Building | 1. Measured Energy Consumption* | | — | — | 824 | 4542 | 3836 | 1585 | — | — | 10,787 | — | — | — | 282 | 499 | — | — | — | 781 | 11,568 |
| | | 2. Installed Equipment Efficiency | | .33 | .35 | .33 | .33 | .33 | .33 | .33 | .33 | | 1.05 | .95 | .85 | .75 | .70 | .80 | .90 | 1.00 | | |
| | | 3. Calculated Building Load | 1×2 | — | — | 272 | 1499 | 1266 | 523 | — | — | 3,560 | / | / | 2÷4 → 1÷5 | | | | / | / | | |
| | | 4. Standard Equipment Efficiency | | .75 | .75 | .80 | .80 | .80 | .80 | .75 | .75 | | 1.05 | .95 | .85 | .75 | .70 | .80 | .90 | 1.00 | | |
| | | 5. Standard Equipment Consumption | 3/4 | — | — | 340 | 1874 | 1583 | 654 | — | — | 4,451 | — | — | — | 282 | 499 | — | — | — | 781 | 5,232 |
| | | 6. Energy to Operate Passive System* | | Manual Controls | | | | — | — | — | — | | Pumps/Fans | 16 | 114 | 216 | 322 | 146 | 19 | — | 1614 | 1,614 |
| | | 7. Total Energy Used | 5+6 | — | — | 340 | 1874 | 1583 | 654 | — | — | 4,451 | — | 16 | 114 | 498 | 821 | 146 | 19 | — | 2395 | 6,846 |
| | Crippled Passive | 8. Measured Energy Consumption* | | 401 | 5208 | 19147 | 27061 | 25690 | 15344 | 3646 | 1342 | 97,839 | 10 | 73 | 1782 | 3492 | 3816 | 2257 | 180 | — | 11,610 | 109,449 |
| | | 9. Degree Day Adjustment | | 1.02 | .96 | .97 | 1.06 | .99 | 1.10 | .92 | .98 | | .98 | 1.07 | 1.04 | .99 | .92 | 1.05 | .98 | 1.09 | | |
| | | 10. Adjusted Energy Consumption | 8×9 | 409 | 5000 | 18573 | 28685 | 25435 | 16879 | 3354 | 1315 | 99,648 | 10 | 78 | 1853 | 3457 | 3511 | 2370 | 176 | — | 11,455 | 111,103 |
| | | 11. Calculated Building Load | 10×2 | 135 | 1652 | 6129 | 9466 | 8393 | 5570 | 1107 | 434 | 32,886 | 10 | 74 | 1575 | 2593 | 2458 | 1896 | 159 | — | 8,765 | 41,651 |
| Building Simulations | DOE-1 Crippled Passive | 12. Predicted Building Load | | — | 992 | 4931 | 8450 | 6776 | 5040 | 27 | — | 28,016 | — | 2 | 1701 | 3828 | 4324 | 2505 | 140 | — | 12,500 | 41,316 |
| | | 13. Adjustment Factor | 11/12 | — | 1.665 | 1.243 | 1.120 | 1.239 | 1.105 | 2.000 | — | | — | 2.000 | .926 | .677 | .568 | .757 | 1.134 | — | | |
| | DOE-1 Conventional Building | 14. Predicted Building Load | | — | 694 | 4194 | 7375 | 6142 | 4706 | 672 | 36 | 23,783 | — | — | 1060 | 2897 | 3247 | 1661 | 107 | — | 8,972 | 32,755 |
| | | 15. Adjusted Building Load | 13×14 | — | 1156 | 5213 | 8262 | 7608 | 5201 | 1344 | — | 28,784 | — | — | 982 | 1962 | 1845 | 1257 | 121 | — | 6,167 | 34,951 |
| | | 16. Predicted Energy Consumption | 15÷4 | — | 1541 | 6516 | 10327 | 9510 | 6501 | 1792 | — | 36,187 | — | — | 1155 | 2616 | 2636 | 1571 | 135 | — | 8,113 | 44,300 |
| | | 17. ENERGY SAVED | 16-7 | — | 1541 | 6176 | 8453 | 7927 | 5847 | 1792 | — | 31,736 | — | -16 | 1041 | 2118 | 1815 | 1425 | 116 | — | 6,499 | 38,235 |
| | BLAST Crippled Passive | 12. Predicted Building Load | | 274 | 2622 | 7304 | 10470 | 7994 | 6085 | 1600 | 845 | 37,194 | 19 | 145 | 1845 | 3159 | 3451 | 2005 | 201 | 7 | 10,832 | 48,026 |
| | | 13. Adjustment Factor | 11/12 | .493 | .650 | .839 | .904 | 1.050 | .915 | .692 | .514 | | .541 | .510 | .854 | .821 | .712 | .946 | .791 | — | | |
| | BLAST Conventional Building | 14. Predicted Building Load | | — | 1678 | 5661 | 8570 | 7065 | 5802 | 1711 | 601 | 31,088 | — | — | 825 | 1964 | 2432 | 1274 | 85 | — | 6,580 | 37,668 |
| | | 15. Adjusted Building Load | 13×14 | — | 1057 | 4750 | 7748 | 7418 | 5311 | 1184 | 309 | 27,777 | — | — | 704 | 1612 | 1732 | 1205 | 67 | — | 5,320 | 35,097 |
| | | 16. Predicted Energy Consumption | 15÷4 | — | 1410 | 5938 | 9685 | 9272 | 6659 | 1578 | 412 | 34,954 | — | — | 829 | 2149 | 2475 | 1506 | 75 | — | 7,034 | 41,968 |
| | | 17. ENERGY SAVED | 16-7 | — | 1410 | 5598 | 7811 | 7689 | 5985 | 1578 | 412 | 30,483 | — | -16 | 715 | 1651 | 1654 | 1360 | 56 | — | 5,436 | 35,919 |

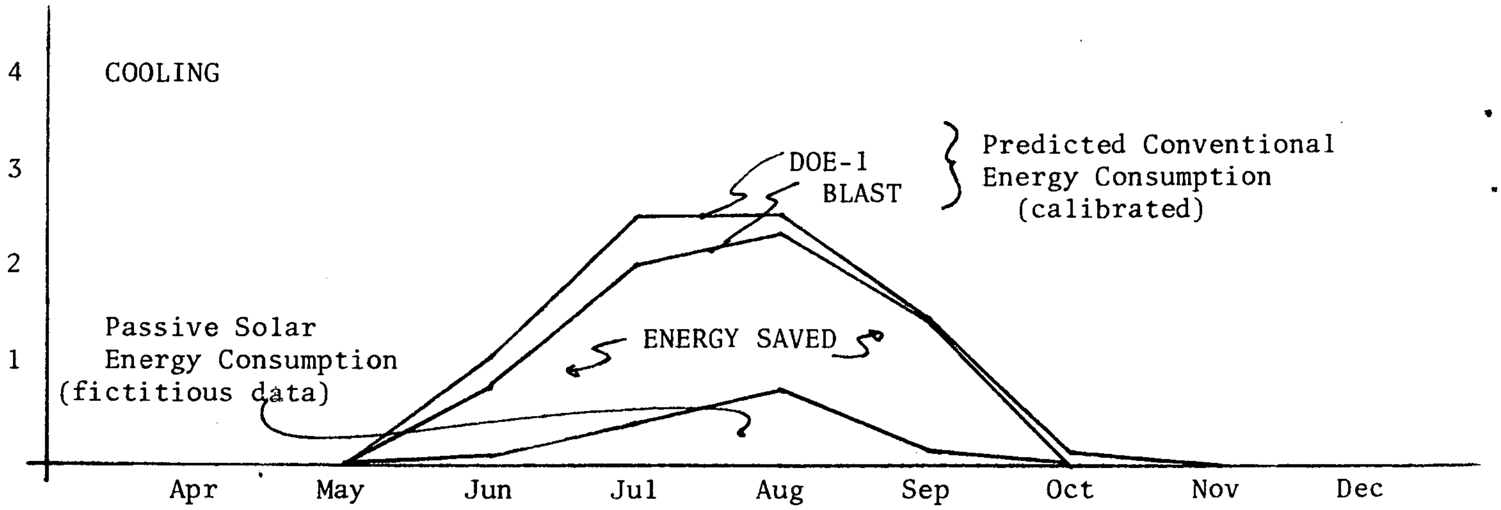
*Measured energy (lines 1, 6, and 8) has been divided by .33 if it is electricity generated off-site.

NOTE: All units are KBTU or dimensionless.

Table 1

Stockton: Graphed Results from Table 1, Lines 7 and 16





# GREENMOSS H.U.D. DEMONSTRATION BUILDING

| | | | | Heating OCT | Heating NOV | Heating DEC | Heating JAN | Heating FEB | Heating MAR | Heating APR | Heating MAY | Heating TOTAL | Cooling APR | Cooling MAY | Cooling JUN | Cooling JUL | Cooling AUG | Cooling SEP | Cooling OCT | Cooling NOV | Cooling TOTAL | Heating & Cooling TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BUILDING MEASUREMENTS | PASSIVE SOLAR BUILDING | 1. MEASURED ENERGY CONSUMPTION* | | 1558 | 5791 | 10691 | 12958 | 9367 | 7652 | 3212 | 733 | 51,962 | | | | | | | | | | 51,962 |
| | | 2. INSTALLED EQUIPMENT EFFICIENCY | | .33 | .33 | .33 | .33 | .33 | .33 | .33 | .33 | | | | | | | | | | | |
| | | 3. CALCULATED BUILDING LOAD | 1×2 | 514 | 1911 | 3528 | 4276 | 3091 | 2525 | 1060 | 242 | 17,147 | | | | | | | | | | 17,147 |
| | | 4. STANDARD EQUIPMENT EFFICIENCY | | .75 | .80 | .80 | .80 | .80 | .80 | .80 | .75 | | | | | | | | | | | |
| | | 5. STANDARD EQUIPMENT CONSUMPTION | 3/4 | 685 | 2389 | 4410 | 5345 | 3864 | 3156 | 1325 | 323 | 21,497 | | | | | | | | | | 21,497 |
| | | 6. ENERGY TO OPERATE PASSIVE SYSTEM* | | MANUAL CONTROLS | | | | — | — | — | — | | | | | | | | | | | |
| | | 7. TOTAL ENERGY USED | 5+6 | 685 | 2389 | 4410 | 5345 | 3864 | 3156 | 1325 | 323 | 21,497 | | | | | | | | | | 21,497 |
| | CRIPPLED PASSIVE | 8. MEASURED ENERGY CONSUMPTION* | | 7398 | 12,057 | 26,524 | 39156 | 27800 | 20472 | 9073 | 4629 | 147,109 | | | | | | | | | | 147,109 |
| | | 9. DEGREE DAY ADJUSTMENT | | .92 | 1.09 | 1.06 | .93 | 1.00 | .97 | 1.04 | 1.01 | | | | | | | | | | | |
| | | 10. ADJUSTED ENERGY CONSUMPTION | 8×9 | 6806 | 13142 | 28115 | 36415 | 27800 | 19858 | 9436 | 4678 | 146,250 | | | | | | | | | | 146,250 |
| | | 11. CALCULATED BUILDING LOAD | 10×2 | 2246 | 4337 | 9278 | 12017 | 9174 | 6553 | 3114 | 1543 | 48,262 | | | | | | | | | | 48,262 |
| BUILDING SIMULATIONS | DOE-1 CRIPPLED PASSIVE | 12. PREDICTED BUILDING LOAD | | 2326 | 4577 | 9414 | 12137 | 8984 | 6798 | 3457 | 1532 | 49,225 | | | | | | | | | | 49,225 |
| | | 13. ADJUSTMENT FACTOR | 11/12 | .966 | .948 | .986 | .990 | 1.021 | .964 | .901 | 1.007 | | | | | | | | | | | |
| | DOE-1 CONVENTIONAL BUILDING | 14. PREDICTED BUILDING LOAD | | 1605 | 3784 | 8652 | 11396 | 8057 | 5899 | 2671 | 1116 | 43,180 | | | | | | | | | | 43,180 |
| | | 15. ADJUSTED BUILDING LOAD | 13×14 | 1550 | 3585 | 8527 | 11282 | 8227 | 5686 | 2406 | 1124 | 42,388 | | | | | | | | | | 42,388 |
| | | 16. PREDICTED ENERGY CONSUMPTION | 15÷4 | 2066 | 4482 | 10659 | 14104 | 10284 | 7108 | 3007 | 1499 | 53,209 | | | | | | | | | | 53,209 |
| | | 17. ENERGY SAVED | 16-7 | 1381 | 2093 | 6249 | 8759 | 6420 | 3952 | 1682 | 1176 | 31,712 | | | | | | | | | | 31,712 |
| | DLAST CRIPPLED PASSIVE | 12. PREDICTED BUILDING LOAD | | 2146 | 4166 | 9114 | 11810 | 9347 | 6294 | 2965 | 1835 | 47,077 | | | | | | | | | | 47,077 |
| | | 13. ADJUSTMENT FACTOR | 11/12 | 1.047 | 1.041 | 1.018 | 1.018 | .992 | 1.041 | 1.050 | 1.156 | | | | | | | | | | | |
| | DLAST CONVENTIONAL BUILDING | 14. PREDICTED BUILDING LOAD | | 2013 | 4063 | 9215 | 11980 | 9214 | 6106 | 2738 | 1199 | 46,528 | | | | | | | | | | 46,528 |
| | | 15. ADJUSTED BUILDING LOAD | 13×14 | 2107 | 4230 | 9380 | 12190 | 9141 | 6357 | 2876 | 1385 | 47,666 | | | | | | | | | | 47,666 |
| | | 16. PREDICTED ENERGY CONSUMPTION | 15÷4 | 2809 | 5287 | 11736 | 15237 | 11426 | 7947 | 3594 | 1840 | 59,874 | | | | | | | | | | 59,874 |
| | | 17. ENERGY SAVED | 16-7 | 2124 | 2898 | 7316 | 9892 | 7263 | 4791 | 2269 | 1525 | 38,078 | | | | | | | | | | 38,078 |

*Measured energy (lines 1, 6, and 8) has been divided by .33 if it is electricity generated off-site.

NOTE: All units are KBTU or dimensionless.

Table 2

*TECHNICAL INFORMATION DEPARTMENT*
*LAWRENCE BERKELEY LABORATORY*
*UNIVERSITY OF CALIFORNIA*
*BERKELEY, CALIFORNIA 94720*