PASSIVE SOLAR CONTRIBUTION TO EARTH SHELTER PERFORMANCE

By

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Stillwater, Oklahoma

1979

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF ARCHITECTURAL ENGINEERING
July, 1981

PASSIVE SOLAR CONTRIBUTION TO EARTH

SHELTER PERFORMANCE

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PREFACE

This study is concerned with the comparison of passive solar performance predictors using a passive solar earth sheltered house as the model. The two methods used are at different levels of sophistication and will be analyzed for their adaptability for use with earth sheltered houses. Also dealt with are the parameters of the earth sheltered or above ground houses that are anticipated as having an effect on passive solar performance. A typical good design for a passive solar earth sheltered house is utilized for the parametric studies that are performed using the two different performance predictors.

The author wishes to express his appreciation to his major adviser, Dr. Lester L. Boyer, Professor of Architecture and Architectural Engineering, for his guidance and assistance throughout this study. Appreciation is also expressed to Walter T. Grondzik, Assistant Professor of Architecture, for his guidance in formulating and organizing the study. A note of thanks is given to W. George Chamberlain, Professor of Architecture, for his participation as a committee member.

Finally, special gratitude is expressed to Eugene and Hazel Helms for their support, understanding, and encouragement.

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CHAPTER I

INTRODUCTION

Energy Incentives

Energy usage was of no concern to most people in the United States until the early 1970's. Fossil fuels seemed to be a never ending resource and were accepted eagerly, being efficient and inexpensive. Inexpensive fuels allowed freedom to design buildings that could be built anywhere. Passive energy design and climate characteristics were not often considered. Mechanical systems were capable of keeping buildings comfortable even if they looked like highrise greenhouses since the amount of energy usage wasn't as important as the architectural statement. Since the 1973 oil embargo and continuous increases in the cost of petroleum, designers and builders have become aware of the need for energy efficient buildings. Designing without respect for regional differences will lead us away from buildings that reflect and perform within the environment of their surroundings. As noted by one source:

> The world environmental 'energy crisis' goes far deeper than simply the depletion of fossil fuels. The crisis is one that is generated at the core of a culture bent on wastefulness. The past technological development has attempted to improve the standard of living which is a necessary and vital part of evolution. However, when in the process it generates unnatural contingencies that tend to destroy the very environment which sustains life, then this form of development must be questioned. The utilization of alternative natural

> energy sources and basic energy conservation principles will inevitably alter the present energy use patterns that have led us to the current dilemma. Furthermore, their application offers the opportunity to show concern for the earth, its people and the environment as a holistic, nonseparable entity.[1]

The energy use levels in the United States are alarming. The U.S. consumes 35 percent of the world's energy diet while only possessing 6 percent of the world population.[2] The increase in fuel costs can not be the only concern, since fossil fuels are non-renewable and are estimated to be depleted near the year 2000. This means that new types of energy will need to be utilized and, since nuclear power has decreased in popularity, coal is our only alternative. However, regulations on pollution control will slow the use of coal. While trying to develop new energy sources, buildings must be designed to operate within the limitations of climatic regions to reduce energy demands.

The commercial and residential sectors use 35 percent of the nation's total energy as shown in Figure 1, much of which architects are capable of reducing. Residential requirements for heating and cooling are about 60 percent of the total residential energy requirements.[3] Reducing the need for heating and cooling will be quite difficult since our culture expects comfort regardless of exterior conditions. Steps toward energy conservation and increasing the designed comfort range have been taken but this will not be enough unless new resources and methods are used to maintain comfort and limit dependence on non-renewable resources.

Earth Shelter Alternative

Techniques used to reduce energy requirements may be new to the present society but will not necessarily remain so. When man first

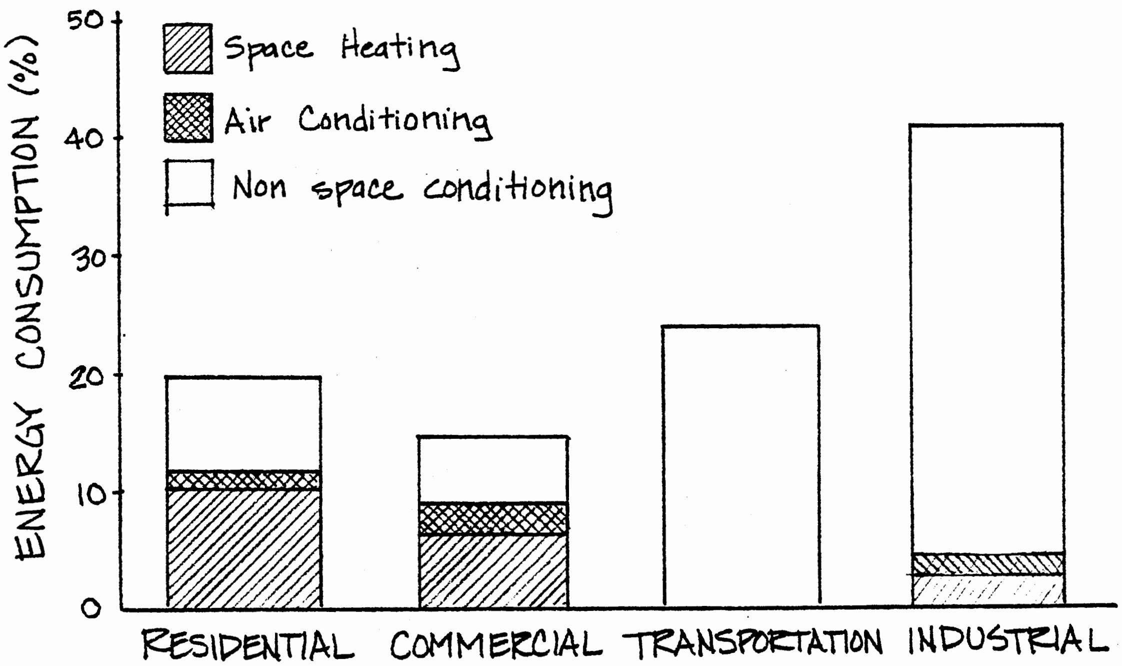


Figure 1. Energy Usage in the United States

appeared on earth he had to rely on materials located nearby to protect him from the weather. Simply being protected from the rain isn't always enough, since a vast majority of the earth is at times too hot or cold for comfort. Early shelters had to provide comfort and security from the exterior climate. For protection from severe weather, living underground became a necessity in various regions around the world. Man has lived underground throughout history and has grown to respect the earth and its processes so that he could live comfortably.

Some men have not forgotten where their roots once lay and they have developed the insight to realize that the past can indeed be looked at for the future. One such man was H.G. Wells, a British author. In

1935 he predicted that "the everytown of the year 2054 will be dug into the hills . . . and not a skyscraper."[4] The prediction by Wells is gradually becoming recognized as a feasible possibility for decreasing energy consumption. Whether he felt it would be necessary to build into the hills for energy purposes, for land preservation or other reasons, is not known. Malcolm Wells, a well known contemporary architect, has been an advocate of earth shelters for the past 20 years for their preservation of land.[5]

We have become a society which covers the land causing an imbalance in nature's life cycle. This imbalance partly explains why ecological concerns have become increasingly important. The beauty of the earth should not be scarred or destroyed by man. We should learn to be more like the Indians, as pointed out by W. Cather:

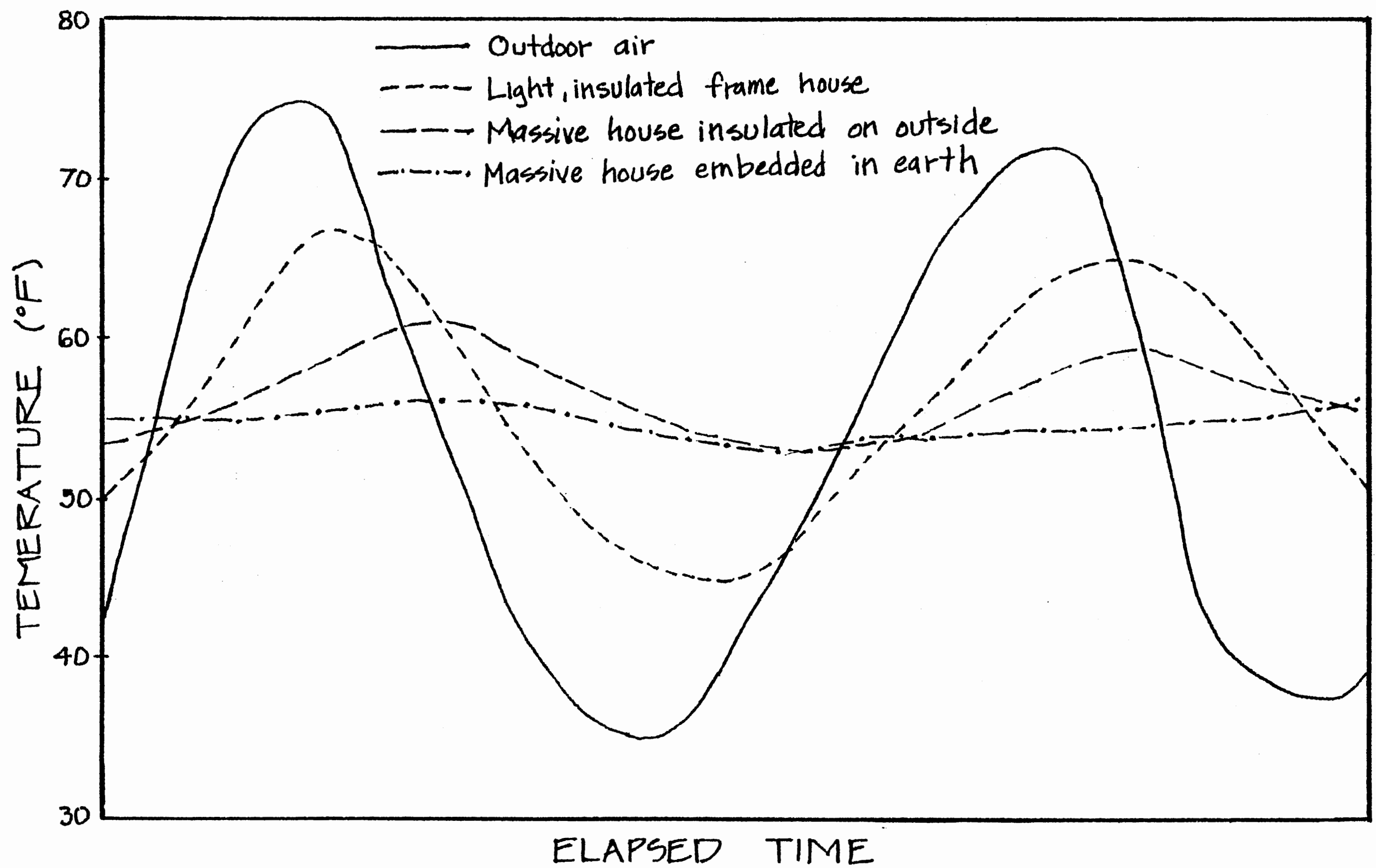
> . . . Father Latour judged that, just as it was the white man's way to assert himself in any landscape, to change it, make it over a little (at least to leave some mark of memorial of his sojourn), it was the Indian's way to pass through a country without disturbing anything; to pass and leave no trace, like fish through the water, or birds through the air.[6]

The "energy crisis" has caused a large number of people to realize that the use of the earth's relatively stable temperature can provide occupant comfort at minimal energy costs. The earth moderates the temperature swings that occur on a daily basis and it has been determined that a time lag of approximately 133 hours occurs at a two-foot depth. The time lag occurs proportionately so that an eight or ten foot depth has a time lag of 2100 to 2200 hours or about 90 days.[7] A reduction of 50 to 75 percent of the normal heating and cooling load requirements can be achieved due to the temperature moderation and time lag of the earth.[8] Temperature moderation effects on an earth sheltered house, with a large thermal mass, are shown schematically in Figure 2. To achieve reductions of this magnitude each house must reflect and respond to the regional and microclimatic demands.

A study at Oklahoma State University points out several reasons for deciding to build an earth sheltered house.[9] The study was directed toward obtaining data from Oklahoma earth sheltered home owners on habitability, energy performance, and construction. The three highest reasons were for reduced heating load, reduced cooling load, and for storm protection. Some home owners expected higher energy savings, however most of the sample were pleased with the energy performance of their homes. Reasons for performance not meeting expectations are primarily due to over expectations and regional considerations not being properly considered in the design of the homes. Orientation, solar control and climate are major parameters which are not properly considered when the typical earth sheltered house is built.

Passive Solar Integration

The earth's moderated temperatures are a definite benefit for the high plains region of the southcentral United States since both heating and cooling are required during the year. During the winter months this region can be subject to severe cold and winds. The winter winds blow across the plains from the north so that protection from the north is needed to reduce infiltration. An asset in the winter is that this region has a good deal of solar radiation to help combat the winter cold to extend the comfortable period of the year, without mechanical heating.[10]



Source: B. Anderson (Ed.), The Solar Home Book, Brick House Publishing Co., Inc., Andover, Massachusetts, 1976, p. 93

Figure 2. Outdoor Temperature Effects on Interior Conditions

Solar radiation has been used for house heating for centuries. The advantages of passive solar systems are those of economics and usage of already existing space and building components.[11] Methods used for space heating that utilize solar gain can lend themselves to aesthetic and functional designs. The architect can then begin responding to climatic and regional influences for each individual building design.

Passive solar heating requires the collection of the sun's energy, storage of this energy as heat, and the distribution of the heat as required.[12] To maximize the amount of solar energy collected, each region must be examined individually. For substantial solar heat gains in the Northern Hemisphere a southerly orientation should be used. Using solar heating can have its drawbacks, since large amounts of thermal mass are required to store the amount of solar energy it would take to heat a house.

Earth sheltered houses normally contain a much larger thermal mass than that normally associated with above ground buildings. The large mass used to support the earth loads, in the roof and walls, works well for storing heat. The thermal time lag properties of concrete work well for distributing the heat hours after receiving the solar energy. The typical earth sheltered house has only one exposed facade, usually southerly, and an earth-backed wall which faces north.[13] The earth on the north wall protects the building from the winter winds and an exposed south wall receives solar radiation in the winter and southerly breezes in the summer. This type of building configuration provides an opportunity to utilize passive solar heating with only minor design changes to utilize solar potential.

FOOTNOTES

[1]A. J. Davis, and R. P. Schubert, Alternative Natural Energy Sources in Building Design, (New York, 1974), p. 7.

[2]Ibid, p. 8.

[3]U.S. Department of Energy, Energy Conservation in the Home, October, 1977, p. 253.

[4]R. Mason, "Projections On The Future of Underground Development." Earth Covered Buildings and Settlements, F. L. Moreland (Ed.), (Arlington, 1978), p. 171.

[5]M. B. Wells, "Nowhere to Go But Down," Progressive Architecture, Vol. 46, No. 2 (February, 1965), p. 175.

[6]W. Cather, Death Comes for the Archbishop, 6th ed. (New York, 1942), p. 265.

[7]W. B. Davis, "Earth Temperature: Its Effect on Underground Residences." Earth Covered Buildings: Technical Notes, F. L. Moreland (Ed.) (Arlington, 1978), p. 205.

[8]L. L. Boyer, M. J. Weber, and W. T. Grondzik, Energy and Habitability Aspects of Earth Sheltered Housing in Oklahoma, Project Report, Presidential Challenge Grant, (Stillwater, Oklahoma, March, 1980).

[9]Ibid., p. 28.

[10]Regional Guidelines for Building Passive Energy Conserving Homes, (Washington, D.C., 1978), p. 207.

[11]E. Mazria, The Passive Solar Energy Book, (Emmaus, Pa., 1979), p. 62.

[12]Ibid, p. 28.

[13]L. L. Boyer and W. T. Grondzik, "Habitability and Energy Performance of Earth Sheltered Dwellings," Proceedings of 3rd Miami International Conference on Alternative Energy Sources, (Miami Beach, Florida, December, 1980.)

CHAPTER II

PROBLEM STATEMENT

Approach

The first part of this study deals with the comparison of passive solar performance predictors using a passive solar earth sheltered house as a model. The two methods that will be used to predict passive solar performance are at different levels of sophistication and need to be analyzed for their adaptability or modification for use on earth sheltered houses. The simplest method determines the passive solar contribution using a tabular method based on data gathered from above ground houses. The second method uses a programmable calculator to determine the solar contribution by mathematical modeling techniques.

The second part of the study will deal with those parameters of the earth sheltered or above ground houses that are anticipated as having an effect on passive solar performance. The study will utilize a typical design for a passive solar earth sheltered house. Changes will be made that have an impact on the amount of solar radiation admitted into the space and the thermal mass that it strikes. At the end of the parametric studies the earth sheltered house will be compared to a similar above ground house to determine if the earth sheltered house utilizes passive solar gains more efficiently due to larger thermal masses.

Purpose

It has been noted that, while an earth sheltered house would perform better with passive solar integrated into the design, most houses have not been designed to incorporate such advantages.[1] A method is needed to assess passive solar contribution and to evaluate passive solar techniques. The easiest and quickest methods may contain assumptions that are not applicable to earth sheltered houses. If simple methods can perform the operations with reasonable accuracy there is no need to use expensive "mainframe" programs. Comparing output from both programs on solar savings fractions will enable judgements to be made as to the relative comparative accuracy of the programs.

The use of methods to predict passive solar contributions will provide information as to the positive attributes for designing with passive solar gains. This study will show how minor changes in building parameters can change the amount of solar contribution that can be expected.

Performance studies of passive solar earth sheltered houses need to be conducted to increase public acceptance. The knowledge obtained from these studies will show that alternatives exist which reduce energy requirements while providing the comfort to which contemporary home owners have been accustomed.

Specific Objectives

The objectives of this study are to compare two different passive solar performance analysis techniques and several passive solar parameters in relation to earth sheltered houses. Objectives are as follows:

1. Present a prototypical example of a passive solar earth sheltered house to be used for analysis.
2. Determine the heat loss requirements for the earth sheltered house and an equivalent above ground house.
3. Compare two different passive solar contribution prediction techniques with respect to earth sheltered houses and determine the applicability of each.
4. Examine the major parameters in an earth sheltered house that are expected to have an impact on passive solar contribution.
5. Compare the solar heat gains and the heat losses of the earth sheltered house and an equivalent above ground house to get an overview of winter performance.

Scope and Limitations

The passive solar earth sheltered house used in this study is designed for the high plains region of the southcentral United States near 36° north Latitude. The case study design for passive solar and earth sheltering is presented as a tentative prototype. It will provide a vehicle for comparing the two passive solar prediction techniques and for examining the parameters that affect passive solar performance. The architectural design, habitability and cooling season performance of the case study will not be addressed in detail, since this study deals primarily with passive solar assessment, but are parameters that have been shown to have an impact on energy consumption.[2] The case study design will incorporate features that benefit cooling season performance since yearly performance is important.

A limitation that is of most concern is the small sample of programs being used for evaluation. Determining which programs are correctly predicting solar performance can be a significant problem if the programs tend to give differing answers. With this is mind, all of the studies are to be compared on increased or decreased performance characteristics. The overall performance for the earth sheltered and above ground house will be evaluated by solar savings fractions (SSF).[3] The SSF will vary within a region since both the microclimate and macroclimate change.

The use of the SSF to evaluate solar heating systems is common, but there is some controversy over the appropriateness of SSF numbers since they represent a ratio of solar heat gain and heat loss. Problems occur in that system costs and system heat losses are not typically included, so that a house with a higher SSF may also have higher initial and operation costs.[4] Economic analysis of passive solar will not be included in the study, since the construction costs of the passive solar earth sheltered case study are felt to be similar to those of the above ground case study.

FOOTNOTES

[1] L. L. Boyer, M. J. Weber, and W. T. Grondzik, Energy and Habitability Aspects of Earth Sheltered Housing in Oklahoma, Project Report, Presidential Challenge Grant (Stillwater, Oklahoma, March, 1980).

[2] Ibid.

[3] U.S. Department of Housing and Urban Development, The First Passive Solar Home Awards, (Washington, D.C., 1979), p. 221.

[4] W. A. Shurcliff, "A Better Approach to Comparing Passively Heated Solar Houses," Solar Age, Vol. 6, No. 2 (February, 1981), p. 20.

CHAPTER III

SELECTION OF EARTH SHELTERED EXAMPLE

Basic Principles

Selection of a prototype passive solar earth sheltered house requires the evaluation of basic building parameters during the selection process. To enhance the use of the earth's relatively stable temperatures the structure needs to fully utilize the number of earth-backed walls. A typical earth sheltered house has three earth-backed walls with the remaining facade being exposed. The exposed facade usually contains a higher percentage of glass than typical above ground houses, since most views and daylighting are normally provided solely from the exposed facade glass area. Additional daylight can come from the use of skylights projecting through the earth covered roof. A well designed earth sheltered house should utilize earth sheltering for the majority of the walls and roof, while providing adequate daylight to minimize possible adverse psychological effects from living underground.

Daylighting schemes can be enhanced to allow for beneficial use of solar gains. A passive solar house typically faces south with a large portion of the facade containing glass for solar heat gain. A well designed solar system should prevent or minimize heat gains during seasons when overheating normally occurs, while the system should collect and distribute the heat during the cooler periods of the year.

The idea of opening up the south side of a building was evident to Socrates who said:

> Now in houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer the path of the sun is right over our heads and above the roof, so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun and the north side lower to keep out the cold winds.[1]

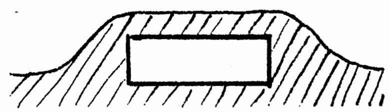
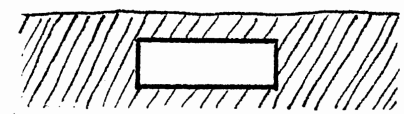
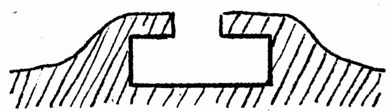
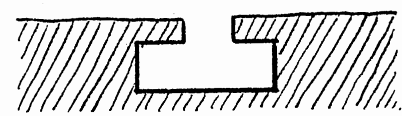
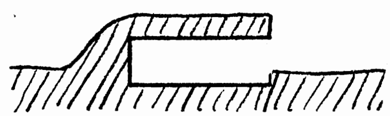
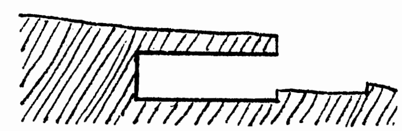
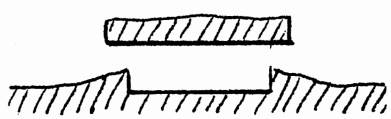
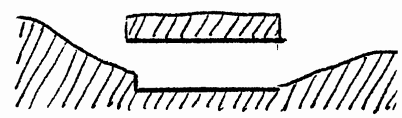
Building Configuration

In general, passive solar earth sheltered houses should have the north side earth-backed while leaving the south facade open to allow for solar gains. Table I shows the general building configurations for earth sheltered houses. The one most common to the central plains region of the United States is the elevational type, since it is most adaptable to the topography. The elevational type, if properly oriented, provides protection from north winds and can incorporate passive solar techniques into the south facade for winter heat gains. To increase solar performance, the roof might be sloped to allow for a larger area of glass and to increase solar penetration into the back of the house. A maximum slope of 1:3 (about 15 degrees) is used, since a slope greater than this would cause maintenance and erosion problems.

A rectangular floor plan with an east-west axis is beneficial to utilize solar gain potential. A glass orientation of true south should be used if possible. A glass orientation facing east can utilize approximately 30 percent of that of a south facing collector.[2] Solar energy should be collected and stored at the same location for the best efficiency to be maintained. This enables a direct gain system to be used which does not require a complicated heat distribution system.

TABLE I

EARTH SHELTERED BUILDING TYPES

Type	Berm New Earth Level Raised Above Existing Grade	Chamber Building Excavated Beneath Existing Grade
1. TRUE UNDERGROUND internally similar to deep space		
2. ATRIUM OR COURTYARD used for entry, light, and air		
3. ELEVATIONAL for doors, windows, outside courts to accomodate slope		
4. SIDE WALL PENETRATIONS for light, air, access, view, and expansion potential		

Source: Kenneth Labs, "The Use of Earth Covered Buildings Through History," Alternatives in Energy Conservation: The Use of Earth Covered Buildings, F. Moreland (Ed.), Fort Worth, Texas, 1975, p. 16.

During the winter, if the major living spaces in the building are located along the south wall with buffer spaces located on the north side, then the maximum interior depth of the space should not exceed 25 to 30 feet.[3] Buffer spaces located on the north side of the building aren't good for passive cooling in the summer. This would negate the surface temperature benefits with earth-backed walls. A shallow building configuration provides the occupied spaces with direct solar gains to provide an efficient method of passive solar heating.

Energy Design Concept

The concept of designing to reduce energy consumption and working in the context of a region is important. An earth sheltered house design in certain areas should maximize the area of earth-backed walls that are left exposed to the interior of the house for the earth's cooling effect during cooling seasons. Since the earth's temperature is relatively moderate at depths of several feet the earth-backed wall temperatures are usually slightly cooler than normal indoor ambient air temperatures. The heat inside of the house then flows into the earth, which acts as a heat sink for an earth sheltered house. This, in turn, reduces the amount of cooling required in the summer compared to that of an above ground structure. The earth sheltered house losses are not as considerable as those in an above ground house, since the earth temperature is warmer than the mean winter air temperatures. An earth sheltered house which is properly designed should use considerably less energy for cooling and heating than an above ground house.

The thermal mass and building configuration of an earth sheltered house should lend itself to passive solar heating. The concept of trapping solar energy for heating is commonly known as the "greenhouse effect." This is the result of solar (short wavelength) radiation being transmitted through glass, or similar material, and striking an absorptive surface. The short wave radiation is absorbed and changes into thermal (long wavelength) radiation which is re-radiated into the space. Glass is opaque to long wave radiation which causes the heat to build up in the space due to little radiation being lost back through the glass. Solar energy can be stored in thermal mass which will gradually release the heat for several hours after the energy was gathered.

Technical Description

A small one-story home designed for central Colorado was one of the houses selected for "The First Passive Solar Home Awards", sponsored by the U.S. Department of Housing and Urban Development.[4] The design was for a passive solar house with all walls being partially earth-backed except for the south facade. The original design used a flat roof with roof monitors located at the back of the house for solar heating and daylight. The modified design for an Oklahoma earth sheltered house assumes the partially earth-backed walls and roof to be fully covered with earth. The remaining exposed wall would remain oriented south for a maximum potential solar input. The roof would be 100 percent earth covered to best represent the earth shelter concept.[5] The floor plan, section, and details are shown in Figures 3 through 6.

To increase the south facing glazing area the roof was sloped 15 degrees, which permits solar energy to penetrate deeper into the space and prevents water runoff problems. Extruded polystyrene insulation is used on the roof, in the exposed facade wall, and 3 feet down the earth-backed walls. The partition walls are reinforced concrete to equalize thermal mass throughout the structure. The concrete floor slab is left exposed (no carpet) to optimize passive properties. Parameter studies will include insulation with an R-value of 4 will be placed over the windows at night to reduce the amount of heat loss through windows. Table II provides a list of technical information for the revised building.

TABLE II

CONSTRUCTION DETAILS

Surface	Insulation Details	R-Value	Concrete Thickness	Earth Covering (Minimum of 2 foot depth)
Roof	2" Polystyrene	10	7"	100%
Walls				
Earth-Backed	2" Polystyrene (3 feet down walls)	10	8"	100%
Exposed Facade	3" Polystyrene	15	8"	None
Interior	None		6"	Not Applicable
Floor	1" Polystyrene (along exposed perimeter)	5	6"	Slab On Grade

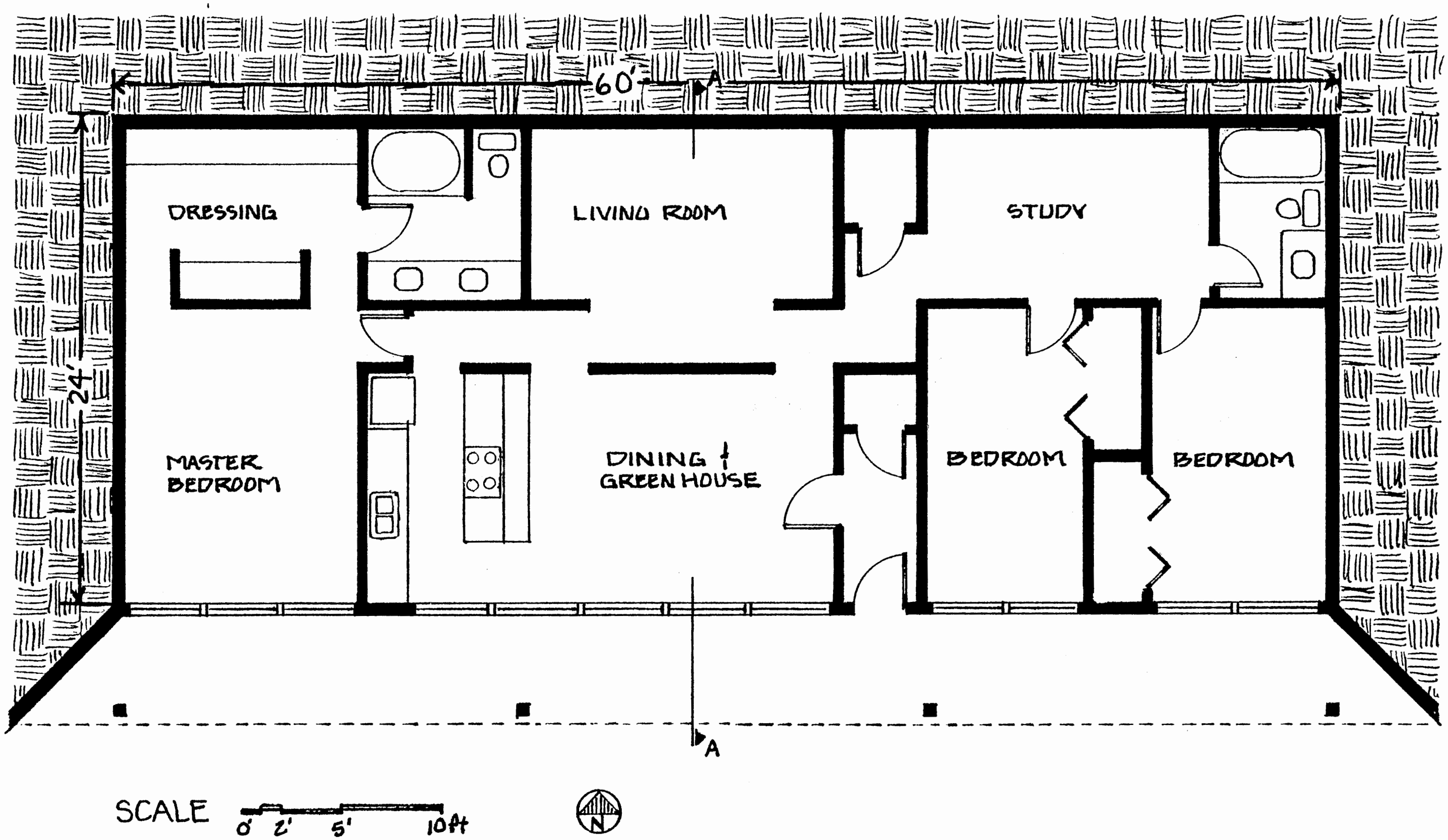


Figure 3. Floor Plan

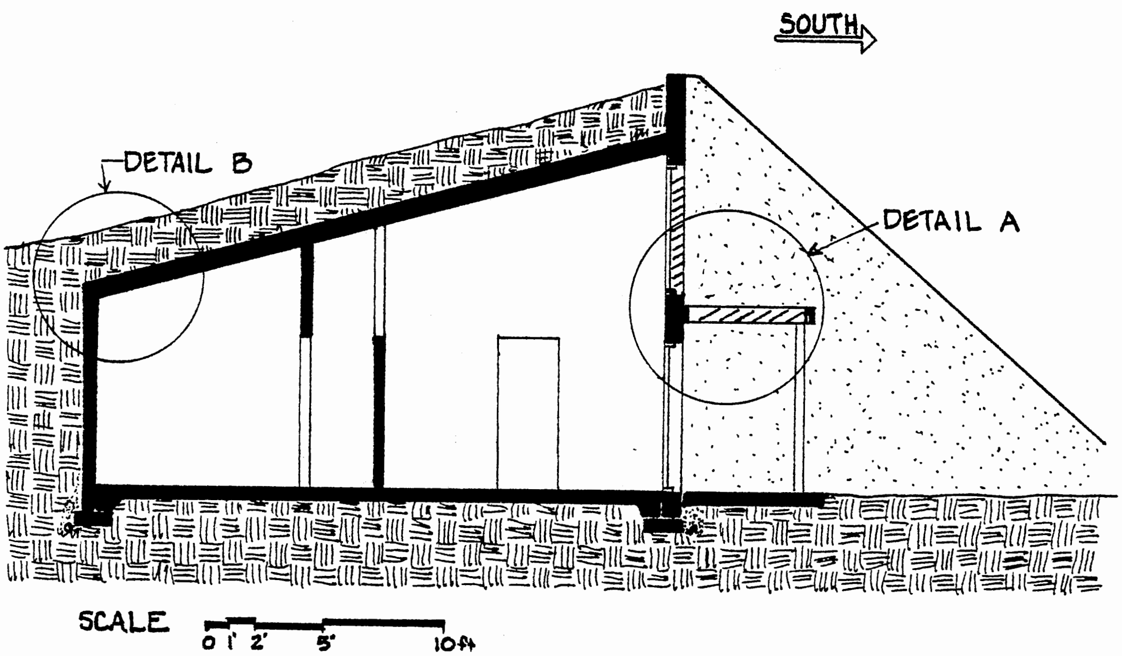


Figure 4. Building Section A

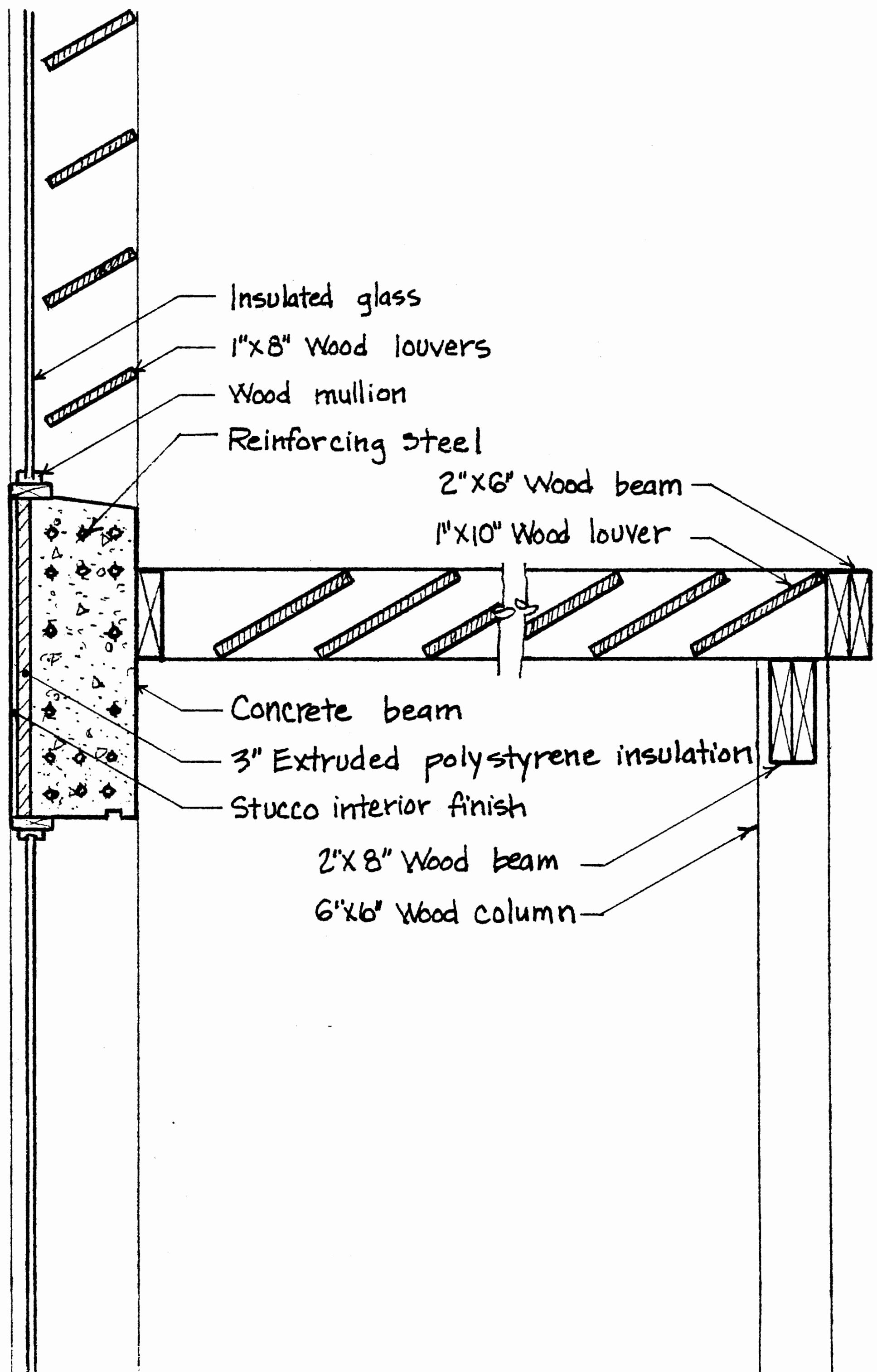


Figure 5. Detail A: Facade Wall and Shading System

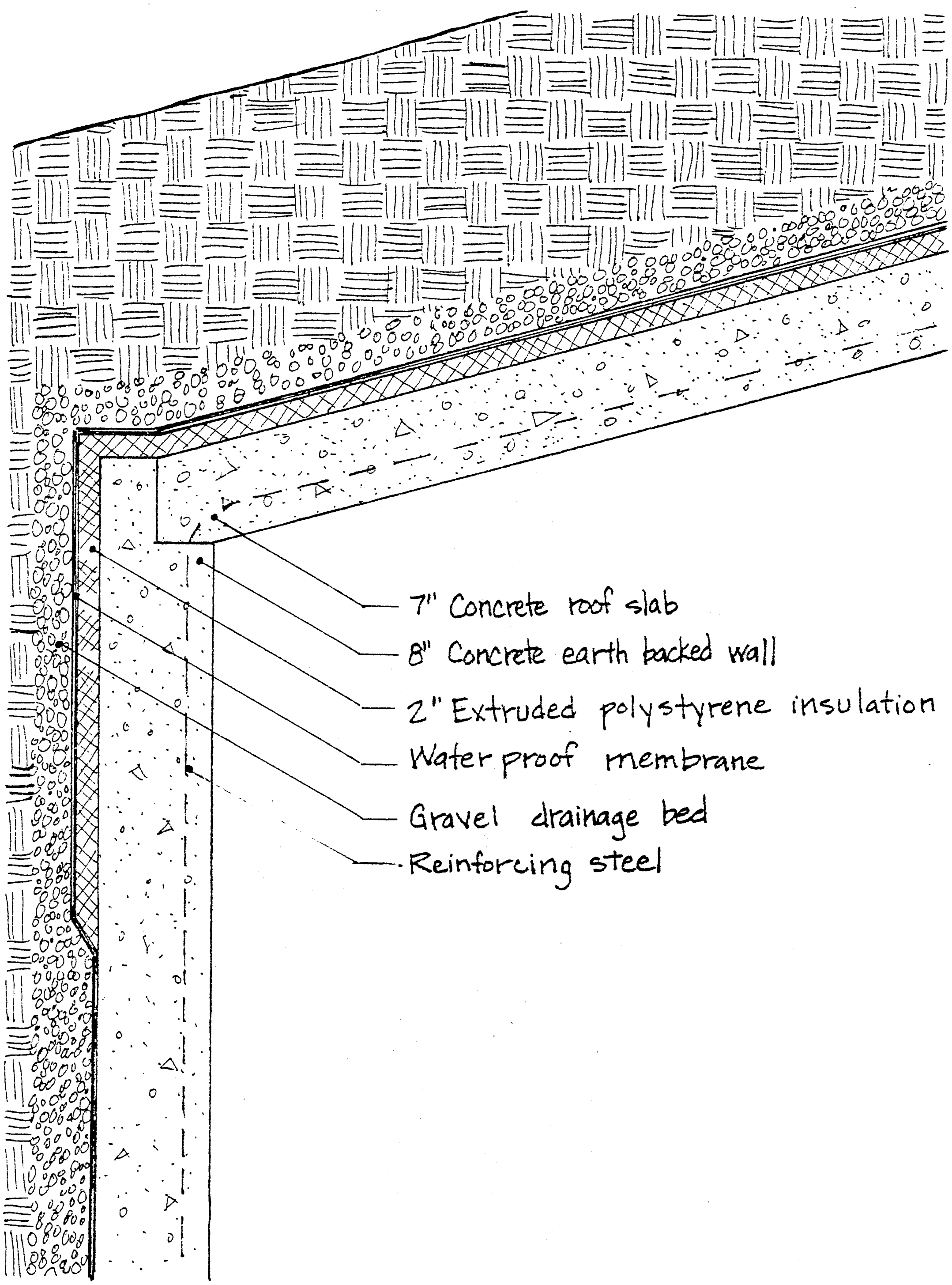


Figure 6. Detail B: Earth-Backed Wall and Roof Structure

FOOTNOTES

[1]B. Anderson (Ed.), The Solar House Book, (Andover, Massachusetts, 1976), p. 11.

[2]D. Wright, Natural Solar Architecture, (New York, 1978), p. 81.

[3]E. Mazria, The Passive Solar Energy Book, (Emmaus, Pa., 1979), p. 84.

[4]U.S. Department of Housing and Urban Development, The First Passive Solar Home Awards, (Washington, D.C., 1979), p. 100.

[5]L. Boyer, "Earth Shelter Trends in the South Central Plains," Proceedings - Underground Space Conference and Exposition, (Kansas City, June, 1981), pp. 135-148.

CHAPTER IV

HOURLY DESIGN HEAT LOSS

Temperature Profile

Heat transfer or flow occurs when a difference in temperature exists. To determine the hourly heat loss profile for a typical day in January rather than design heat loss, information on hourly outdoor air temperatures is required. Hourly temperatures are needed to determine hourly heat losses to compare with the hourly solar heat gains. Solar gains are collected during the warm hours of the day when heating loads are not as severe as during nighttime conditions. Excess solar heat must be vented outside or stored in thermal mass, which can be used to warm the interior during the evening and night when solar gains are not available.

Records for average hourly outdoor air temperatures for January are not available for the Oklahoma City area.[1] To determine the design temperature profile, three-hour temperature interval data for two days, January 10th and 20th, were averaged over a 19 year period to obtain a temperature profile for a 'typical' January day as shown in Appendix A. Mean daily temperatures for January, over the same period of time, were averaged to provide a check against the temperature profile daily mean of 32.7°F for the typical day, which was close to the daily mean temperature of 34.8°F. The temperature profile used for heat loss calculations is shown in Figure 7.

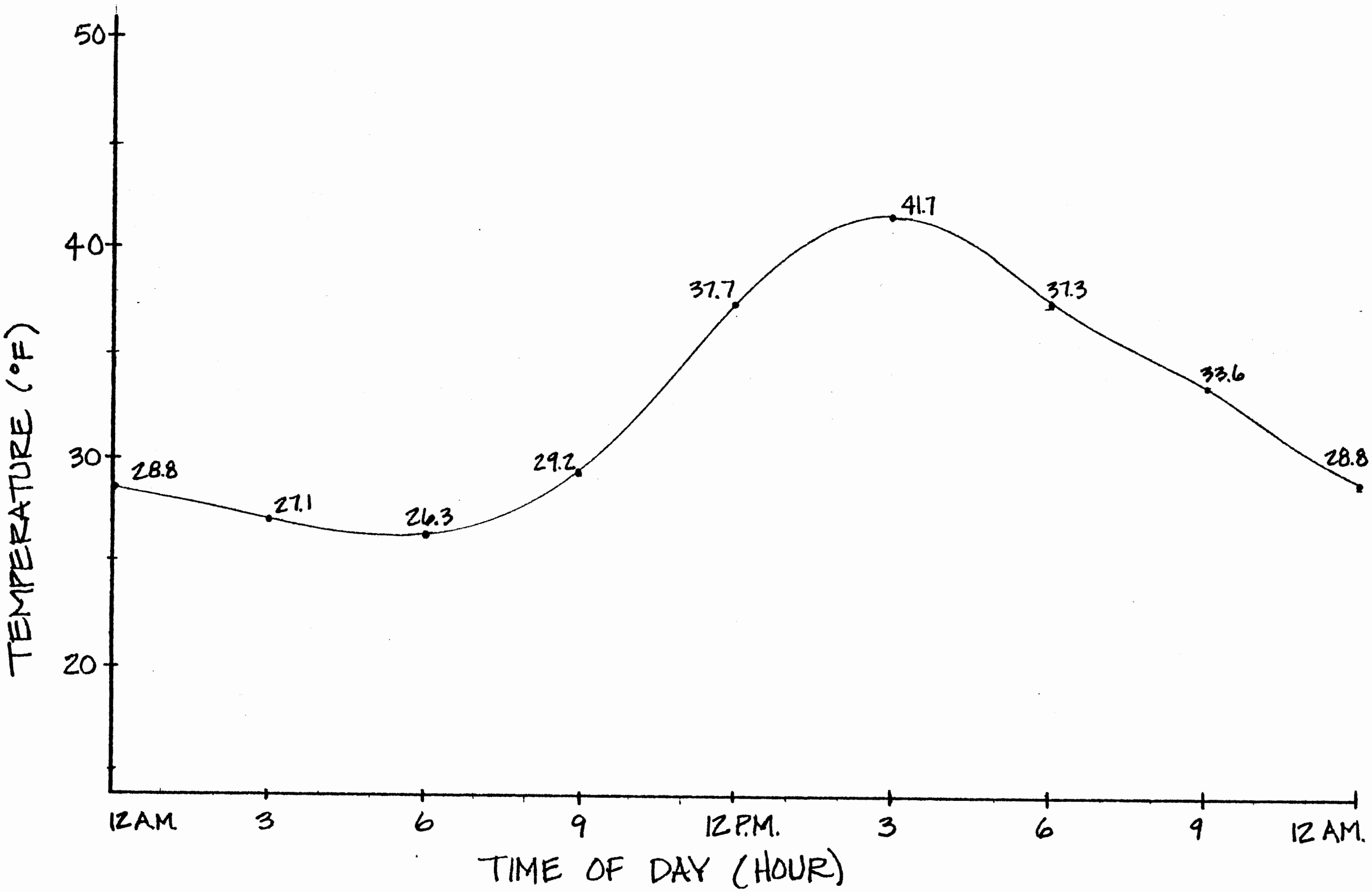


Figure 7. Oklahoma City Typical January Daily Temperature Profile for Heat Loss Calculations

Earth Sheltered House

Description of Method

The heat loss of an earth sheltered house is determined from considerably different methods than that used on an above ground house. A method to be used for determining the design heat loss values for basements and below grade walls is presented in the ASHRAE 1977 Fundamentals.[2] The method was established from tabulated data from full scale models with basement depths of up to 7 feet and floor widths of 20 to 32 feet.

A thesis on earth shelter energy analysis points out that typical earth sheltered houses exceed the basement depth limits so that heat loss values had to be extrapolated for earth shelter calculations.[3] Table III shows the extrapolated values used to determine heat loss for substantially below grade walls.

Procedure

The procedure for determining the total building hourly heat loss consists of summing the heat losses through each of the building components. Determination of the heat losses is described below:

Step 1: Sum up the tabulated heat loss values of each incremental wall depth below grade to obtain the total heat loss value per linear foot of earth-backed wall. The heat loss value is then multiplied by the perimeter of the earth-backed wall to determine the heat loss occuring through the earth-backed walls. The perimeter of earth-backed surfaces must include the increased area of wall due to the sloped roof. The first five feet of earth-backed wall, measured horizontally from the exterior wing wall connection, will be insulated to help mitigate winter heat losses from those earth-backed surfaces.

TABLE III

HEAT LOSS THROUGH BELOW GRADE WALLS
(BTUH/(SQ FT)/(F))

Depth (ft)	Path Length Through Soil (ft)	Heat Loss			
			Insulation		
		Uninsulated	1 in.	2 in.	3 in.
0-1 (1st)	0.68	0.410	0.152	0.093	0.067
1-2 (2nd)	2.27	0.222	0.116	0.079	0.059
2-3 (3rd)	3.88	0.155	0.094	0.068	0.053
3-4 (4th)	5.52	0.119	0.079	0.060	0.048
4-5 (5th)	7.05	0.096	0.069	0.053	0.044
5-6 (6th)	8.65	0.079	0.060	0.048	0.040
6-7 (7th)	10.28	0.069	0.054	0.044	0.037
7-8 (8th)	11.80	0.059	0.050	.041	.035
8-9 (9th)	13.35	0.049	0.047	.039	.034
9-10 (10th)	14.93	0.045	0.045	.038	.034

Note: Values above dashed line from Table 1, Chapter 24, ASHRAE 1977 Fundamentals, p. 24.4.
Values below dashed line from Table VII, Chapter 5, T.N. Bice, Energy Analysis of Earth Sheltered Dwellings, p. 38.

Step 2: Heat loss through the earth covered roof is determined using the tabulated values for below grade walls. Tabulated values for below grade walls may need to be interpolated to determine appropriate vertical path length, the distance from roof to earth's surface. This value is then multiplied by the roof area. Current studies have led to the development of other methods to determine the heat loss through earth covered roofs.[4]

Step 3: Earth temperature, to be used for heat loss calculations, is determined by the amplitude A (magnitude factor for the fluctuation in the earth's temperature) being subtracted from the mean annual air temperature.[5] For the central plains area (36° N. Latitude) of the United States the amplitude factor, earth temperature swing, is 22°F. Earth temperature lags behind the monthly air temperature by a month or two. Since the lowest ambient atmospheric temperatures typically occur in January, the maximum amplitude factor is for February or March. For this reason, an amplitude factor of 20°F will then be used for determining the January hourly heat loss.

Step 4: Heat loss through earth-backed surfaces is established by summing the heat loss values determined above, and multiplying by the difference in the indoor temperature (65°F) and the external earth design temperature.

Step 5: Heat loss through exposed surfaces is calculated using the basic formula for heat loss by conduction and convection:

$$Q = UA\ (ti - to) \qquad (4.1)$$

Step 6: Edge loss for slab-on-grade floors is found using tabulated values, for heat loss per foot of exposed edge, multiplied by the perimeter of exposed slab.

Step 7: Infiltration losses are estimated at half an air change per hour, which is higher than what would be expected for an earth sheltered house. This is approximately the minimum number of air changes that will enable adequate comfort.[6]

$$Q = 1.08\ (CFM)\ (ti - to) \qquad (4.2)$$

Total heat loss is obtained by summing steps four through seven. The daily heat loss for the earth shelter base house is indicated in Table IV. "41% glass" represents the highest possible glazing area of the south face, excluding doors, mullions, and closets as a percentage of the gross floor area.

TABLE IV

EARTH SHELTER HOUSE HEAT LOSS (41% GLASS)

Factor	Daily Heat Loss (Btu)	Daily Total (Btu)
Earth-backed surfaces	102,328	
Edge loss	44,640	
Infiltration	112,524	= 228,580
Exposed surfaces (excluding glazing losses)	17,087	
Interior heat gains	-48,000	

Above Ground House

Building Construction

The present trend toward energy conservation in residential construction is to heavily insulate homes to minimize the impact of the exterior climate. The "Arkansas House" is one such prototype.[7] The exterior wall construction has 6" of glass fiber insulation (R=19) while 12" of glass fiber insulation (R=38) is used in the ceiling. Double pane windows, with a restriction of 8 percent of the gross living area, and insulated doors are also used to minimize heat loss.

Calculations for heat loss will use these values with the exception of the restriction on window area. To compare the energy performance of the passive solar earth sheltered house to the new "passive solar" "Arkansas" house the window areas will be the same with all windows located on the south facade. Orientation and building configuration, size, and shape, will also be the same for both houses as shown on Figures 3 and 4.

Procedure

Heat loss calculations for the above ground house are performed using the basic method for heat loss by conduction and convection presented in the ASHRAE 1977 Fundamentals.[8] The procedure for the hourly heat losses consists of summing the heat losses through each of the building components. Determination of the heat losses is described below:

Step 1: Calculate the air-to-air heat transfer coefficients, U, for the ceiling, walls, doors, and glass. Multiply heat transfer coefficients by the respective areas for each surface. The value for each surface type is multiplied by the temperature difference between the interior (65°F) and exterior, on an hourly basis.

Step 2: Edge loss for slab-on-grade floors is found using tabulated values, for heat loss per foot of exposed edge, multiplied by exposed perimeter of floor slab.

Step 3: Infiltration losses are estimated at half an air change per hour, while the construction could cause the infiltration losses to be somewhat higher than calculated. Total heat loss is obtained by summing steps one through three. The daily heat loss for the above ground base house is indicated in Table V.

The earth-backed and exposed surface losses of the earth sheltered house are larger than the exposed surface losses on the above ground house. This is primarily due to the earth sheltered house not utilizing insulation along most of the earth-backed walls, to allow the earth to act as a heat-sink during the cooling season, while the above ground house is heavily insulated to minimize heat flow. The edge loss for the earth sheltered house is about one-third of that for the above ground house, which more than compensates for the difference in heat losses through the roof and walls.

TABLE V

ABOVE GROUND HOUSE HEAT LOSS (41% GLASS)

Factor	Daily Heat Loss (Btu)	Daily Total (Btu)
Edge loss	120,960	
Infiltration	112,524	= 253,161
Exposed surfaces (excluding glazing losses)	67,677	
Interior heat gains	-48,000	

FOOTNOTES

[1]Local Climatological Data - Oklahoma City, Oklahoma, National Oceanic and Atmospheric Administration, Asheville, North Carolina).

[2]ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 24, Heating Load, American Society Heating, Refrigerating, and Air-Conditioning Engineers, (New York, 1977).

[3]T. N. Bice, Energy Analysis of Earth Sheltered Dwellings, Thesis in Architectural Engineering, (Stillwater, Oklahoma, 1980), p. 36.

[4]E. F. Blick, "A Simple Method for Determining Heat Flow Through Earth Covered Roofs." Proceedings of Earth Sheltered Building Design Innovations Conference, L. L. Boyer (Ed.), (Stillwater, Oklahoma, April, 1980).

[5]ASHRAE Handbook and Product Directory--1977 Fundamentals, p. 245.

[6]J. D. Balcomb, Passive Solar Design Handbook: Passive Solar Design Analysis, Volume 2, Los Alamos Scientific Laboratory, (Washington, D. C., 1980), p. 37.

[7]M. J. McGuinness, B. Stein, and J. S. Reynolds, Mechanical and Electrical Equipment for Buildings, 6th ed., (New York, 1980), p. 144.

[8]ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 24, Heating Load, American Society Heating, Refrigerating, and Air-Conditioning Engineers, (New York, 1977).

CHAPTER V

PASSIVE SOLAR PERFORMANCE PREDICTORS

Passive Solar Design Analysis (LASL)

Description of Method

A correlational process for determining the solar performance of small buildings was developed to provide designers with a method to evaluate winter heating performance without using a computer program.[1] The process uses mathematical models, for heat flow and heat storage, to provide tables and figures to be used for evaluating solar performance. Full scale models and test cells were tested to compare experimental results with hour-by-hour calculations to determine the acceptability of the mathematical models used for passive solar analysis. The final step in the method is to determine the monthly solar savings fraction (SSF) to evaluate solar performance. The monthly SSF is based on the following equation:

$$SSF = 1 - \frac{\text{auxiliary heating requirements (Btu/day)}}{\text{building load}}$$

Procedure

The procedure used for determining the SSF requires a minimal amount of calculation and ascertaining a few values from tables and figures. The procedure is as follows:

Step 1: Determine the building load coefficient (BLC) to define the thermal load of the building. The building load coefficient is found by summing up heat losses through walls (excluding south facing glass), floor, roof, and infiltration to determine the Btuh/°F loss for 24 hours. Heat losses are calculated by the methods presented in this study to enable comparisons between the different prediction methods and to calculate earth sheltered heat losses.

Step 2: Determine the solar radiation received per square foot of collector area per month (S). This is the daily solar energy incident on a square foot of vertical glazing multiplied by the number of days in the month and factors related to particular solar installations (orientation, tilt, overhangs, etc.).

Step 3: Determine the monthly degree days (DD) corresponding to the proper effective base temperature (T).

Step 4: Divide absorbed solar radiation (S) by number of degree days (DD) to obtain quotient S/DD.

Step 5: Calculate the load collector ratio (LCR) by dividing BLC (Btu/DD) by south facing collection area (AC). Determine the monthly SSF from Figure 8 using LCR and thermal mass. Figure 8 is for Albuquerque, which has a S/DD of 36. This is comparable to that of Oklahoma City with a value of 31.5. For insulation with an R value other than 0 or 9, the SSF must be modified as shown in Appendix B. Table VI shows the SSF for the earth shelter and above ground house, with 41% glass (of gross floor area), night insulation (R-4) and a sloped roof. The earth shelter house required considerably less auxiliary heat than the above ground house due to lower heat losses and a larger thermal mass (300 lb/ft glass compared to 115 lb/ft glass).

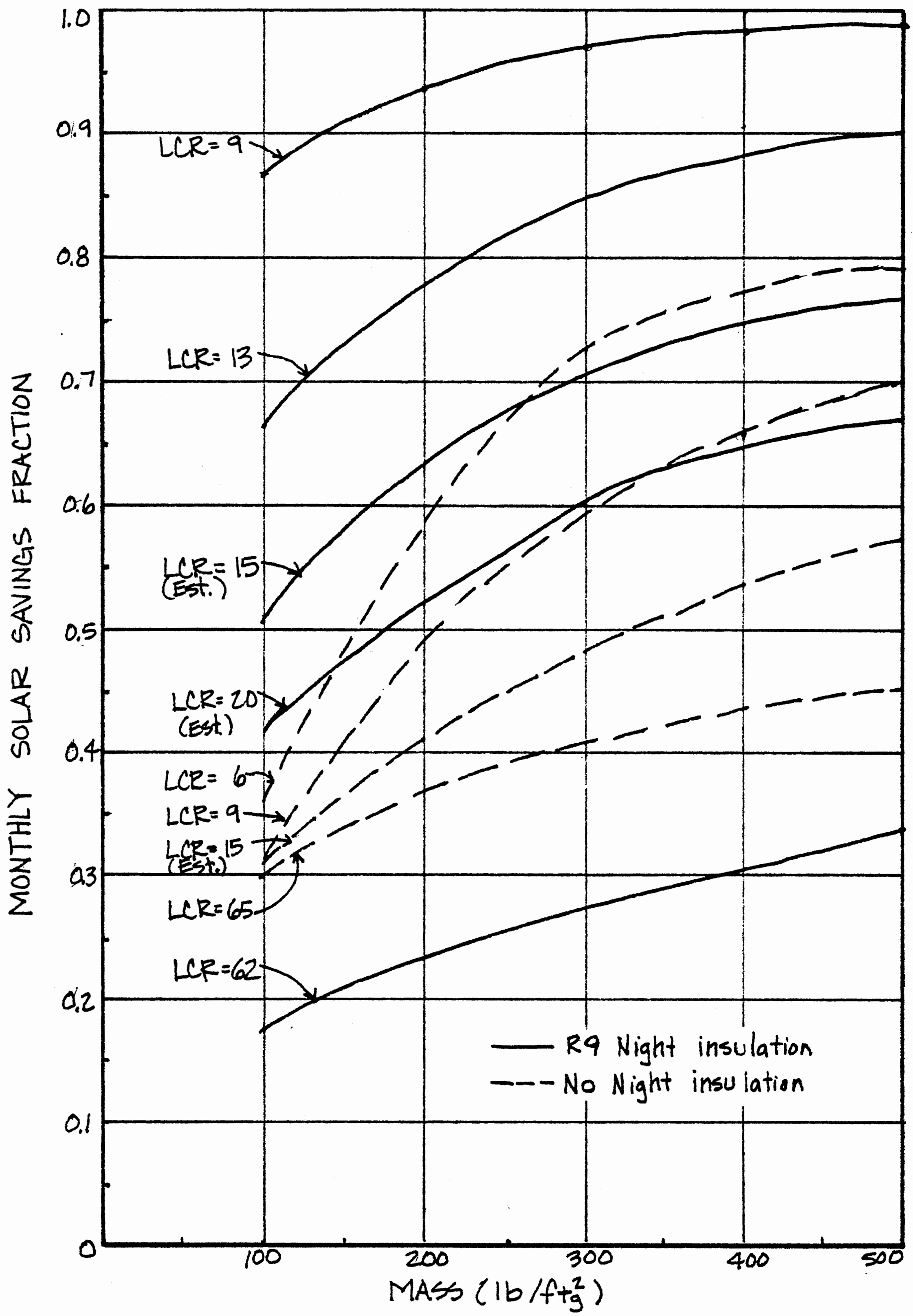


Figure 8. SSF Curves for Direct Gain System

TABLE VI

LASL SOLAR PERFORMANCE PREDICTION (41% GLASS)

House Type	Auxiliary Heat (Btu/day)	SSF
Earth Shelter (41% Glass)	27,784	0.86
Above Ground (41% Glass)	72,096	0.67

Princeton Energy Group Programs (PEGFIX/PEGFLOAT)

Description of Method

PEGFIX and PEGFLOAT are two programs that were designed for ease of use by those with little experience in calculator programming.[2] Knowledge of passive solar systems, building construction, and heat transfer principles are useful in selecting appropriate input data and understanding program functions. Direct gain and greenhouse performance, free standing or isolated, can be predicted with the programs for a 24 hour period. Mathematical modeling techniques are used in determining solar gains, air and storage temperatures, heat loss, and auxiliary heating requirements. PEGFLOAT is used for spaces that are heated only by solar gains and are not vented, which requires that space temperatures "float" with outdoor air temperature and solar gains. The PEGFIX program allows the user to specify the interior temperature range that is to be maintained by auxiliary heat or by venting excess heat. The PEGFIX program is to be used since control of space temperature is important for satisfying contemporary expectations of comfort.

Procedure

The procedure used for determining the SSF using the PEGFIX program is as follows:

Step 1: Determine storage mass effectiveness, for thickness of concrete or masonry storage, using routine "B" of the PEGFIX program. The storage heat capacity (MC sto) is the sum of primary and secondary storage. Primary storage is that area that receives sunlight directly most of the day and secondary is that which receives little or no sunlight directly.

Step 2: Determine the heat transfer coefficient (UA sto) between storage mass and surrounding air. This coefficient determines the rate of heat loss from storage to the air by natural convection and radiation.

Step 3: Determine day and night overall building heat loss coefficients (UA day and UA night). This allows the use of night insulation for glazing areas. The earth sheltered losses are not dependent on the outdoor (ambient) air temperature but are divided by the average night or day temperature to approximate the UA format required by the program.

Step 4: Solar split input information is broken into the fraction of solar radiation absorbed by storage (f sto) and the fraction heating the air (f air) with a small percentage being reradiated back outside.

Step 5: Determine the upper (80°F) and lower limits (65°F) for acceptable air temperatures (T max, T min). When the temperature exceeds the upper limits the excess heat will be exhausted. T vent is set equal to zero so that heat will be exhausted outside, as specified by the PEGFIX program. Auxiliary heat is used to maintain the lower temperature requirement of 65°F.

Step 6: Store daily average temperature (T avg) and the daily temperature swing (T swing).

Step 7: Store the clear area of solar glazing (Ag). For input of hourly solar radiation data glazing area should be zero, area of glazing is included with hourly radiation data.

Step 8: Store hourly solar radiation data (I hour). This is the solar radiation on a vertical surface multiplied by glass transmittance and the area of glazing receiving direct sunlight.

Step 9: Determine initial temperature of the storage mass (T sto). Initial temperature of storage mass should be within one degree of the storage temperature at the end of the day (T sto, 24) to get accurate results.

Step 10: Execute the program to obtain interior and storage air temperatures, and auxiliary heating or venting requirements. The SSF can be determined by subtracting the auxiliary requirements from the heating load and dividing by the heating load. Table VII shows the SSF for the earth shelter and above ground house using the PEGFIX program.

TABLE VII

PEGFIX SOLAR PERFORMANCE PREDICTION (41% GLASS)

House Type	Auxiliary Heat (Btu/day)	SSF
Earth Shelter (41% Glass)	19,610	0.91
Above Ground (41% Glass)	61,660	0.75

Study Model Analysis

Accurate input of information is essential for obtaining reliable results from the prediction methods. Both methods require the user to know the unshaded collector area to determine the amount of solar radiation transmitted through the collector area. The LASL method requires the use of factors to adjust the amount of solar radiation being transmitted. The method provides factors for overhangs but doesn't have any for vertical fins or wing walls. The PEGFIX program requires hourly unshaded collector areas to be used to account for overhangs and wing walls.

A quick and accurate method for determining the unshaded collector area is to use a scale study model and a heliodon and sunlamp to establish sun patterns from the overhangs and wing walls.[3] Figure 9 shows the scale study model with 41% glass mounted on the heliodon which was used to determine the unshaded collector area for the parameter studies as indicated in Table VIII.

The model was also used to estimate the thermal mass that would be used for primary and secondary storage. Estimating the thermal mass areas was accomplished by marking grid patterns on the interior surfaces to rapidly and accurately determine radiation patterns on the storage areas. Using a scale model on the heliodon provides fast and fairly accurate evaluation of sun angles and shading device performance without the use of cumbersome protractors or tedious mathematical methods.

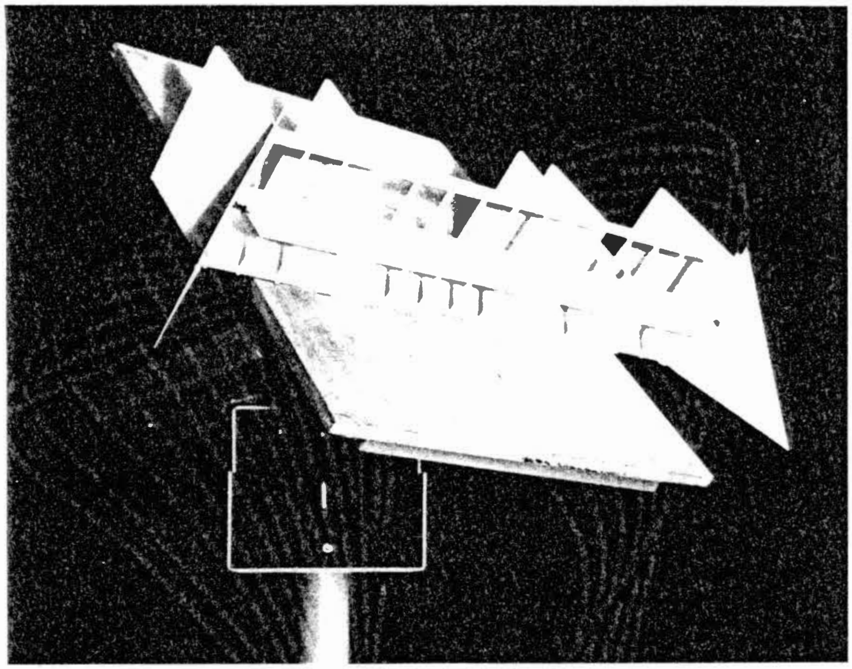


Figure 9. View of Study Model and Heliodon

TABLE VIII

UNSHADED COLLECTOR AREA (SQ. FT.)

Wing Wall Angle From Normal	Time of Day 8	9	10	11	12	1	2	3	4
0°	388	414	414	440	446	440	414	414	388
15°	405	432	432	460	446	460	432	432	405
30°	422	450	450	460	446	460	450	450	422
45° - 41% glass	440	468	450	460	446	460	450	468	440
45° - 35% glass	377	401	386	394	382	394	386	401	377
45° - 29% glass	314	334	322	329	319	329	322	334	314
45° - 20% glass	260	280	250	240	230	240	250	280	260

FOOTNOTES

[1]J. D. Balcomb, Passive Solar Design Handbook: Passive Solar Design Analysis, Los Alamos Scientific Laboratory, (Washington, D.C., 1980).

[2]W. L. Glennie, PEGFIX PEGFLOAT Handbook. Princeton Energy Group, (Princeton, New Jersey, 1978).

[3]Sun Shadow Calculator, (Heliodon), Heliolux Company, (San Francisco).

CHAPTER VI

PARAMETRIC STUDIES

Collector Percentage

Predictor Method Comparison

Calculated solar savings fractions (SSF) and auxiliary heat requirements for the different collector percentages (41%, 35%, 29%), with respect to gross floor area, differ considerably in solar performance as presented in Table IX. The values obtained from the LASL method for SSF are slightly lower than those calculated using the PEGFIX program. Auxiliary heating requirements calculated using the LASL method are roughly equal to those obtained from the PEGFIX program. The difference is probably due to the method of calculating the auxiliary heat requirements using degree days and building load coefficient.[1] The LASL method closely predicts the solar performance with 35% collector percentage but results for the 41% and 29% collector percentage differ from those obtained using the PEGFIX program.

Collector Percentage Comparison

Hourly auxiliary heating requirements and heat loss profiles for each collector percentage are shown in Figures 10, 11 and 12. The auxiliary heating requirements are obtained from the PEGFIX program, using a Hewlett-Packard 41C calculator, card reader and printer.[2]

TABLE IX

PARAMETER ONE STUDY - PERCENT GLASS

	Predictor Method			
	LASL		PEGFIX	
Percent Glass	Auxiliary Heat (Btu/day)	SSF	Auxiliary Heat (Btu/day)	SSF
41	27,784	0.86	19,610	0.91
35	46,442	0.77	47,470	0.80
29	73,910	0.64	81,068	0.66

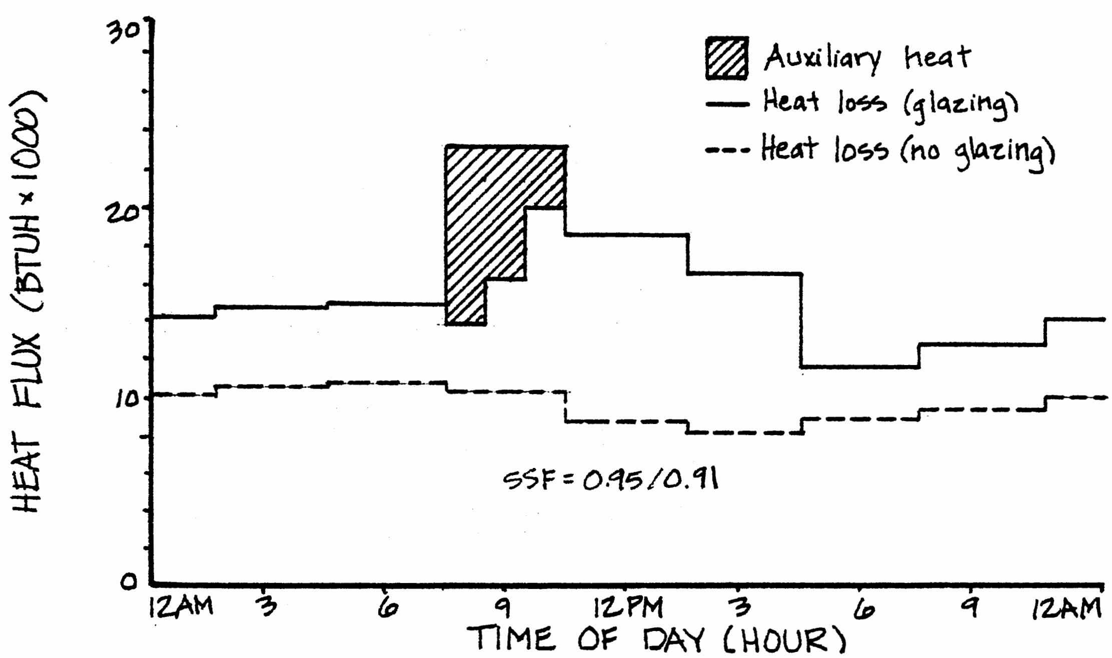


Figure 10. Parameter One Study (41% Glass)

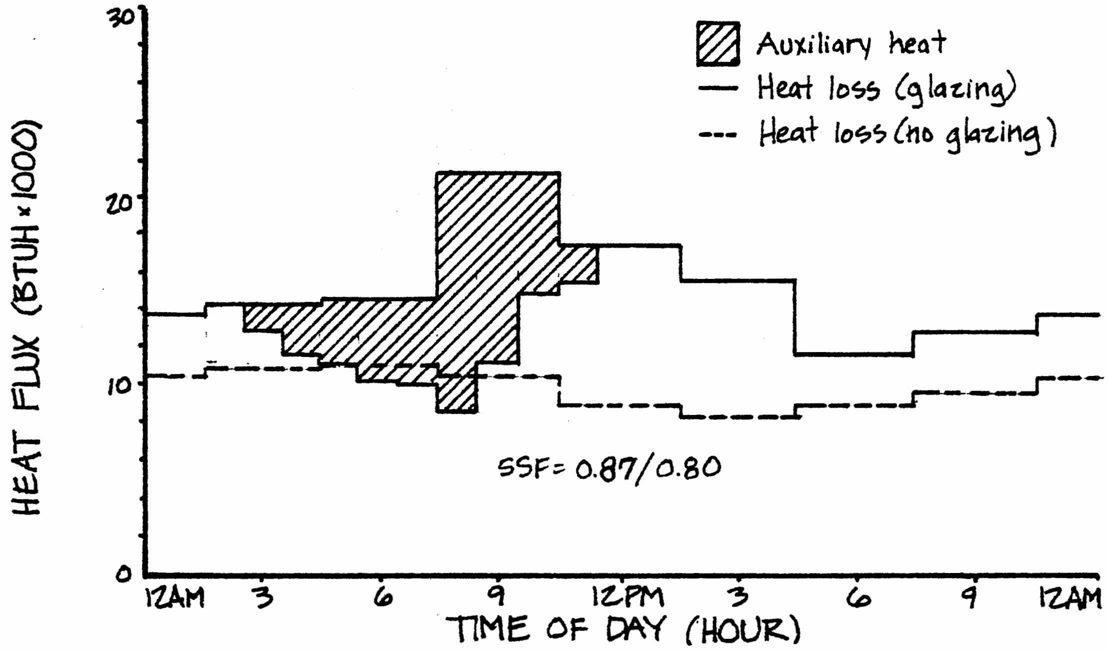


Figure 11. Parameter One Study (35% Glass)

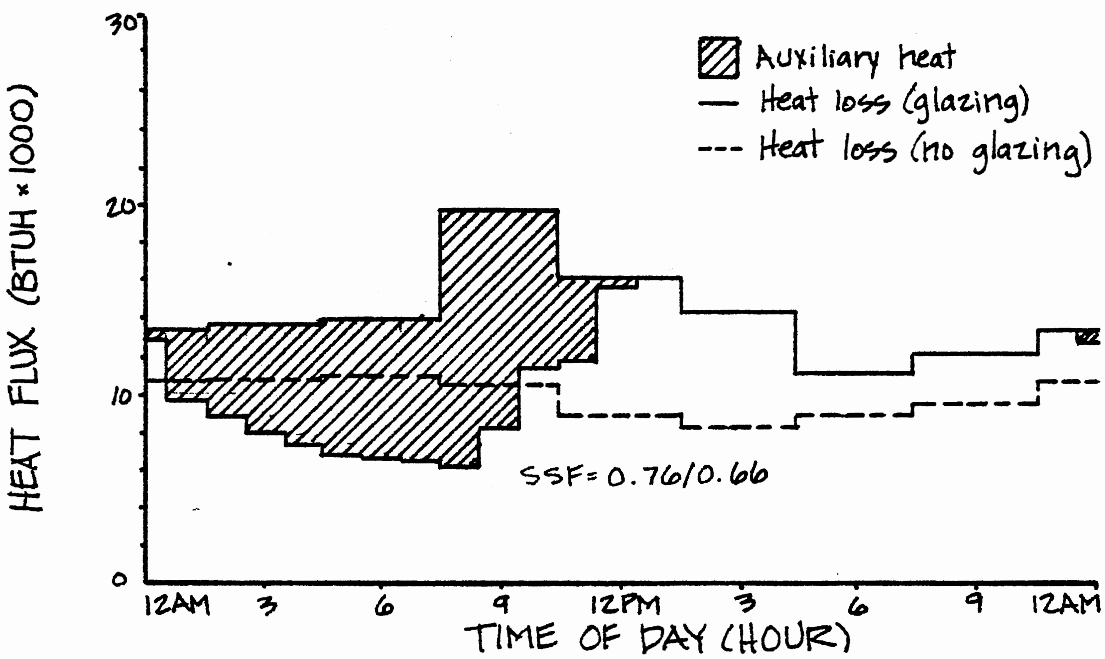


Figure 12. Parameter One Study (29% Glass)

Heat loss is determined using the method previously described in Chapter IV for earth sheltered structures. Heat loss profiles are calculated in three hour intervals to correspond with temperature data intervals.

The Figures 10, 11 and 12 show that the collector area, or percentage, has a large impact on the solar contribution. The larger collector area, or 41% collector percentage to floor area, results in higher heat losses, when including collector aperture losses, but these additional losses are more than made up by the increased solar radiation being transmitted into the space. The two SSF values indicated on the parameter study figures are calculated by two different methods. The first includes glazing losses in building loads while the second does not, which is compatable with the LASL method for calculating the SSF.

It is interesting to note that the largest auxiliary heating requirements, as shown previously in Figures 10, 11 and 12, occur around sunrise (approximately 8 a.m.). In the early daylight hours air temperatures are low and solar radiation rates are nominal. The auxiliary heating requirements could be lowered by leaving the night insulation in place for a few daylight hours until radiation rates are surpassing heat losses. This additional factor will not be modeled due to the fact that the PEGFIX program requires the removal of night insulation during the "daylight" hours.

Night Insulation

Prediction Method Comparison

Differences between the methods showed up again in the parameter two study, on whether or not to use night insulation over the collector area. Both methods indicate a marked increase in performance when R-4 night insulation is used as seen in Table X. When using night insulation, the thermal storage prevents inside air temperatures from dropping as rapidly as it would normally in a house not using night insulation and having less thermal storage.

TABLE X

PARAMETER TWO STUDY - NIGHT INSULATION

	Predictor Method			
	LASL		PEGFIX	
Night Insulation	Auxiliary Heat (Btu/day)	SSF	Auxiliary Heat (Btu/day)	SSF
R-4 (41% glass)	27,784	0.86	19,610	0.91
None (41% glass)	99,227	0.50	141,520	0.40

The auxiliary heat required when night insulation isn't used is estimated by the methods as being 70,000 to 120,000 Btu/day greater than when night insulation is used. This indicates that both methods predicted an increased in the auxiliary heating requirements by a considerable amount. The SSF for the LASL method is slightly different than that from the PEGFIX program which could be partially due to estimating LCR lines on Figure 8.

Night Insulation Comparison

Auxiliary heating requirements, without the use of night insulation, are four to seven times as large as the auxiliary heating required when night insulation is used, as seen in Figures 13 and 14. The increased glazing losses without night insulation cause a lot of the heat stored in thermal mass to be reradiated outside which causes lower indoor air temperatures that must be made up for with fossil fuels and mechanical systems.

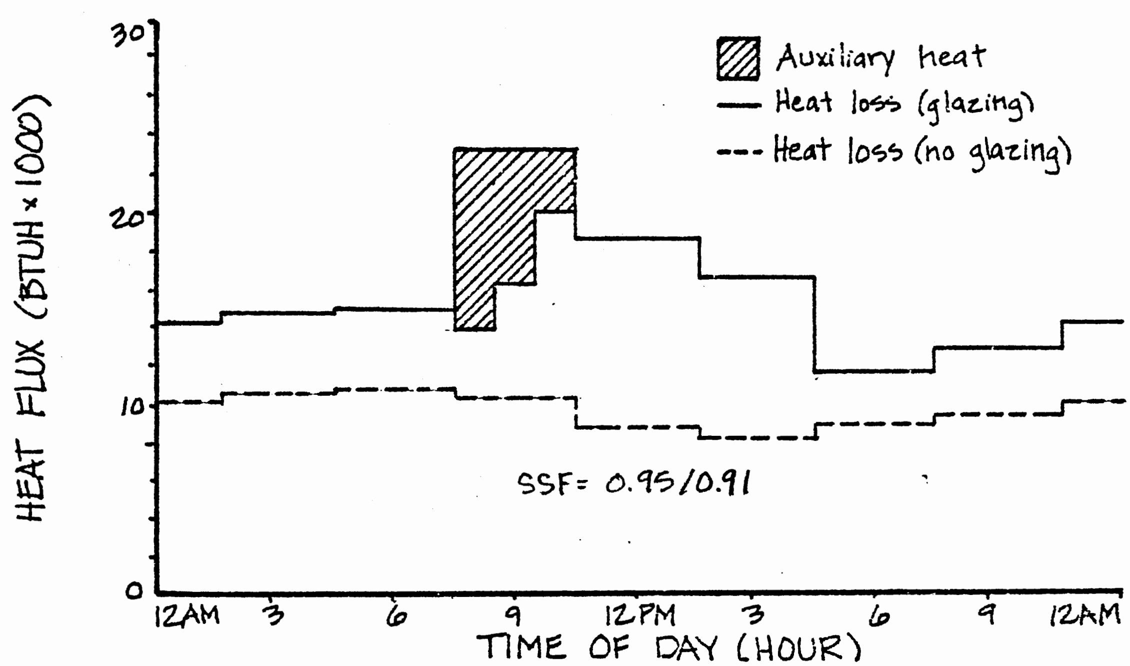


Figure 13. Parameter Two Study (R-4 Night Insulation)

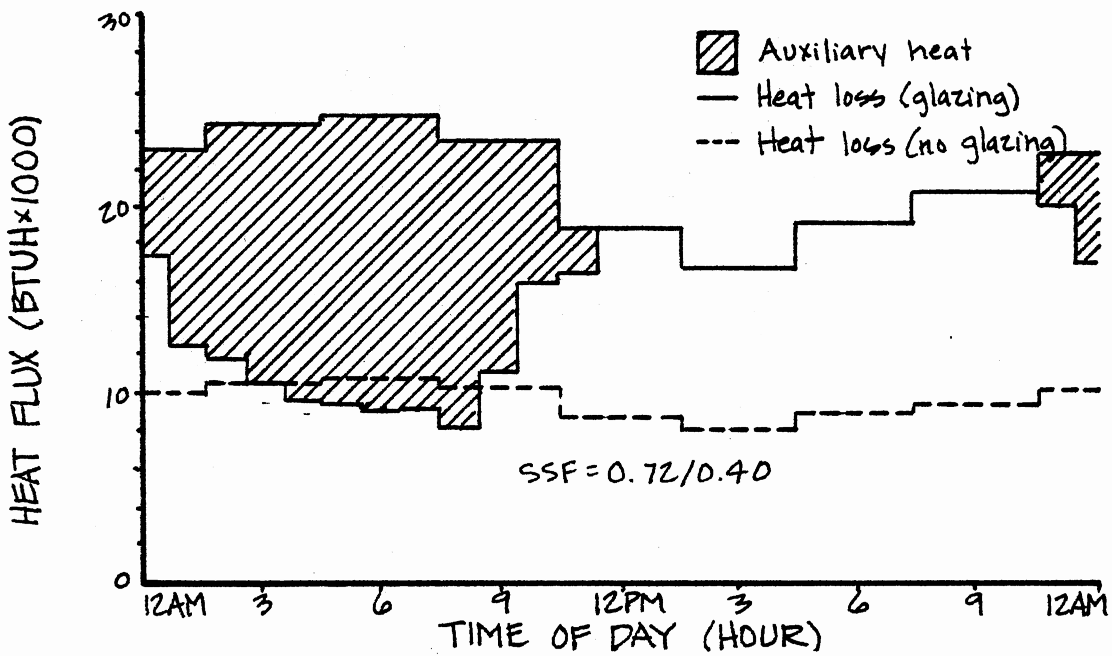


Figure 14. Parameter Two Study (No Night Insulation)

The use of night insulation can save tremendous amounts of energy, whether the building is a passive solar and earth shelter design or not, but is not 'normal' practice in construction. The high cost of energy is making some people aware of the potential for saving large amounts of energy and money by using night insulation.[3] When using night insulation precautions should be taken to prevent or control condensation on the glass and insulation.

Roof Configuration

Prediction Method Comparison

Auxiliary heat requirements calculated by the PEGFIX program are about 10,000 Btu/day less than those determined using the LASL method on parameter three study of a sloped roof versus a flat roof, as seen in Table XI. Both methods indicate that a change from a building configuration with a sloped roof, with 588 square feet of south facing glass (41%), to a flat roof configuration, with 288 square feet of south facing glass (20%), could approximately triple the amount of auxiliary heat required to maintain a 65°F inside air temperature. The SSF difference between the two methods is of a magnitude that is fairly consistant in the previous parameter studies.

Table XI

PARAMETER THREE STUDY - ROOF CONFIGURATION

	Predictor Method			
	LASL		PEGFIX	
Roof Configuration	Auxiliary Heat (Btu/day)	SSF	Auxiliary Heat (Btu/day)	SSF
Sloped 15%	25,460	0.84	7,870	0.96
Flat	46,973	0.64	18,372	0.90

Roof Configuration Comparison

The heat loss profiles for the building configurations with a 15° sloped roof or a flat roof are quite different, as seen in Figures 15 and 16. The heat loss for the building with a flat roof is considerably less than that with a sloped roof due to the large area of glazing associated with the sloped roof building configuration. The decrease in glazing area results in a much smaller solar gain and a larger quantity of auxiliary heat being required, since south facing glass provides a net heat gain.

The typical earth sheltered house generally has a flat roof while most solar homes have sloped roofs. It is evident that incorporating a sloped roof, that isn't too steep for earth cover, in an earth sheltered home improves solar performance. This can also improve the distribution and penetration of daylight into areas of the earth sheltered house that might normally receive minimal daylight.

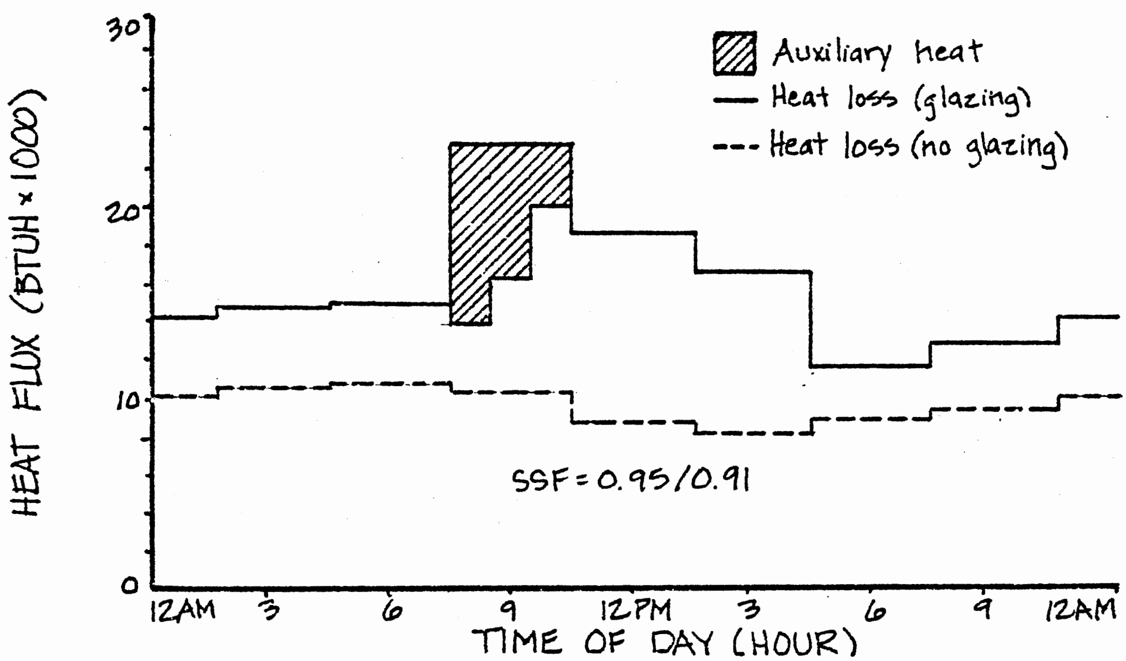


Figure 15. Parameter Three Study (Sloped Roof)

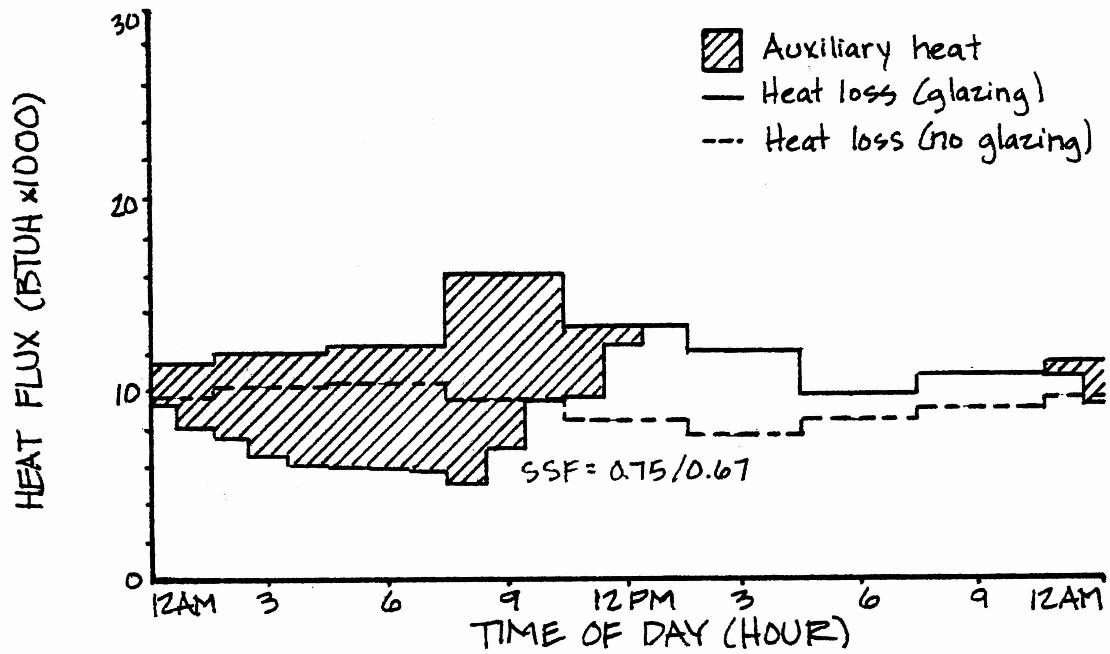


Figure 16. Parameter Three Study (Flat Roof)

Thermal Mass Location

Predictor Method Comparison

Direct gain passive solar buildings normally have an exposed floor slab for thermal mass. In the parameter four study the thermal mass located in bearing and partition walls and floor slabs is evaluated for its effectiveness in storing heat. The LASL method and PEGFIX auxiliary heat requirements and SSF's are fairly close in comparison for the SSF and auxiliary heat requirements as indicated in Table XII. The SSF difference between the two methods is 5 to 10% with the LASL method predicting the SSF to be slightly smaller than that predicted by the PEGFIX program.

The differences between the two methods decrease as the amount of thermal mass increases. This could be caused due to the total thermal storage mass located along the back of the house. This wasn't included in either method but may need to be considered for the LASL method.

TABLE XII

PARAMETER FOUR STUDY - THERMAL MASS LOCATION

Thermal Mass Location	Predictor Method LASL Auxiliary Heat (Btu/day)	SSF	PEGFIX Auxiliary Heat (Btu/day)	SSF
Floor ($115 lb/ft^2 g$)	57,552	0.71	42,460	0.81
Floor and Bearing Walls ($242 lb/ft^2 g$)	33,737	0.83	23,272	0.90
Floor, Bearing and Partition Walls ($300 lb/ft^2 g$)	27,784	0.86	19,610	0.91

Thermal Mass Comparison

The amount of thermal mass has a definite impact on auxiliary heat requirments as seen in Figures 17, 18 and 19. Increasing the amount of thermal mass enables more solar energy to be stored without overheating or venting, resulting in smaller amounts of auxiliary heat being needed to maintain interior air temperature at 65°F.

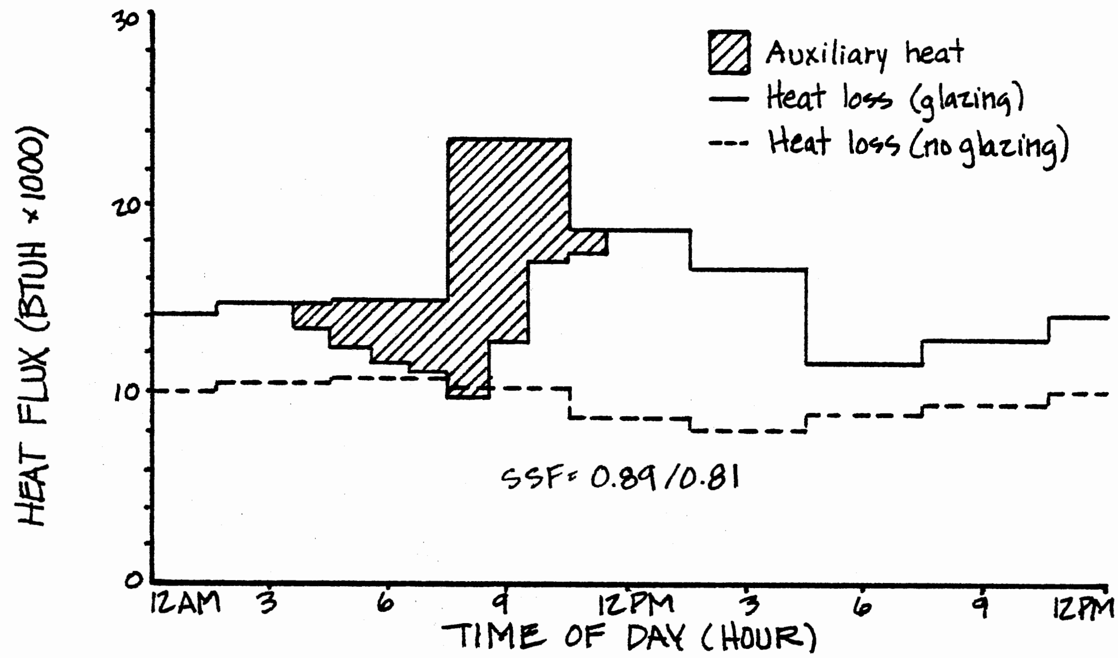


Figure 17. Parameter Four Study (Floor Thermal Mass - 115 lb/ft^{2}g)

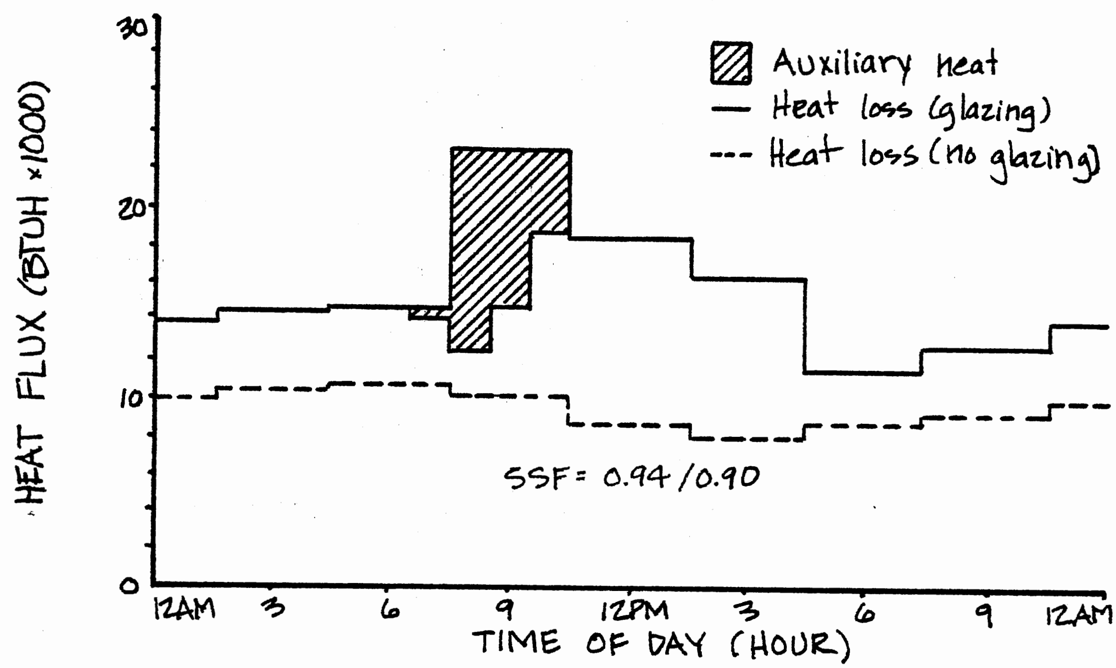


Figure 18. Parameter Four Study (Floor and Bearing Wall Thermal Mass - 242 lb/ft^{2}g)

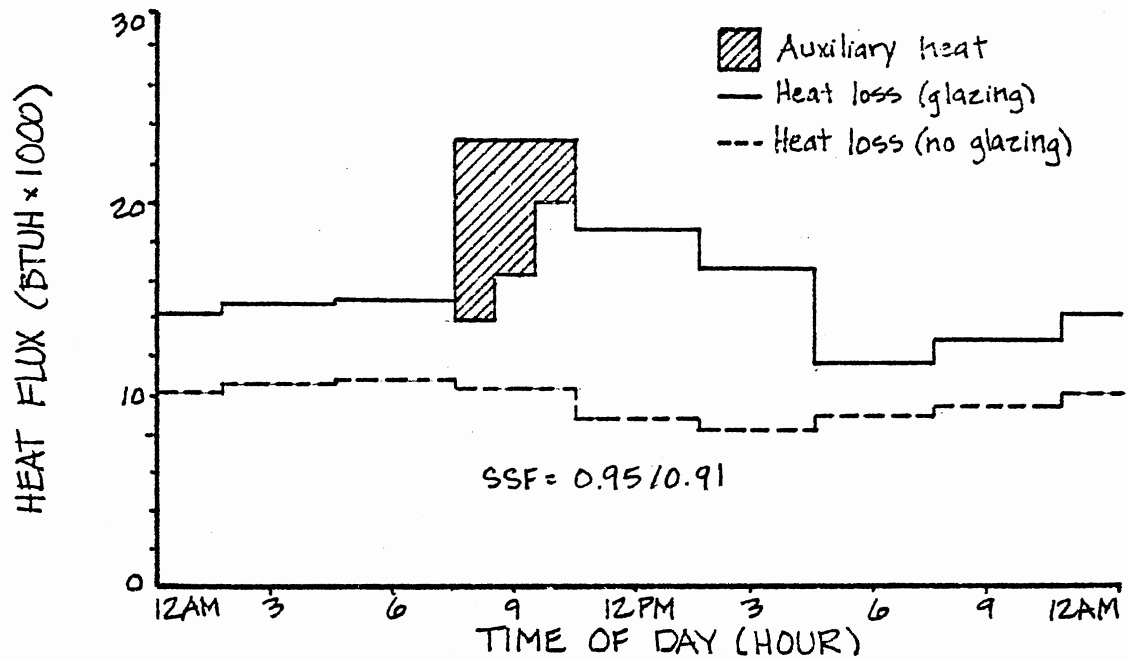


Figure 19. Parameter Four Study (Maximum Thermal Mass - 300 lb/ft^{2}g)

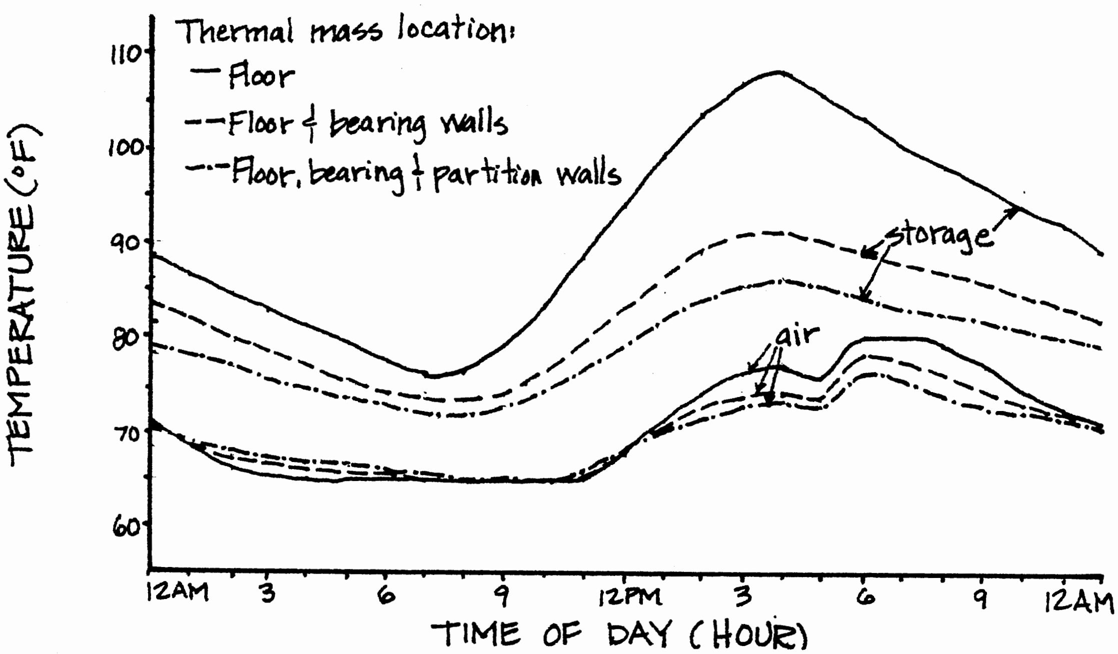


Figure 20. Air and Storage Temperature Variations

The amount of thermal mass is a major factor in the fluctuation of air and storage temperatures as shown in Figure 20. Using the floor slab as the only thermal storage mass results in a wide fluctuation in interior air temperatures and high storage temperatures. The greatest amount of thermal storage mass is associated with an air temperature swing of 11.7°F and storage temperatures not exceeding 86°F.

Retaining (Wing) Walls

Prediction Method Comparison

The calculated SSF and auxiliary heating requirements for the parameter five study of wing walls, as indicated in Table XIII, are similar to the values obtained from the collector percentage study with 41 percent glass. The values from the LASL method are consistantly about 8,000 Btu/day higher than those calculated using the PEGFIX program. The SSF obtained from the LASL method are 5 percent lower than those from the PEGFIX program.

Wing Wall Comparisons

In this study the wing wall angles didn't have a large impact on auxiliary heating requirements or the SSF, as seen in Figures 21 through 24. The wing wall position isn't a major factor in this study due to the length of the exposed wall. The building configuration, as demonstrated by the exposed wall length compared to its height, is an important factor in the amount of collector area shaded by the wing walls.

Table XIII

PARAMETER FIVE STUDY - WING WALL ORIENTATION

	Predictor Method			
	LASL		PEGFIX	
Wing Wall Angle from Normal	Auxiliary Heat (Btu/day)	SSF	Auxiliary Heat (Btu/day)	SSF
0°	33,737	0.83	26,468	0.88
15°	31,753	0.84	25,245	0.89
30°	29,768	0.85	21,954	0.90
45°	27,784	0.86	19,610	0.91

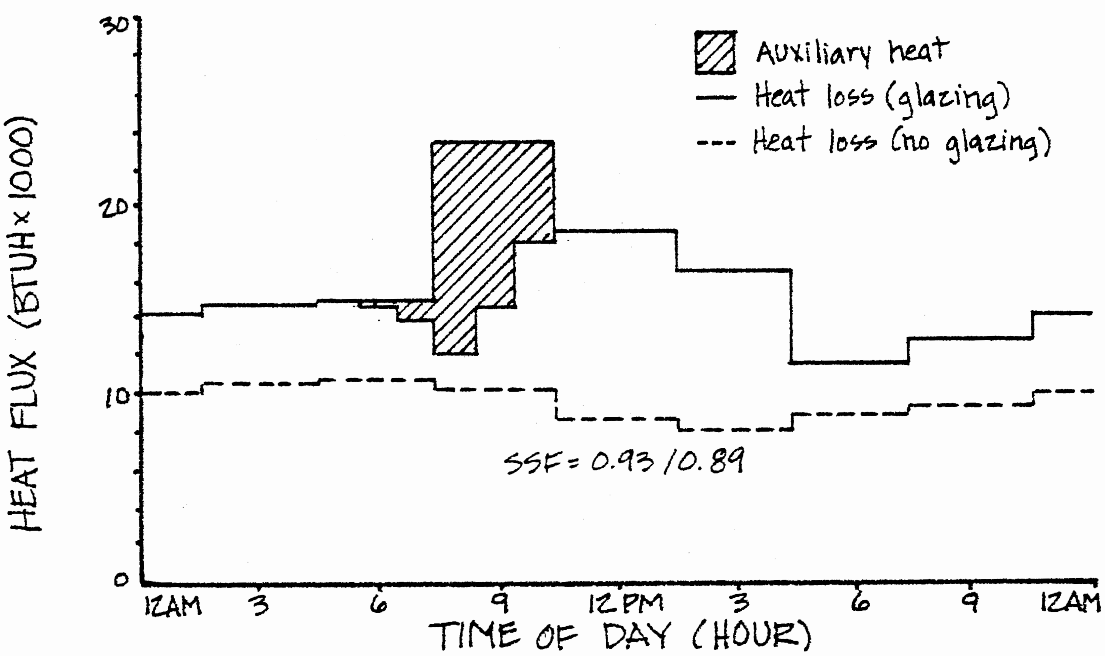


Figure 21. Parameter Five Study (0° Wing Walls)

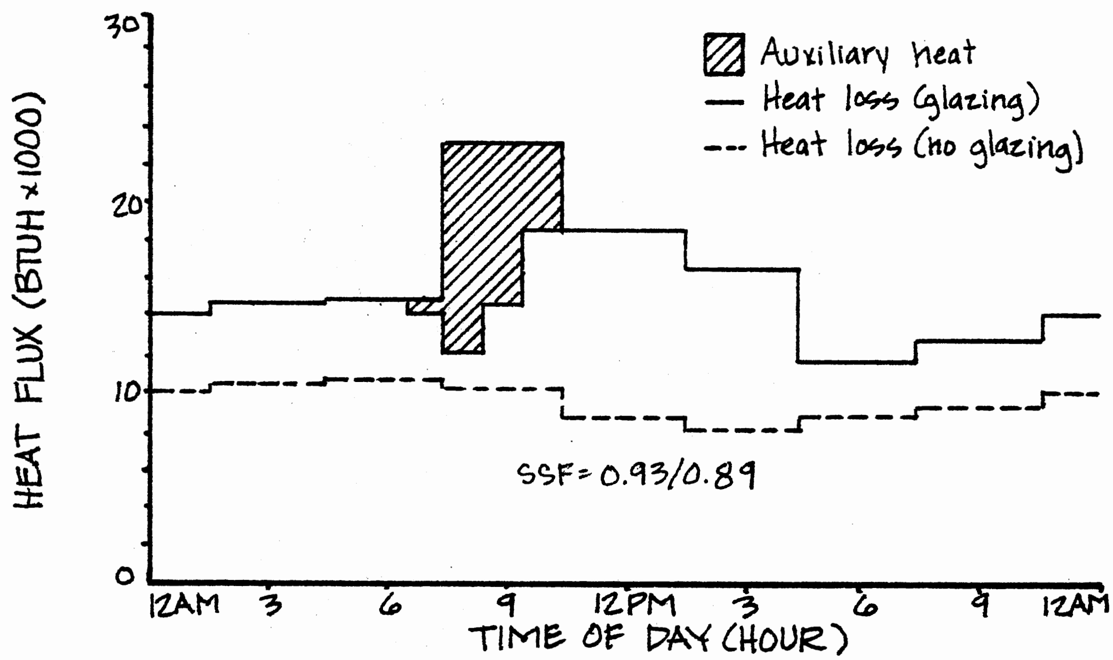


Figure 22. Parameter Five Study (15° Wing Walls)

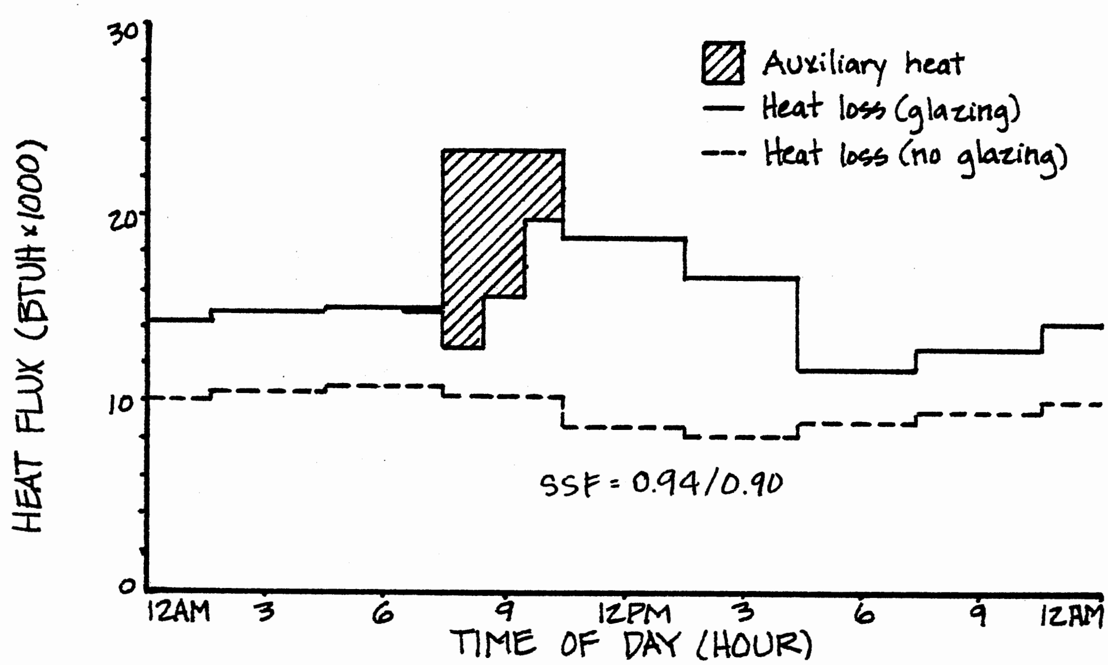


Figure 23. Parameter Five Study (30° Wing Walls)

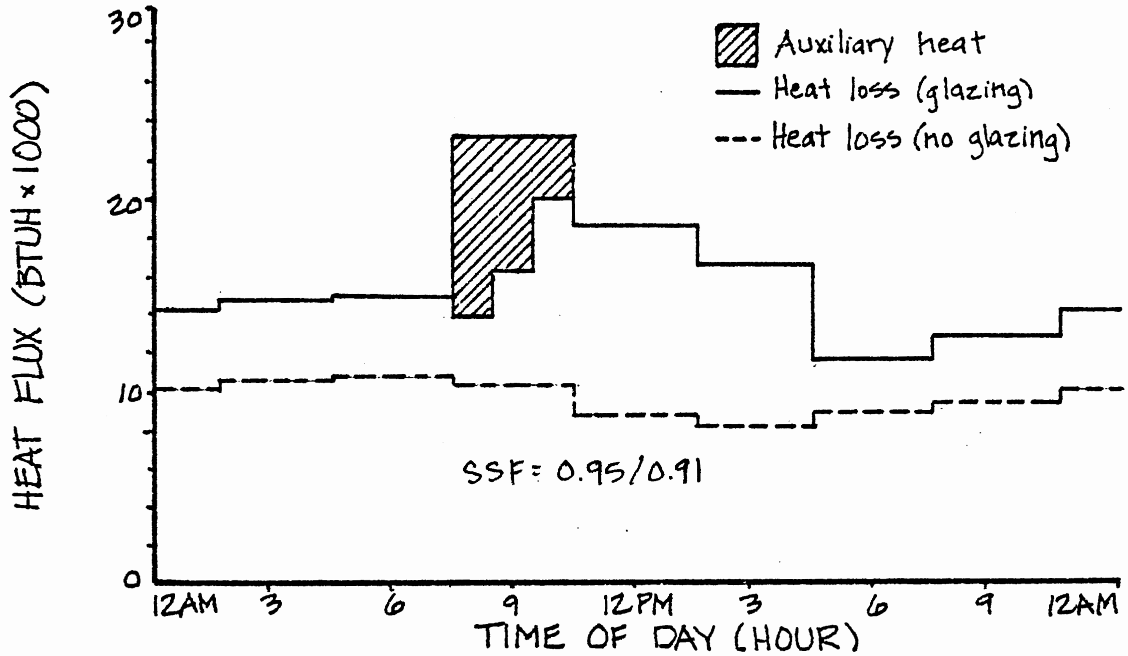


Figure 24. Parameter Five Study (45° Wing Walls)

FOOTNOTES

[1]J.D. Balcomb, Passive Solar Design Handbook: Passive Solar Design Analysis, Volume 2, Los Alamos Scientific Laboratory, (Washington, D.C., 1980), p. 133.

[2]W.L. Glennie, PEGFIX PEGFLOAT Handbook. Princeton Energy Group, (Princeton, New Jersey, 1978), p. 59.

[3]W.K. Langdon, Movable Insulation, (Emmaus, Pa, 1980), p. 3.

CHAPTER VII

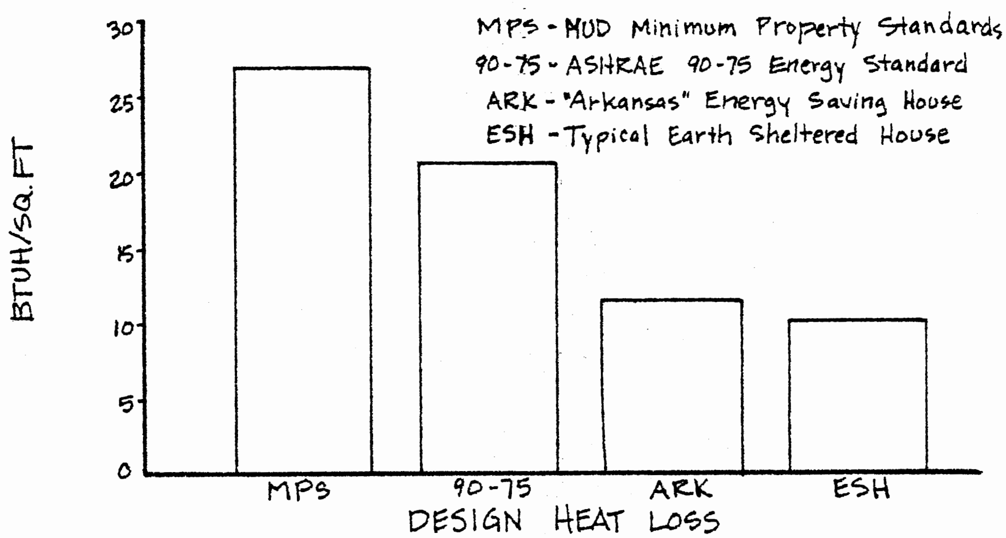
EARTH SHELTER AND ABOVE GROUND COMPARISONS

Heating Season

Performance Comparison

According to a recent study the heat loss for an earth sheltered house is comparable to that of an equivalent above ground house using "Arkansas" energy conserving building practices, as seen in Figure 25. The earth shelter losses are shown to be just less than those of the "Arkansas" house, but it is interesting to look at typical January heat loss profiles, excluding glazing losses, as shown in Figure 26. The stabilizing effects of the earth-backed surfaces flatten the heat loss profile associated with the earth sheltered house, with changes in the heat loss profile being due to exposed surface and infiltration losses. The earth sheltered house has lower heat losses than the above ground house, with the largest difference being during the night when the temperatures are lowest.

The hourly heat loss profiles of the earth shelter house and the above ground house are similar, but the auxiliary heating requirements are considerably different, as shown in Figures 27 and 28. The lack of thermal mass in the above ground house prevents full and effective use of the solar energy entering the space. The above ground house has a usable thermal storage mass of 67,500 pounds compared to 176,250 pounds for the earth sheltered house. The usable thermal mass is that storage which is located in the front three-fourths of the house. Increasing the thermal mass enables the thermal energy to be transferred through the thermal storage by conduction and convection. Air and storage temperatures are directly related to the amount and location of thermal mass , as shown in Figure 29. The solar radiation entering a space heats up the thermal mass resulting in high storage temperatures when the amount of storage is too small. The air and storage temperatures of the earth sheltered house are much more stable than those of the above ground house. The rapid fluctuation in air temperature and high storage temperatures associated with small storage masses such as that associated with conventional above ground houses, would create an uncomfortable environment.



Source: L. L. Boyer and W. T. Grondzik, "Habitability and Energy Performance of Earth Sheltered Dwellings." Preceedings of 3rd Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December, 1980, p. 23.

Figure 25. Design Heat Loss Comparison

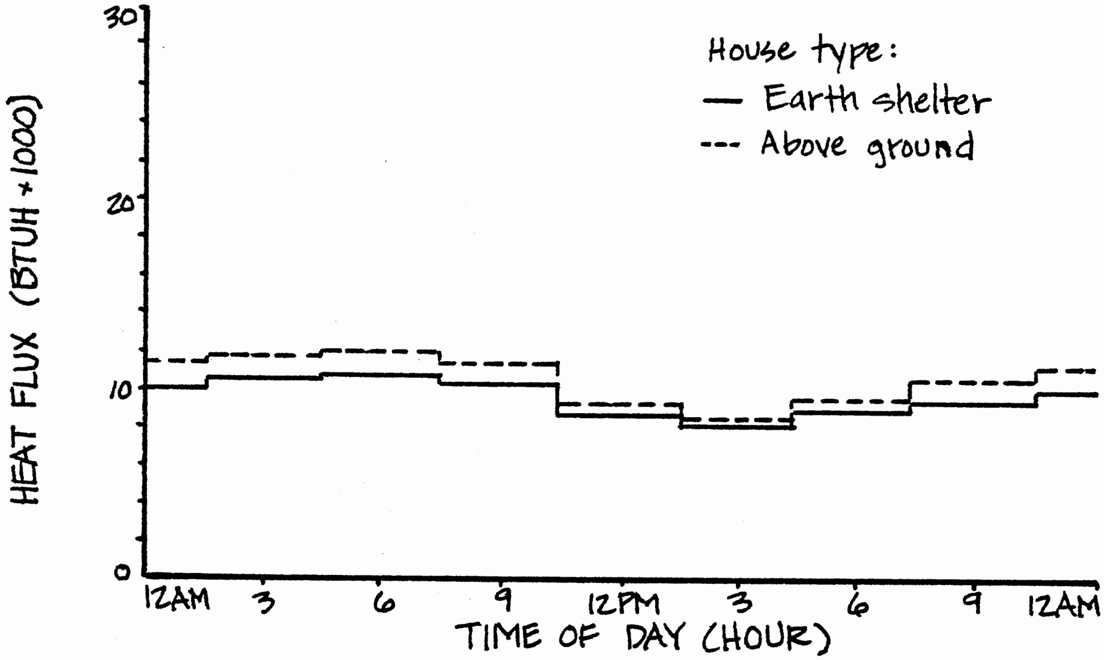


Figure 26. Heat Loss Comparison for Earth Shelter and Above Ground House

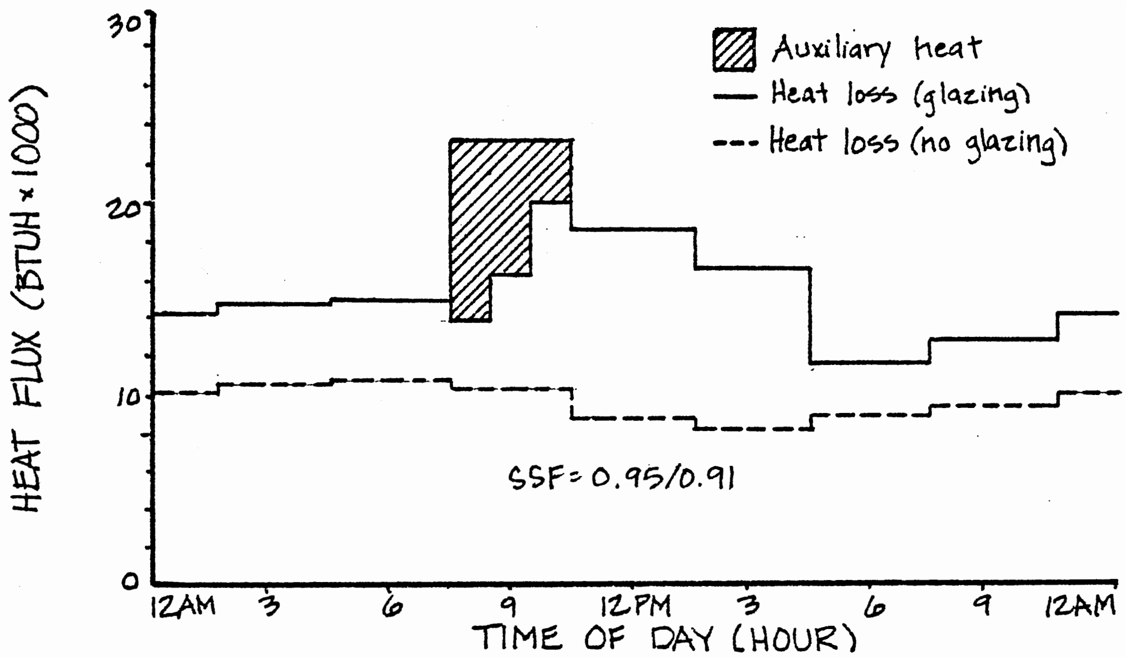


Figure 27. Earth Shelter Heat Loss Profile

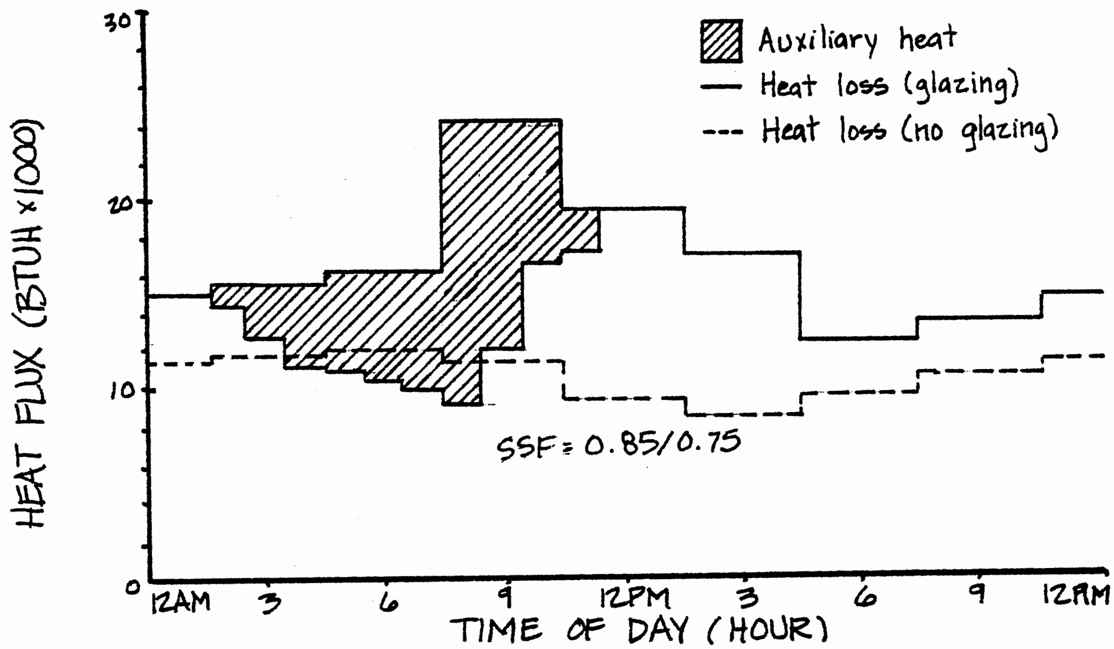


Figure 28. Above Ground Heat Loss Profile

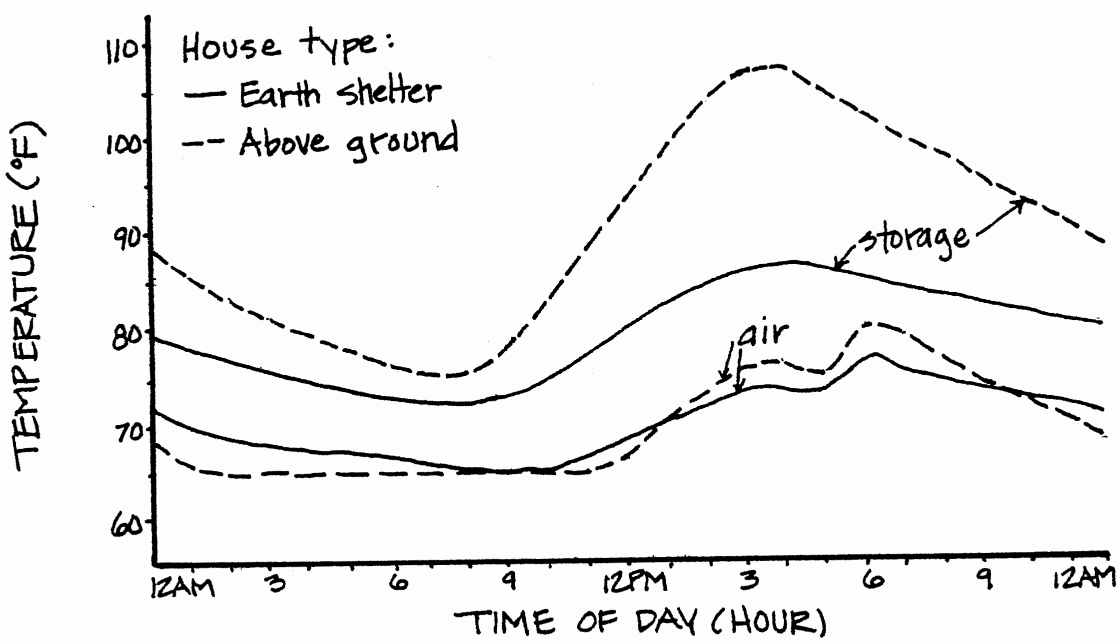


Figure 29. Air and Storage Mass Temperature Comparisons

Prediction Method Comparison

The LASL method was developed for small above ground passive solar structures, while the PEGFIX program is flexible enough to be used on a wide variety of small passive solar projects. The results of both methods are similar for the earth shelter house and the above ground house, as indicated in Table XIV. The LASL method predicted slightly lower SSF and higher auxiliary heating requirements than predicted using the PEGFIX program. The SSF using the LASL method was 5 to 7 percent lower than the PEGFIX method, with about 9,000 Btu/day difference in auxiliary heating requirements predicted by both methods.

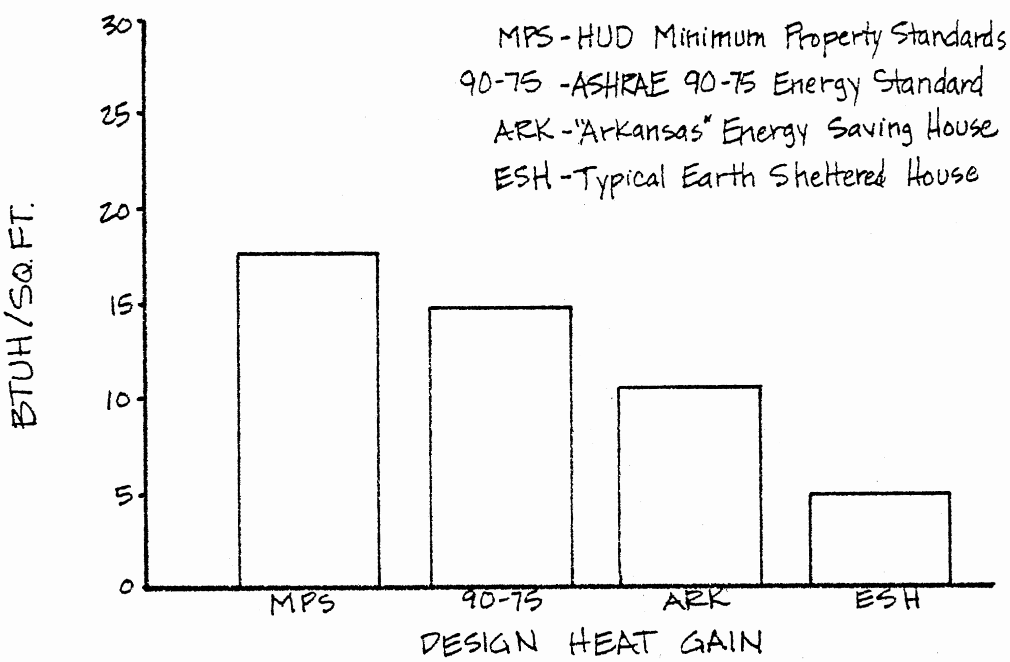
TABLE XIV

EARTH SHELTER AND ABOVE GROUND COMPARISON

	Predictor Method			
	LASL		PEGFIX	
House Type	Auxiliary Heat (Btu/day)	SSF	Auxiliary Heat (Btu/day)	SSF
Earth Shelter (41% Glass)	27,784	0.86	19,610	0.91
Above Ground	72,096	0.67	61,660	0.75

Cooling Season

An energy comparison of two different types of building structures should include both the heating season (heat loss) and cooling season (heat gain). The passive solar earth sheltered house was designed to minimize summar solar heat gains by integrating overhangs and louvers into the design. An analysis of summer performance is not an objective of this study, but should be mentioned. A study on earth shelter design heat gains indicated that an earth sheltered house performs considerably better, as shown in Figure 30, than a similar "Arkansas" energy conserving house.

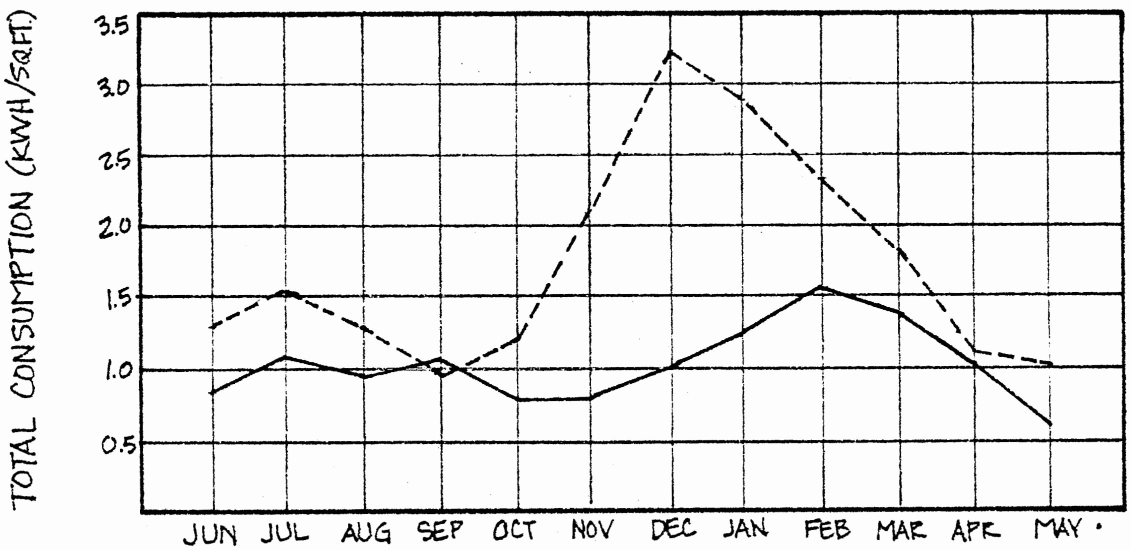


Source: L. L. Boyer and W. T. Grondzik, "Habitability and Energy Performance of Earth Sheltered Dwellings." Preceedings of 3rd Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December, 1980, p. 23.

Figure 30. Design Heat Gain Comparison

Overview of Performance

The heat loss of the earth sheltered house is less than that of an above ground house constructed to "Arkansas" energy conserving standards. The thermal mass of the earth sheltered house enables it to use less than one-third of the auxiliary heat required for the above ground house. Studies indicate that design heat gains and cooling related energy consumption of earth sheltered houses are considerably lower than those of energy conserving above ground houses. Figure 31 shows the comparison of the mean monthly total energy consumption of five earth sheltered houses and twenty above ground houses. The earth sheltered houses use substantially less energy than equivalent above ground houses. The five earth sheltered houses ar typical earth sheltered houses and are not representative of well designed passive solar houses, which would further decrease winter energy consumption. Winter and summer performance information indicates that an earth sheltered house uses considerably less energy than a similar energy conserving above ground house.



Source: L. L. Boyer and W. T. Grondzik, "Habitability and Energy Performance of Earth Sheltered Dwellings." Preceedings of 3rd Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December, 1980, p. 23.

Figure 31. Earth Shelter vs. Above Ground Energy Consumption

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary of Procedure

Typical January heat loss profiles were established for the parameter study cases and for an equivalent above ground house using energy conserving standards. The methods used to calculate heat losses were defined along with all assumptions documented in the calculations. A study model was used for determining accurate input information for both solar savings prediction methods. Detailed calculations and documented input values were used to enable a better understanding of method requirements and procedures.

Parameter studies were compared for the auxiliary heat required and the highest solar savings fraction (SSF). When parameter studies on the earth sheltered house were completed the resulting "optimized" earth sheltered house was compared to an energy conserving above ground house. The comparisons between housing types are primarily directed toward heat loss and auxiliary heating requirements.

Summary of Findings

Both prediction methods used agree fairly closely on the SSF and auxiliary heating requirements. The LASL method typically predicted slightly lower SSF values than that of the PEGFIX program but the difference was usually less than 10 percent. The PEGFIX program and LASL method results seem reasonable since parameter and input changes resulted in output information that appeared logical.

The parameter studies showed that some changes can have a dramatic impact on the amount of auxiliary heat required to maintain 65°F. Large collector areas, night insulation and increased thermal mass were factors that had a dramatic impact of increasing the SSF as shown in Figures 32, 33 and 34. The use of a sloped roof and wing walls 45° from normal to facade also increased the passive solar contribution that could be expected as shown in Figures 35 and 36.

The earth sheltered house heat loss was somewhat less than that of the above ground house but the earth sheltered house performed considerably better in storing and distributing solar energy. Increased thermal mass, that is associated with earth sheltered houses, prevents high storage temperatures and dampens air temperature fluctuations.

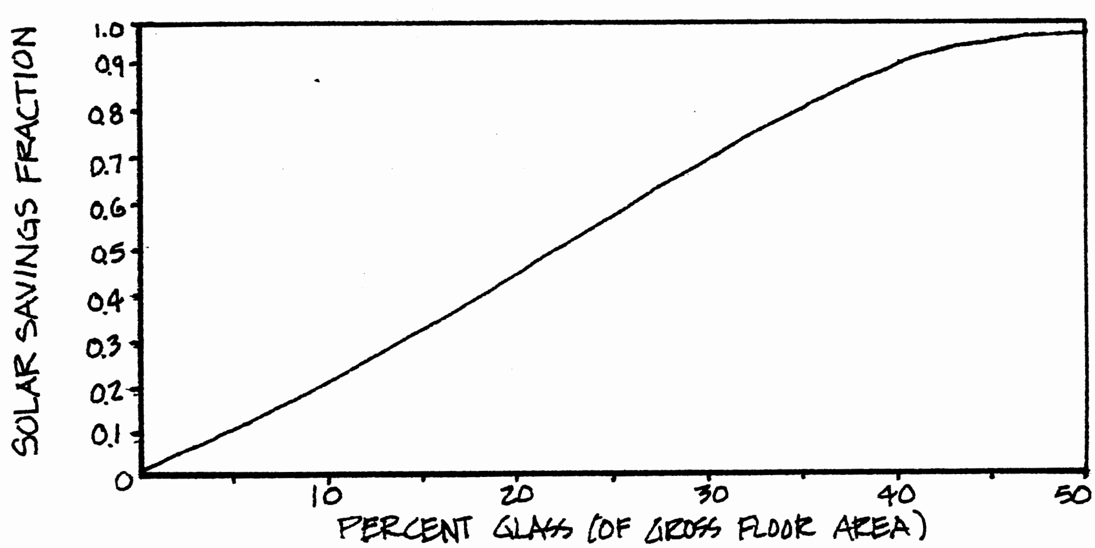


Figure 32. SSF and Collector Percentage Comparison

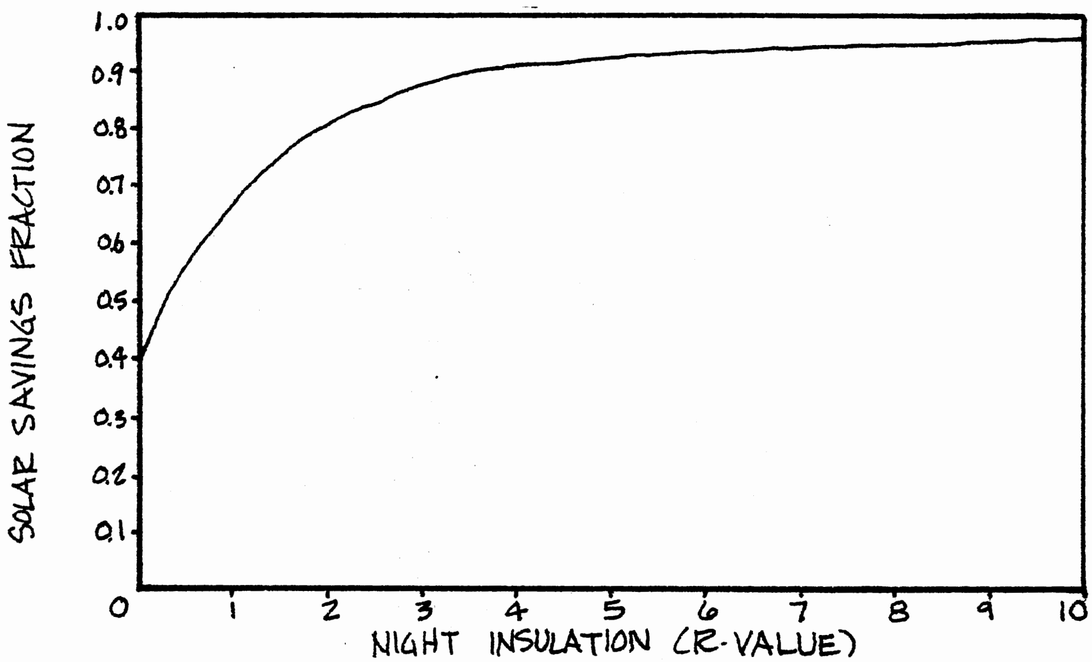


Figure 33. SSF and Night Insulation Comparison

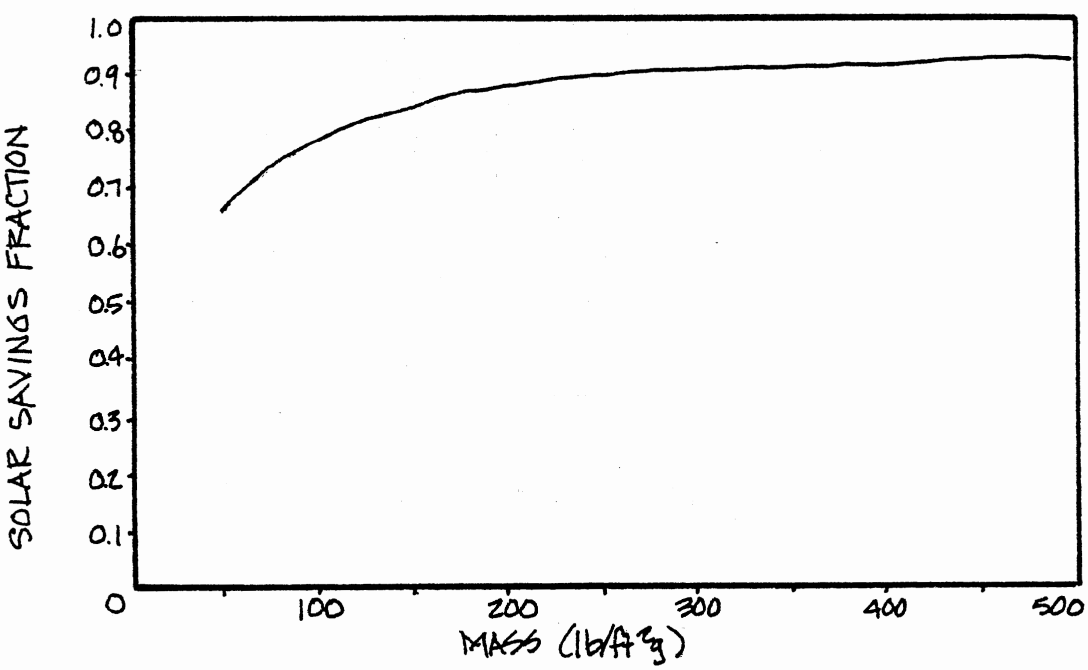


Figure 34. SSF and Thermal Mass Comparison

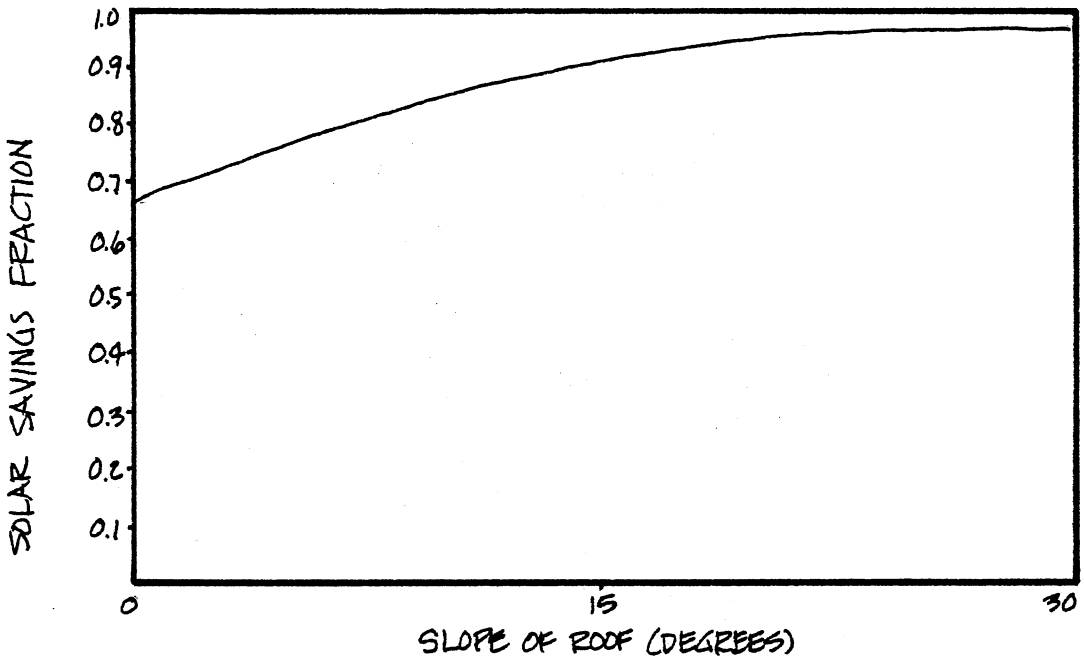


Figure 35. SSF and Roof Configuration Comparison

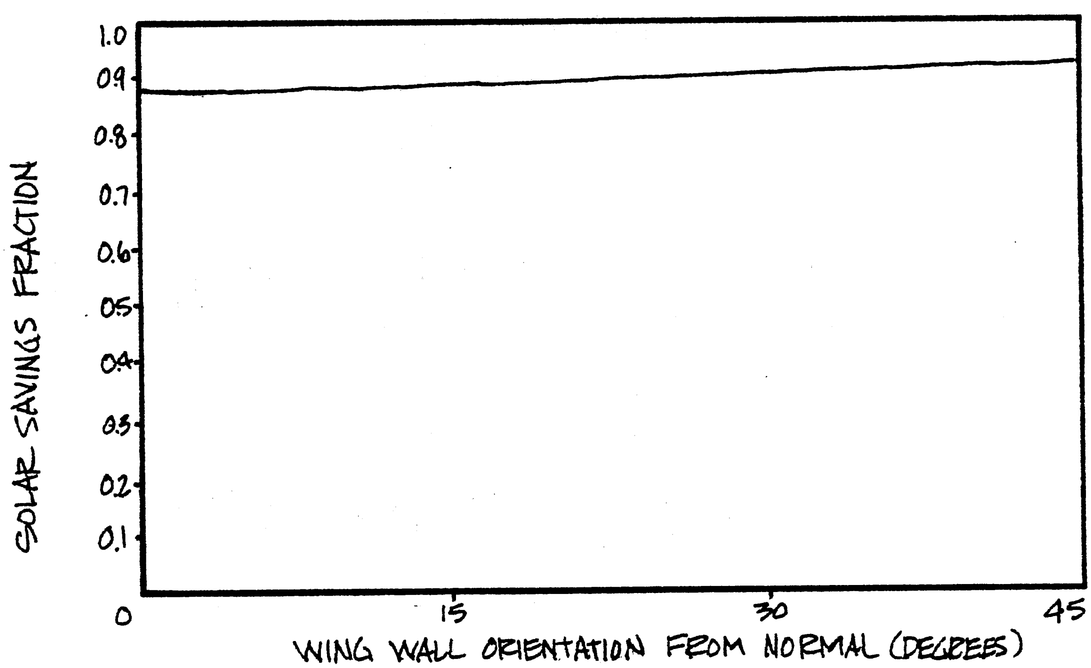


Figure 36. SSF and Wing Wall Orientation Comparison

Conclusions

Earth sheltered housing is a viable alternative to above ground housing. This study has shown that a passive solar earth shelter will use less than one-third of the auxiliary heating required and an increase in the SSF of 16 percent over an equivalent passive solar above ground house using "Arkansas" energy conserving practices.

The two solar performance prediction methods are in fairly close agreement for the SSF and auxiliary heating requirements of the earth sheltered house parameter studies and the above ground house. The LASL method and PEGFIX program results seem to be reasonable while there is some concern over the accuracy of the programs. The validity of the LASL method, PEGFIX/PEGFLOAT and other programs could be checked if on-site monitoring data was readily available.

The utilization of increased thermal mass that is associated with earth sheltered houses provides passive solar adaptability that is not normally available with conventional above ground houses as indicated in Table XV. While this study was not directed toward occupant comfort it is felt that earth sheltered houses would provide higher levels of comfort due to smaller fluctuations in air and interior surface temperature due to earth sheltering and large amounts of thermal mass stabilizing temperatures.

TABLE XV

EARTH SHELTER vs. ABOVE GROUND SUMMARY

House Type	Auxiliary Heat Required (Btu/day)	SSF	Storage Temperature (°F) Minimum	Maximum
Earth Shelter	19,610	0.91	72.3	86
Above Ground (115 lb/ft^2g)	61,660	0.75	75.6	107.1

Note: The values are obtained using the PEGPIX program rather than the LASL method for SSF, auxiliary heat and temperature information. Best conditions developed for the earth sheltered house during this study include: 41% (of gross area) glass
night insulation (R-4)
sloped roof
45° wing walls
300 lb/ft^2g

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APPENDIX A

HEAT LOSS CALCULATIONS

A-1 TEMPERATURE PROFILE DATA

1971 to 1980: DAY	YEAR	HOUR 00	03	06	09	12	15	18	21
January 10	1980	39	42	44	47	50	54	57	58
	1979	25	26	28	30	32	32	28	25
	1978	17	14	11	15	19	26	25	24
	1977	-02	04	03	10	19	23	18	11
	1976	36	38	41	43	51	55	48	44
	1975	54	50	39	33	33	35	34	28
	1974	20	20	17	17	18	20	18	16
	1973	09	09	10	11	14	15	14	14
	1972	37	34	31	40	53	59	49	40
	1971	33	28	27	33	47	51	41	36
AVERAGE		26.8	26.5	25.1	27.9	33.6	37.0	33.2	29.6
January 20	1980	40	36	35	34	36	37	37	37
	1979	34	33	32	33	38	41	36	34
	1978	13	12	09	07	15	19	15	15
	1977	26	27	27	34	52	54	41	36
	1976	30	27	23	26	44	51	42	33
	1975	26	21	19	26	44	54	50	44
	1974	38	33	31	32	49	58	52	43
	1973	53	49	46	51	55	57	52	52
	1972	38	38	41	44	44	45	42	40
	1971	25	26	27	31	45	51	47	44
AVERAGE		32.3	30.2	39.0	31.8	42.2	46.7	41.4	37.8

Source: Local Climatological Data - Oklahoma City, Oklahoma, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

1961 to 1970: DAY	YEAR	HOUR 00	03	06	09	12	15	18	21
January 10	1970	27	28	30	32	35	38	39	38
	1969	22	22	23	24	28	31	29	25
	1968	29	28	28	29	31	33	33	33
	1967	34	27	30	30	42	48	41	37
	1966	45	41	36	40	54	59	50	41
	1965	20	18	15	17	26	35	29	24
	1964	31	27	22	27	47	52	48	44
	1963	41	33	31	36	46	37	25	21
	1962	7	5	3	4	8	10	12	8
	1961	NOT AVAILABLE							
AVERAGE		28.4	25.4	24.2	26.6	35.2	38.1	34.0	30.1
January 20	1970	18	19	20	22	25	25	24	24
	1969	43	42	43	45	51	61	56	52
	1968	40	40	40	40	48	56	54	52
	1967	30	28	31	33	53	62	58	51
	1966	28	27	27	27	29	31	30	30
	1965	41	39	35	39	46	53	43	33
	1964	40	35	32	34	56	64	57	44
	1963	4	4	11	29	36	34	25	25
	1962	5	4	3	4	15	18	18	20
	1961	NOT AVAILABLE							
AVERAGE		27.7	26.4	26.9	30.3	39.9	44.9	40.6	36.8

Source: Local Climatalogical Data - Oklahoma City, Oklahoma, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

January Average Temperatures

YEAR	TEMPERATURE	YEAR	TEMPERATURE
1980	38.2	1970	31.8
1979	25.4	1969	38.8
1978	26.3	1968	36.6
1977	29.2	1967	41.8
1976	39.0	1966	33.8
1975	40.3	1965	38.8
1974	35.0	1964	40.1
1973	33.3	1963	28.3
1972	34.9	1963	28.3
1971	36.9		

Source: Local Climatalogical Data - Oklahoma City, Oklahoma, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

TEMPERATURE PROFILE/AVERAGE COMPARISONS

Daily Temperature Averages	January Averages
January 10th - 30.11°F 1962 - 1980	34.78°F
January 20th - 35.31°F 1962 - 1980	

The average temperature for January 10 and 20 from 1962 to 1980 is 32.71°F as compared to the January average temperatures of 34.78°F during the same period of time. The temperature profile will be used since it is close to the profile of a typical daily profile in January. Hourly averaged temperatures for 1962 to 1980 are as follows:

HOUR							
00	03	06	09	12	15	18	21
28.8	27.1	26.3	29.2	37.7	41.7	37.3	33.6

Temperatures are hourly averaged values for 1962 to 1980.

A-2 CONSTRUCTION U-FACTORS

EARTH SHELTERED HOUSE

EARTH BACKED SURFACES:

Wall - 2" Polyurethane (R-10)

Roof - 2" Polyurethane (R-10)

EXPOSED SURFACES:

Wall -	R-Value	
3" Polyurethane	15	
8" Concrete	(8)(0.19)	
Y2" Stucco	(0.5)(0.20)	
Ext. Air Film	0.68	
Int. Air Film	0.17	
	R=17.47	U = 0.06

Glass - double insulated glass with adjustment factor for wood frame

	(0.65)(0.95)	U = 0.62
with night insulation	(R-4)	U = 0.18
Wood door with storm door		U = 0.33

ABOVE GROUND HOUSE

EXPOSED SURFACES:

Wall -	R-Value	
batt insulation	19	
1/2" gypsum	0.45	
1/2" sheathing	1.22	
3/4" air space	0.94	
4" face brick	4(0.11)	
Ext. air film	0.68	
Int. air film	0.17	
	R=22.9	U = 0.04
Roof -		
batt insulation	38	
1/2" gypsum	0.45	
7 1/2" air space	0.84	
3/4" plywood	0.93	
3/8" built-up roof	0.33	
ext. air film	0.61	
int. air film	0.17	
	R=41.33	U = 0.02

Glass - double insulated glass with adjustment factor		
	(0.65)(0.95)	U = 0.62
with night insulation (R-4)		U = 0.18
Wood door with storm door		U = 0.33

Source: M.J. McGuinness, B. Stein, and J.S. Reynolds, Mechanical and Electrical Equipment for Buildings, 6th ed., John Wiley and Sons, New York, 1980.

A-3 PARAMETRIC STUDIES

Parameter 1 Study

Change	Percent glass with respect to floor area (41%, 35%, 29%) with respect to south facade (70%, 60%, 50%)
Constants	Night insulation (R-4) Sloped Roof (15°) Maximum thermal mass Wing walls (45° from normal to south facade)

Parameter 2 Study

Change	No night insulation
Constants	Percent glass (41%) Sloped roof (15°) Maximum thermal mass Wing walls (45° from normal)

Parameter 3 Study

Change	Flat roof (use maximum area of glass - 20%)
Constants	Night insulation (R-4) Maximum thermal mass Wing walls (45° from normal)

Parameter 4 Study

Change	Thermal mass (floor only, floor and bearing walls)
Constants	Percent glass (41%) with sloped roof (15°) Night insulation (R-4) Wing walls (45° from normal)

Parameter 5 Study

Change	Wing wall angles from normal (0°, 15°, 30°)
Constants	Percent glass (41%) with sloped roof (15°) Night insulation (R-4) Maximum thermal mass

A-4 EARTH SHELTERED HOUSE HEAT LOSSES

Parameter 1 Study House - 41% Glass

1) Heat loss through below grade walls: Table III

loss per length of wall = 0.482 Btuh/ft°F
length of wall = 60 + 2 (24) = 108 ft.
loss per length of wall because of slope roof increased area = 0.041 Btuh/ft°F
length of additional area = 2(16) + 2(8) = 48 ft.
Total heat loss = (0.482)(108) = (0.041)(48) = 54.03 Btuh/°F

2) Heat loss through roof slab: Table III

2 in. insulation & 2 ft. earth cover (interpolate)
loss per square foot of roof = 0.08
roof area (sloped = 1500 ft^2)
Total heat loss (0.08)(1500) = 120.0 Btuh/°F

3) Temperature difference between earth and interior:

Amplitude factor = 20
earth temperature = (Ea - A) = 60.5 - 20 = 40.5°F
average temperature (year) = 60.5°F*
temperature difference 65 - 40.5 = 24.5°F

4) Total heat losses for earth-backed surfaces:

(54.03 + 120.0) x (24.5°F) = 4263.74 Btuh

5) Exposed surface heat losses: (70% glass - 41% of gross area)

door (0.35)(21 ft^2) = 6.93 Btuh/°F
wall (0.06)(252 ft^2) = 15.12 Btuh/°F
glass w/o insulation (0.62)(588 ft^2) = 364.56 Btuh/°F
w/ insulation (0.18)(588 ft^2) = 105.84 Btuh/°F
Total heat loss w/o insulation = 386.66 Btuh/°F
Total heat loss w/ insulation = 127.89 Btuh/°F

6) Edge loss:

edge loss factor = 31 Btuh/ft
exposed length = 60 ft
Total losses = (31)(60) = 1860 Btuh

*Source: Local Climatalogical Data - Oklahoma City, Oklahoma, National Oceanic and Atmospheric Administration, National Climate Center, Asheville, North Carolina.

7) Infiltration losses (1/2 air change/hour)
Volume = ([8 + 14]/2)(24)(60) = 15,840 ft^3

$$1.1 \frac{15840}{60x2} = \underline{145.2 \text{ Btuh/°F}}$$

8) Heat loss summary:

earth sheltered losses & edge loss = 6123.74 Btuh
exposed surface losses & infiltration losses:
w/o night insulation = 531.81 Btuh/°F
w/ night insulation = 273.09 Btuh/°F

Assume internal heat gain of 2000 Btuh. This is used to calculate the expected heat loss of a typical January day for a residence. A value of 20,000 Btu/day per person is suggested for internal loads. The 2000 Btuh value equals 48,000 Btu/day which is slightly higher than 40,000 Btu/day for 2 people.

Source: J.D. Balcomb, Passive Solar Design Handbook: Passive Solar Analysis, Los Alamos Scientific Laboratory, U.S. Department of Energy, Washington, D.C., 1980, p. 141.

A-5 ABOVE GROUND HOUSE HEAT LOSSES

CONDITIONS:

41% glass (with respect to floor area)
15° sloped roof
R-4 night insulation
6" exposed floor slab (this is thicker than the average floor slab but was assumed reasonable for a passive solar house)

1) Heat loss through exposed surfaces:
door - (0.33)(21 ft^2) = 6.93 Btuh/°F
wall - area = (2)(11)(24) + (8)(60) + 252 = 1260 ft^2
(0.04)(1260 ft^2) = 50.4 Btuh/°F
glass - w/o insulation (0.62)(588 ft^2) = 364.56 Btuh/°F
w/ insulation (0.18)(588 ft^2) = 105.84 Btuh/°F
roof - (0.02)(1500 ft^2) = 30 Btuh/°F

2) slab edge loss:
edge loss factor = 30 Btuh/ft
exposed length = 2(60) +2 (24) = 168 ft
Total edge loss = (30)(168) = 5040 Btuh

3) Infiltration losses (1/2 air change/hour)
Volume = 15,840 ft^3

$$1.08 \frac{15,840}{60 \times 2} = 142.56 \text{ Btuh/°F}$$

4) Heat loss summary
edge loss = 5040 Btuh
exposed surface and infiltration losses:
w/o insulation = 594.45 Btuh/°F
with insulation = 333.73 Btuh/°F
internal heat gain = 2000 Btuh

A-6a HOURLY HEAT LOSSES (INCLUDING GLAZING LOSSES)

PARAMETER 1 STUDY

Constant losses: 6123.7 - 2000 = 4123.7 Btuh
Exposed surface & infiltration losses:

41% glass	day = 531.8 Btuh/°F	night = 273.1 Btuh/°F
35% glass	day = 484.8 Btuh/°F	night = 264.7 Btuh/°F
29% glass	day = 437.7 Btuh/°F	night = 252.9 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	09 (Day)	12 (Day)	15 (Day)	18	21
41	14,010	14,474	14,693	23,162	18,642	16,515	11,689	12,699
35	13,706	14,156	14,368	21,480	17,359	15,420	11,456	12,435
29	13,279	13,709	13,911	19,793	16,073	14,322	11,129	12,065

PARAMETER 2 STUDY

Constant losses: 4123.7 Btuh
Exposed surface & infiltration losses:
No insulation day & night = 531.8 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	09 (Day)	12 (Day)	15 (Day)	18	21
41	23,375	24,279	24,704	23,162	18,642	16,515	18,855	20,822

PARAMETER 3 STUDY

Constant losses: 4123.7 Btuh
Exposed surface & infiltration losses:
Flat roof day = 334.3 Btuh/°F
night = 207.6 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	09 (Day)	12 (Day)	15 (Day)	18	21
60	11,639	11,992	12,158	16,092	13,250	11,913	9,874	10,642

PARAMETER 4 STUDY

Thermal mass study (Exposed floor, Bearing & Partition walls)
Hourly heat losses are the same as Parameter 1 study with 41 percent glass.

PARAMETER 5 STUDY

Wing wall study (0°,15° & 30° from normal to facade wall)
Hourly heat losses are the same as Parameter 1 study with 41 percent glass.

ABOVE GROUND HOURLY HEAT LOSSES

Constant losses: slab edge = 5040 Btuh
Internal heat gains = 2000 Btuh
Constant heat losses = 5040 - 2000 = 3040 Btuh
Exposed surface & infiltration losses:
day = 594.45 Btuh/°F
night = 335.73 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	Day 09	Day 12	Day 15	18	21
70	15,193	15,764	16,033	24,321	19,268	16,891	12,340	13,582

A-6b HOURLY HEAT LOSSES (EXCLUDING GLAZING LOSSES)

PARAMETER 1 STUDY

Constant losses: 6123.7-2000 = 4123.7 Btuh
Exposed surface & infiltration losses:
41% glass = 167.2 Btuh/°F
35% glass = 172.3 Btuh/°F
29% glass = 177.3 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	Day 09	12	15	18	21
41	10,176	10,460	10,594	10,109	8,688	8,019	8,755	9,374
35	10,361	10,654	10,792	10,242	8,827	8,138	8,896	9,534
29	10,542	10,843	10,985	10,471	8,964	8,255	9,035	9,691

PARAMETER 2 STUDY

No night insulation study. Hourly heat losses are the same as Parameter 1 study with 41 percent glass.

PARAMETER 3 STUDY

Constant losses: 4123.7 Btuh
Exposed surface & infiltration losses: 155.7 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	Day 09	12	15	18	21
20	9,760	10,025	10,149	9,698	8,374	7,752	8,437	9,013

PARAMETER 4 STUDY

Thermal mass study (exposed floor, exposed floor & bearing walls). Hourly heat losses are the same as Parameter 1 study with 41 percent glass.

PARAMETER 5 STUDY

Wing wall study (0°, 15° & 30° from normal to facade wall). Hourly heat losses are the same as Parameter 1 study with 41 percent glass.

ABOVE GROUND HOURLY HEAT LOSSES

Constant losses: slab edge = 5040 Btuh
Internal heat gains = 2000 Btuh
Constant heat losses = 5040 - 2000 = 3040 Btuh
Exposes surface & infiltration losses = 229.9 Btuh/°F

HOURLY LOSSES (Btuh)

Percent glass	00	03	06	09	Day 12	15	18	21
41	11,362	11,753	11,937	11,270	9,316	8,397	9,408	10,259

APPENDIX B

INPUT/OUTPUT DATA (LASL)

B-1 SSF CALCULATIONS

PARAMETER 1 STUDY (41% GLASS)

1) BLC (building load coefficient):
Constant losses:
Earth backed surfaces = 4263.7 Btuh
Edge loss = 1860 Btuh
Heat gains = 2000 Btuh
Total losses = 4123.7 Btuh/32.7°F = 126.1 Btuh/°F
Exposed losses (not including collector area) = 167.2 Btuh/°F
BLC = 24 (126.1 + 167.2) = 7,039.2 Btu/°F

2) S (solar radiation absorbed per square foot of collector per month):
Daily rate of radiation entering the space through unshaded collector area was obtained from E. Mazria, The Passive Solar Energy Book, p. 354.
Daily radiation on horizontal surface = 938 $Btu/ft^2 day$
Conversion factor for collector tilt (vertical) and double pane transmittance = 1.1
Overhang multiplication factor -
Y/H (separation) = 0.136 X/H (overhang) = 0.455
factor = 0.72
since the overhang is louvers to permit daylight to enter in the winter 50% transmittance for the 28% shaded area will be used.
factor = 0.72 + (0.50)(0.28) = 0.86
S = (938)(1.1)(0.86)(31 days/month) = 27,508 $Btu/ft^2 month$

3) DD (degree days corresponding to base temperature of 65°F):
DD_{65} = 874

4) S/DD:
S/DD = 27,508/874 = 31.47

5) LCR - load collector area (BLC/AC)
BLC = 7,039.2 Btuh/°F
AC (collector area) = 588 ft^2
LCR = 7,039.2/588 = 12.0
Determine monthly SSF:
$SSF = (F_1)(SSF_0) + (F_2)(SSF_9)$
$F_1 = 1 - y$ $F_2 = y = R(9 + R_0)/9$ $(R_0 = R)$
Since S/DD = 31.47 the Figures for Albuquerque will be used from J.D. Balcomb, Passive Solar Design Handbook: Passive Solar Design Analysis, p. 70 will be used (Figure 8 in Chapter V).

Available storage:	sq. ft.	cu. ft.	lb.
Floor slab (6")	900	450	67,500
Bearing walls (8")	750	500	75,000
Partition walls (6")	450	225	33,750

Mass ($16/ft^2 g$) = (67,500 + 75,000 + 33,750)/588 = 300 $lb/ft^2 g$
From Figure 8 with LCR = 12.0 & Mass = 300
$SSF_0 = 0.55$ $SSF_9 = 0.88$ $F_2 = 4(9 + 0.55)/9(0.55 = 4) = 0.933$
$F_1 = 0.067$ SSF = (0.067)(0.55) = (0.933)(0.88) = 0.86

PARAMETER 1 STUDY (35% GLASS)

1) BLC:
Constant losses = 126.1 Btuh/°F
Exposed losses = 172.3 Btuh/°F
BLC = 24 (126.1 + 172.3) = 7161.6 Btu/ft^{2}day

2) S = 27,508 Btu/ft^{2}month

3) DD_{65} = 874

4) S/DD = 27,508/874 = 31.47

5) LCR (BLC/AC):
LCR = 7161.6/504 = 14.2
Determine monthly SSF:
LCR = 14.2 & Mass = 300
SSF_0 = 0.42 SSF_9 = 0.79
F_2 = 4(9 + 0.42)/9(0.42 + 4) = 0.947 F_1 = 0.053
SSF = (0.053)(0.42) + (0.947)(0.79) = 0.77

PARAMETER 1 STUDY (29% GLASS)

1) BLC:
Constant losses = 126.1 Btuh/°F
Exposed losses = 177.3 Btuh/°F
BLC = 24 (126.1 + 177.3) = 7281.6 Btu/ft^{2}day

2) S = 27,508 Btu/ft^2

3) DD_{65} = 874

4) S/DD = 27,508/874 = 31.47

5) LCR (BLC/AC):
LCR = 7281.6/420 = 17.3
Determine monthly SSF:
LCR = 17.3 & Mass = 300
SSF_0 = 0.41 SSF_9 = 0.65
F_2 = 4(9 + 0.41)/9(0.41 +4) = 0.948 F_1 = 0.052
SSF = (0.052)(0.41) + (0.948)(0.65) = 0.64

PARAMETER 2 STUDY

1) BLC:
Same as Parameter 1 study with 41% glass
BLC = 7,039.2 Btu/°F

2) S = 27,508 Btu/ft^2

3) DD_{65} = 874

4) S/DD = 31.47

5) LCR (BLC/AC):
same as Parameter 1 study with 41% glass
LCR = 12.0 & Mass = 300
Determine monthly SSF:
SSF = 0.50

PARAMETER 3 STUDY

1) BLC
Constant losses = 126.1 Btuh/°F
Exposed losses = 155.7 Btuh/°F
BLC = 24 (126.1 + 155.7) = 6763.2 Btu/°F

2) S:
Overhang multiplication factor -
Y/H (separation) = 0.136 S/H (overhang) = 0.833
factor = 0.50 (extrapolated value)
factor = 0.50 + (0.50)(0.50) = 0.75
S = (938)(1.1)(0.75)(31) = 23,989 Btu/ft^{2}month

3) DD_{65} = 874

4) S/DD = 23,989/874 = 27.4

5) LCR (BLC/AC)
LCR = 6763.2/288 = 23.5
Determine SSF:
LCR = 23.5 & Mass = 300
SSF_0 = 0.48 SSF_9 = 0.56
F_2 = 4(9 + 0.48)/9(0.48 + 4) = 0.940 F_1 = 0.060
SSF = (0.060)(0.48) + (0.940)(0.56) = 0.56

PARAMETER 4 STUDY (FLOOR SLAB)

1) BLC:
Same as Parameter 1 study with 41% glass.
BLC = 7,039.2 Btu/°F

2) S = 27,508 same as Parameter 1 study

3) DD_{65} = 874

4) S/DD = 31.47

5) LCR (BLC/AC)
Same as Parameter 1 study with 41% glass.
LCR = 12.0 & Mass = 67,500/588 = 115
SSF_0 = 0.33 SSF_9 = 0.73
F_2 = 4(9 + 0.33)/9(0.33 + 4) = 0.958 F_1 = 0.042
SSF = (0.042)(0.33) + (0.958)(0.73 = 0.71

PARAMETER 4 STUDY (FLOOR SLAB & BEARING WALLS)

1) BLC:
same as Parameter 1 study with 41% glass
BLC = 7,039.2 Btu/°F

2) S = 27,508 same as Parameter 1 study

3) DD_{65} = 874

4) S/DD = 31.47

5) LCR (BLC/AC)
LCR = 12.0 & Mass = 67,500 + 75,000)/588 = 242
Determine monthly SSF.
SSF_0 = 0.50 SSF_9 = 0.85
F_2 = 4(9 = 0.50)/9(0.50 + 4) = 0.938 F_1 = 0.065
SSF = (0.062)(0.50 + (0.938)(0.85) = 0.83

PARAMETER 5 STUDY (WING WALL NORMAL TO FACADE)

1) BLC:
   Same as Parameter 1 study with 41% glass.
   BLC = 7,039.2 Btu/°F

2) S = (938)(1.1)(0.84)(31) = 26,868 Btu/ft^{2}month

3) DD_{65} = 874

4) S/DD = 26,868/874 = 30.74

5) LCR (BLC/AC):
   LCR = 12.0 & Mass = 300
   Determine monthly SSF
   SSF_0 = 0.83
   Changes of 0.03 in the SSF are due to S/DD being slightly different from Parameter 1 study with 41% glass (estimated).

PARAMETER 5 STUDY (WING WALL 15° FROM NORMAL)

1) BLC:
   Same as Parameter 1 study with 41% glass.
   BLC = 7,039.2 Btu/°F

2) S = (938)(1.1)(0.85)(31) = 27,188 Btu/ft^{2}month

3) DD_{65} = 874

4) S/DD = 27,188/874 = 31.1

5) LCR (BLC/AC):
   LCR = 12.0 & Mass = 300
   Determine monthly SSF.
   SSF = 0.84
   Change of 0.02 in SSF due to S/DD (estimated).

PARAMETER 5 STUDY (WING WALL 30° FROM NORMAL)

1) BLC:
   Same as Parameter 1 study with 41% glass.
   BLC = 7,039.2 Btu/°F

2) S = 27,508 Same as Parameter 1 study

3) DD_{65} = 874

4) S/DD = 31.47

5) LCR (BLC/AC)
Same as Parameter 1 study with 41% glass.
LCR = 12.0 & Mass = 300
Determine monthly SSF:
SSF = 0.85
Change of 0.01 in SSF due to S/DD (estimated).

ABOVE GROUND HOUSE

1) BLC:
Constant losses -
Edge loss = 5040 Btuh
Heat gain = 2000. Btuh
Total gains = (5040 - 2000)/32.7 = 93.0 Btuh/°F
Exposed losses = 229.9 Btuh/°F
BLC = 24(93.0 + 229.9) = 7749

2) S = 27,508 Same as Parameter 1 study

3) DD_{65} = 874

4) S/DD = 31.47

5) LCR (BLC/AC)
LCR = 7,749/588 = 13.1 & Mass = 67,500/588 = 115
Determine monthly SSF.
SSF_0 = 0.34 SSF_9 = 0.68
$F_2 = 4(9 + 0.34) + 9(0.34 + 4) = 0.956$ $F_1 = 0.044$
SSF = (0.044)(0.34) + (0.044)(0.68) = 0.67

B-2 AUXILIARY HEATING REQUIREMENTS

Qaux/day = (1 - SSF)(DD)(BLC)/31

Study	SSF	DD	BLC	Qaux/31
Par. 1 - 41% glass	0.86	874	7,039	27,784
Par. 1 - 35% glass	0.77	874	7,162	46,442
Par. 1 - 29% glass	0.64	874	7,282	73,910
Parameter 2	0.50	874	7,039	99,227
Parameter 3	0.56	874	6,763	83,896
Par. 4 - floor	0.71	874	7,039	57,552
Par. 4 - floor & b.walls	0.83	874	7,039	33,737
Par. 5 - normal	0.83	874	7,039	33,737
Par. 5 - 15°	0.84	874	7,039	31,753
Par. 5 - 30°	0.85	874	7,039	29,768
Above ground	0.67	874	7,749	72,096

APPENDIX C

INPUT/OUTPUT DATA (PEGFIX)

MC sto (Btu/°F) - effective heat capacity of the thermal storage that is available for collecting and storing solar energy.
Storage is divided into two categories:
MC pri - primary storage (receives sunlight most of the day)
MC sec - secondary storage (receives little or no direct sunlight)

UA sto (Btuh/°F) - heat transfer coefficient between storage mass and surrounding air.

UA day, UA night (Btuh/°F) - total hourly heat loss from house to outside air.
UA values are used by the program to calculate heat losses (exposed and earth backed surfaces minus internal gains) by multiplying by hourly air temperature difference (ti - to). To approximate the actual heat losses for earth backed surface losses (Btuh) required dividing by the average day/night temperature to allow inputting of earth sheltered loads into the program, since space isn't allocated for constant loads.

fsto,fair - solar split for incoming radiation
fsto = αsto x Psto   sto = 0.9   Psto = 0.8
fair = α air x Psto   air = 0.6   Pair = 0.1
where α is the average absorptivity of the spaces and P is the weighting factor
fsto = 0.72   fair = 0.06
1 - (0.72 + 0.06) = 0.22 - This is the fraction not absorbed directly (half is reradiated outside and the rest is absorbed)
fsto = 0.81   fair = 0.07

Tsto (°F) - initial storage temperature
temperature at the end of the day should be within one degree of initial temperature for accurate resutls.

Tmin, Tmax (°F) - minimum (65°) and maximum (80°) temperature limits for interior.

Tvent (°F) - venting temperature
set to zero for venting excess heat to outside.

Tavg (°F) - average outside (ambient) temperature

Tswing (°F) - outside temperature range

Ag (ft^2) - area of collector glazing (unshaded only)
Use 90 percent of area to allow for window mullions. Set to zero for I hour usage.

S day (Btu/ft^2) - total radiation received through one square foot of collector area. Set to zero for I hour usage.

L days - length of the day, sunrise to sunset
Length of day use for calculations is nine.

I hour (Btuh) - hourly rate of radiation entering the space through unshaded collector area.
The hourly values are proportioned on the basis of the SHGF (Solar Heat Gain Factors) profile from 1977 ASHRAE FUNDAMENTALS with the daily total being from E. Mazria, The Passive Solar Energy Book, p. 354.

Average daily solar radiation on a horizontal surface in January for Oklahoma City = 938 Btu/(day)(ft^2)

SHGF (36° N. Latitude)

A.M.	SHGF	P.M.
8	89	4
9	164.5	3
10	212.5	2
11	241	1
	250	12
	1664	

Solar Profile

A.M.	Hhour	P.M.
8	50	4
9	93	3
10	120	2
11	136	1
	141	12
	939	

daily comparison

C-2 INPUT CALCULATIONS

PARAMETER 1 STUDY (41% GLASS)

1) MC sto:
MC sto = (volume) (capacitance) (effectiveness factor)
effectiveness factor is determined by routine "B" in PEGFIX/PEGFLOAT program.
Available Storage:
Bearing walls (8") - 750 ft^2/500 ft^3
Floor slab (6") - 900 ft^2/450 ft^3
Partition walls (6") - 450 ft^2/225 ft^3
Primary storage:
Bearing walls - 260 ft^2/174 ft^3
Floor slab 400 ft^2/200 ft^3
Partition walls - 200 ft^2/100 ft^3
Secondary storage:
Bearing walls - 490 ft^2/327 ft^3
Floor slab - 500 ft^2/250 ft^3
Partition walls - 250 ft^2/125 ft^3
MC pri = (174)(30)(0.63) + (200)(30)(0.79) + (100)(30)(0.79)
MC pri = 7.438.86 Btu/°F
MC sec = 1/3 [(327)(30)(0.63) + (250)(30)(0.79) + (125)(30)(0.79)]
MC sec = 7,985.1 Btu/°F
MC sto = 7,438.86 + 7,985.1 = 15,423.96 Btu/°F

2) UA sto:
UA sto = (1.5)(Area of prim. stor.) + (0.3)(Area of sec. stor.)
UA sto = (1.5)(860) + (0.3)(1240) = 1662 Btuh/°F

3) UA day/UA night:
Earth backed surface losses = 4263.74 Btuh
internal heat gains (people, appliances, lights, etc.) = 2000 Btuh
convert constant (Btuh) losses & gains to UA values (Btuh/°F)
average night (5 p.m. - 7 a.m.)/day (8 a.m. - 4 p.m.) temperatures
night = (6,123.7 - 2000)/34.4° = 119.9 Btuh/°F
day = (6,123.7 - 2000)/28.8° = 143.2 Btuh/°F
Exposed surface and infiltration losses:
w/o night insulation = 531.8 Btuh/°F
w/ R-4 night insulation = 273.1 Btuh/°F
UA night = 119.9 + 273.1 = 373.0 Btuh/°F
UA day = 143.8 + 531.8 = 675.6 Btuh/°F

4) Ihour:
Ihour = (Hhour)(Rhour)(Ag) (Tinstantaneous)
Rhour - hourly correction factor for tilt of collector
Tinstantaneous - instantaneous glass transmittance at each hour
Rhour = 1.1, this is for converting horizontal radiation values to vertical values and includes transmittance losses for double glazed glass. Taken from E. Mazria, p. 358.
Tinstantaneous values are included in Rhour but additional losses occur at early hours due to low angle of incidence [shown as Tmodified(Tactual)]

Time a.m.	Time p.m.	Hhour	x Rhour x	Ag	x	T	=	Ihour
8	4	50	1.1	440		.89(.67)	=	21,538
9	3	93	1.1	468		.95(.70)	=	44,525
10	2	120	1.1	450		.96(.72)	=	57,024
11	1	136	1.1	460		1(.75)	=	68,816
	12	141	1.1	446		1(.75)	=	69,175

PARAMETER 1 STUDY (35% GLASS)

1) MC sto:
MC sto = (149)(30)(0.63) + (171)(30)(0.79) + (86)(30)(0.79) + 1/3 [(351)(30)(0.63) + (279)(30)(0.79) + (140)(30)(0.79)]
MC sto = 14,428 Btu/°F

2) UA sto:
UA sto = (1.5)(223 + 343 + 171) + (0.3)(527 + 557 + 279)
UA sto = 1,514 Btuh/°F

3) UA day/UA night
Constant losses:
day = (6,123.7 - 2,000)/28.8° = 143.2 Btuh/°F
night = (6,123.7 - 2,000)/34.4° = 119.9 Btuh/°F
Exposed surface and infiltration losses:
w/o night insulation = 484.8 Btuh/°F
w/ R-4 night insulation = 264.7 Btuh/°F
UA day = 143.2 + 484.8 = 628.0 Btuh/°F
UA night = 119.9 + 264.7 = 384.6 Btuh/°F

4) Ihour:

Time a.m.	Time p.m.	Hhour	x Rhour x	Ag	x	T	=	Ihour
8	4	50	1.1	377		.89	=	18,461
9	3	93	1.1	401		.93	=	38,164
10	2	120	1.1	386		.96	=	48,878
11	1	136	1.1	394		1	=	58,985
	12	141	1.1	382		1	=	59,293

PARAMETER 1 STUDY (29% GLASS)

1) MC sto:
MC sto = (124)(30)(0.63) + (143)(30)(0.79) + (71)(30)(0.79) + 1/3 [(377)(30)(0.63) + (307)(30)(0.79) +)136)(30)(0.79)]
MC sto = 13,290 Btu/°F

2) UA sto:
UA sto = (1.5)(185 = 286 = 143) + (0.3)(565 + 614 + 271)
UA sto = 1,356 Btuh/°F

3) UA day/UA night:
Constant losses:
day = 143.2 Btuh/°F night = 119.9 Btuh/°F

Exposed surface & infiltration losses:
w/o night insulation = 437.7 Btuh/°F
w/R-4 night insulation = 252.9 Btuh/°F
UA day = 143.2 + 437.7 = 580.9 Btuh/°F
UA night = 119.9 + 252.9 = 372.8 Btuh/°F

4) Ihour:

Time a.m.	Time p.m.	Hhour	x Rhour	x Ag	x T	= Ihour
8	4	50	1.1	314	.89	= 15,384
9	3	93	1.1	334	.93	= 31,804
10	2	120	1.1	322	.96	= 40,731
11	1	136	1.1	329	1	= 49,154
	12	141	1.1	319	1	= 49,411

PARAMETER 2 STUDY

1) MC sto:
MC sto = 15,423.96 Btu/°F (same as Parameter 1 - 41% glass)

2) UA sto:
UA sto = 1,356 Btuh/°F (same as Parameter 1 - 41% glass)

3) UA day/UA night:
Constant losses:
day = 143.2 Btuh/°F night = 119.9 Btuh/°F
Exposed surface & infiltration losses:
day & night w/o R-4 window insulation = 531.8 Btuh/°F
UA day = 143.2 + 531.8 = 675.0 Btuh/°F
UA night = 119.9 + 531.8 = 651.7 Btuh/°F

4) Ihour
same as Parameter 1 - 41% glass

Time a.m.	Time p.m.	Ihour
8	4	21,538
9	3	44,525
10	2	57,024
11	1	68,816
	12	69,175

PARAMETER 3 STUDY

1) MC sto:
MC sto = (86)(30)(0.63) + (165)(30)(0.79) + (55)(30)(0.79) +
1/3 [(413)(30)(0.63) + (285)(30)(0.79) + (170)(30)(0.79)]
MC sto = 13,035.8 Btu/°F

2) UA sto:
UA sto = (1.5)(130 + 330 + 110) + (0.3)(620 + 570 + 340)
UA sto = 1,314 Btuh/°F

3) UA day/UA night
Constant losses:
day = 143.8 Btuh/°F
night = 119.9 Btuh/°F
Exposed surface and infiltration losses:
w/o night insulation = 334.3 Btuh/°F
w/ R-4 night insulation = 207.6 Btuh/°F
UA day = 143.8 + 334.3 = 478.1 Btuh/°F
UA night = 119.9 + 207.6 = 327.5 Btuh/°F

4) Ihour:

Time a.m.	Time p.m.	Hhour	x Rhour	x Ag	x T	= Ihour
8	4	50	1.1	260	.89	= 12,727
9	3	93	1.1	280	.93	= 26,639
10	2	120	1.1	250	.96	= 31,680
11	1	136	1.1	240	1	= 35,904
	12	141	1.1	230	1	= 35,673

PARAMETER 4 STUDY (FLOOR SLAB)

1) MC sto:
MC sto = (200)(30)(0.79) + 1/3 [(250)(30)(0.79)]
MC sto = 6,715 Btu/°F

2) UA sto:
UA sto = (1.5)(400) + (0.3)(500)
UA sto = 750 Btuh/°F

3) UA day/UA night:
UA day = 675.6 Btuh/°F
UA night = 373.0 Btuh/°F
Same as Parameter 1 study with 41% glass

4) Ihour
same as Parameter 1 - 41% glass

Time a.m.	Time p.m.	Ihour
8	4	21,538
9	3	44,525
10	2	57,024
11	1	68,816
	12	69,175

PARAMETER 4 STUDY (FLOOR SLAB & BEARING WALLS)

1) MC sto:
MC sto = (174)(30)(0.63) + (200)(30)(0.79) + 1/3 [(327)(30)(0.63) + (250)(30)(0.79)]
MC sto = 12,064 Btu/°F

2) UA sto:
UA sto = (1.5)(260 + 400) + (0.3)(490 + 500)
UA sto = 1,287 Btuh/°F

3) UA day/UA night:
UA day = 675.6 Btuh/°F
UA night = 373.0 Btuh/°F
same as Parameter 1 study with 41% glass

4) Ihour
same as Parameter 1 - 41% glass

Time a.m.	Time p.m.	Ihour
8	4	21,538
9	3	44,525
10	2	57,024
11	1	68,816
	12	69,175

PARAMETER 5 STUDY (WING WALL NORMAL TO FACADE)

1) MC sto:
MC sto = (174)(30)(0.63) + (196)(30)(0.79) + (97)(30)(0.79) + 1/3 [(327)(30)(0.63) + (254)(30)(0.79) + (128)(30)(0.79)]
MC sto = 15,311 Btu/°F

2) UA sto:
UA sto = (1.5)(260 + 392 + 194) + (0.3)(490 + 508 + 256)
UA sto = 1,645 Btuh/°F

3) UA day/UA night:
same as Parameter 1 study with 41% glass.
UA day = 675.6 Btuh/°F
UA night = 373.0 Btuh/°F

4) Ihour:

Time a.m.	Time p.m.	Hhour	x Rhour x	Ag	x T	= Ihour
8	4	50	1.1	388	.89	= 18,993
9	3	93	1.1	414	.93	= 39,388
10	2	120	1.1	414	.96	= 52,462
11	1	136	1.1	440	1	= 65,824
	12	141	1.1	446	1	= 69,175

PARAMETER 5 STUDY (WING WALL 15° FROM NORMAL)

1) MC sto:
MC sto = (174)(30)(0.63) + (200)(30)(0.79) + (97)(30)(0.79) + 1/3 [(327)(30)(0.63) + (250)(30)(0.79) + (128)(30)(0.79)]
MC sto = 15,374 Btu/°F

2) UA sto:
UA sto = (1.5)(260 + 400 + 194) + (0.3)(490 + 500 + 256)
UA sto = 1,655 Btuh/°F

3) UA day/UA night:
same as Parameter 1 study with 41% glass.
UA day = 675.6 Btuh/°F
UA night = 373.0 Btuh/°F

4) Ihour:

Time a.m.	p.m.	Hhour	x Rhour x	Ag	x	T	=	Ihour
8	4	50	1.1	405		.89	=	19,825
9	3	93	1.1	432		.93	=	41,100
10	2	120	1.1	432		.96	=	54,743
11	1	136	1.1	460		1	=	68,816
	12	141	1.1	446		1	=	69,175

PARAMETER 5 STUDY (WING WALL 30° FROM NORMAL

1) MC sto:
Same as Parameter 1 study with 41% glass.
MC sto = 15,423.96 Btu/°F

2) UA sto:
Same as Parameter 1 study with 41% glass.
UA sto = 1662 Btuh/°F

3) UA day/UA night:
Same as Parameter 1 study with 41% glass.
UA day = 675.6 Btuh/°F
UA night = 373.0 Btuh/°F

4) Ihour:

Time a.m.	p.m.	Hhour	x Rhour x	Ag	x	T	=	Ihour
8	4	50	1.1	422		.89	=	20,657
9	3	93	1.1	450		.93	=	42,813
10	2	120	1.1	450		.96	=	57,024
11	1	136	1.1	460		1	=	68,816
	12	141	1.1	446		1	=	69,175

ABOVE GROUND HOUSE

1) MC sto:
MC sto = (200)(30)(0.79) + 1/3 [(250)(30)(0.79)]
MC sto = 6,715 Btu/°F

2) UA sto:
UA sto = (1.5)(400) + (0.3)(500)
UA sto = 750 Btuh/°F

3) UA day/UA night:
Constant losses (slab edge) = 5040 Btuh
internal gains = 2000 Btuh
converted values (Btuh to Btuh/°F)
day = (5040 - 2000)/28.8° = 105.6 Btuh/°F
night = (5040 - 2000)/34.4° = 88.4 Btuh/°F
Exposed surface & infiltration losses:
day = 544.5 Btuh/°F
night = 335.7 Btuh/°F
UA day = 105.6 + 594.5 = 700.1 Btuh/°F
UA night = 88.4 = 335.7 = 424.1 Btuh/°F

4) Ihour
same as Parameter 1 - 41% glass

Time		Ihour
a.m.	p.m.	
8	4	21,538
9	3	44,525
10	2	57,024
11	1	68,816
	12	69,175

SSF CALCULATIONS & SUMMARY

SSF = 1 - (auxiliary heat/heat loss)
where auxiliary heat is taken from PEGFIX output and heat loss is determined using hourly heat loss values from Appendix A.

Study	Auxiliary	Heat loss including glazing losses	SSF	Heat loss excluding glazing losses	SSF
Par. 1 - 41% glass	19,610	377,652	0.95	228,525	0.91
Par. 1 - 35% glass	47,470	361,140	0.87	232,482	0.80
Par. 1 - 29% glass	81,068	342,843	0.76	236,358	0.66
Parameter 2	141,520	511,062	0.72	228,525	0.40
Parameter 3	73,447	292,680	0.75	219,624	0.67
Par. 4 - floor	42,460	377,652	0.89	228,525	0.81
Par. 4 - floor & b.walls	23,272	377,652	0.94	228,525	0.90
Par. 5 - normal	26,468	377,652	0.93	228,525	0.89
Par. 5 - 15°	25,295	377,652	0.93	228,525	0.89
Par. 5 - 30°	21,954	377,652	0.94	228,525	0.90
Above ground	61,660	400,176	0.85	251,106	0.75

C-3

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	675.6	Ag	0	hour	value	hour	value
UAnight	373.0	Sday	0	8	21,538	1	68,816
MCsto	15,424	Lday	9.0	9	44,525	2	57,024
UA sto	1,662	T avg	32.7°	10	57,024	3	44,525
f sto	0.81	T swing	15.4°	11	68,816	4	21,538
f air	0.07	Tmin	65°	12	69,175		
Tsto	79°	Tmax	80°				
		T vent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Q aux	Q ex	Hour	Tair	Tsto	Q aux	Q ex
1	69.3	78.0			13	70.1	82.1		
2	68.4	77.0			14	71.9	84.2		
3	67.6	76.1			15	73.1	85.6		
4	66.9	75.1			16	73.5	86.0		
5	66.3	74.2			17	73.0	85.2		
6	65.8	73.4			18	76.7	84.3		
7	65.3	72.5			19	75.8	83.5		
8	65.0	72.3	9,480		20	74.8	82.6		
9	65.0	73.2	7,060		21	73.7	81.7		
10	65.0	74.9	3,070		22	72.6	80.7		
11	65.8	77.1			23	71.5	79.8		
12	67.9	79.6			24	70.5	78.8		

DAILY TOTALS	
Tair	
ΔTsto	-0.2
Qloss	
Qex	
Qaux	19,610
Qloss max	
CFM max	
Q aux max	9,480

NOTES:

PARAMETER 1 STUDY. (41% GLASS)
R-4 NIGHT INSULATION
15° SLOPED ROOF
MAXIMUM THERMAL MASS
45° WING WALLS

PROJECT: ____________________ TRIAL #: By:

LOCATION: ____________________ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
				hour	value	hour	value
UAday	628.0	Ag	0	8	18,461	1	58,985
UAnight	384.6	Sday	0	9	38,164	2	48,878
MCsto	14,428	Lday	9.0	10	48,878	3	38,164
UA sto	1514.4	T avg	32.7	11	58,985	4	18,461
f sto	0.81	T swing	15.4	12	59,293		
f air	0.07	T min	65°				
T sto	76°	T max	80°				
		T vent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Q aux	Q ex	Hour	Tair	Tsto	Q aux	Q ex
1	65.9	75.0			13	68.2	79.6		
2	65.0	74.0			14	69.8	81.5		
3	65.0	73.1	1,490		15	70.9	82.7		
4	65.0	72.3	2,710		16	71.3	83.1		
5	65.0	71.6	3,630		17	70.8	82.4		
6	65.0	70.9	4,270		18	73.6	81.5		
7	65.0	70.3	4,680		19	72.6	80.6		
8	65.0	70.3	12,500		20	71.6	79.7		
9	65.0	71.3	10,000		21	70.5	78.8		
10	65.0	73.0	6,290		22	69.4	77.9		
11	65.0	75.1	1,900		23	68.3	76.9		
12	66.2	77.3			24	67.2	75.9		

DAILY TOTALS	
Tair	
ΔTsto	-0.1
Qloss	
Qex	
Qaux	47,410
Qloss max	
CFM max	
Qaux max	12,500

NOTES:

PARAMETER 1 STUDY - (35% GLASS)

PROJECT: ______ TRIAL #: By:

LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	580.9	Ag	0	hour	value	hour	value
UAnight	372.8	Sday	0	8	15,384	1	49154
MCsto	13,290	Lday	9.0	9	31,804	2	40,731
UA sto	1356	T avg	37.7°	10	40,731	3	31,804
f sto	0.81	T swing	15.4°	11	49,154	4	15,384
f air	0.07	Tmin	65°	12	49,411		
Tsto	73°	Tmax	80°				
		T vent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Q aux	Q ex	Hour	Tair	Tsto	Qaux	Q ex
1	65.0	72.2	3,570		13	66.5	77.6		
2	65.0	71.5	4,830		14	68.0	79.2		
3	65.0	70.9	5,820		15	69.0	80.4		
4	65.0	70.3	6,540		16	69.3	80.6		
5	65.0	69.8	7,020		17	68.7	79.9		
6	65.0	69.3	7,270		18	71.1	79.1		
7	65.0	68.9	7,340		19	70.1	78.2		
8	65.0	69.0	13,700		20	69.1	77.3		
9	65.0	70.0	11,500		21	68.0	76.4		
10	65.0	71.6	8,150		22	66.9	75.5		
11	65.0	73.6	4,340		23	65.8	74.6		
12	65.0	75.6	481		24	65.0	73.6	507	

DAILY TOTALS	
Tair	
ΔTsto	+ 0.6
Qloss	
Qex	
Qaux	81,068
Qloss max	
CFM max	
Q aux max	13,700

NOTES:

PARAMETER 1 STUDY - (29% GLASS)

PROJECT:	TRIAL #: By:
LOCATION:	DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
				hour	value	hour	value
UAday	675	Ag	0	8	21,538	1	68,816
UAnight	651.7	Sday	0	9	44,525	2	57,024
MCsto	15,424	Lday	9.0	10	57,024	3	44,525
UAsto	1,665	Tavg	32.7	11	68,816	4	21,538
f sto	0.81	T swing	15.4	12	69,175		
f air	0.07	Tmin	65				
Tsto	74	Tmax	80				
		T vent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Q aux	Q ex	Hour	Tair	Tsto	Q aux	Q ex
1	65.0	73.1	10,200		13	68.5	80.0		
2	65.0	72.3	12,100		14	70.4	82.1		
3	65.0	71.5	13,600		15	71.7	83.6		
4	65.0	70.8	14,606		16	72.2	84.1		
5	65.0	70.2	15,100		17	71.7	83.3		
6	65.0	69.7	15,400		18	70.9	82.1		
7	65.0	69.2	15,306		19	69.6	80.8		
8	65.0	69.3	15,000		20	68.2	79.5		
9	65.0	70.5	12,000		21	66.7	78.2		
10	65.0	72.5	7,480		22	65.3	76.9		
11	65.0	74.9	2,180		23	65.0	75.6	2,730	
12	66.4	77.4			24	65.0	74.6	5,830	

DAILY TOTALS	
Tair	
ΔTsto	+ 0.6
Qloss	
Qex	
Qaux	141,520
Qloss max	
CFM max	
Qaux max	15,400

NOTES:

PARAMETER 2 STUDY -
NO NIGHT INSULATION
41% GLASS

PROJECT:	TRIAL #:	By:
LOCATION:	DATE:	

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				I_{hour} (hourly radiation rate)			
UA_{day}	478.1	A_g	0	hour	value	hour	value
UA_{night}	327.5	S_{day}	0	8	12,727	1	35,904
MC_{sto}	13,036	L_{day}	9.0	9	26,639	2	31,680
UA_{sto}	1314	T_{avg}	32.7	10	31,680	3	26,639
f_{sto}	0.81	T_{swing}	15.4	11	35,904	4	12,727
f_{air}	0.07	T_{min}	65	12	35,673		
T_{sto}	72	T_{max}	80				
		T_{vent}	0	Total Daily S_{day}			

HOURLY RESULTS									
Hour	T_{air}	T_{sto}	Q_{aux}	Q_{ex}	Hour	T_{air}	T_{sto}	Q_{aux}	Q_{ex}
1	65.0	71.3	3,410		13	65.8	74.9		
2	65.0	70.7	4,530		14	67.0	76.2		
3	65.0	70.2	5,360		15	67.8	77.1		
4	65.0	69.7	5,970		16	68.1	77.4		
5	65.0	69.2	6,350		17	67.7	76.8		
6	65.0	68.8	6,550		18	69.3	76.1		
7	65.0	68.5	6,590		19	68.4	75.4		
8	65.0	68.5	11,100		20	67.5	74.6		
9	65.0	69.3	9,250		21	66.6	73.8		
10	65.0	70.6	6,610		22	65.6	73.0		
11	65.0	72.1	3,130		23	65.0	72.3	718	
12	65.0	73.5	949		24	65.0	71.6	2,270	

DAILY TOTALS	
T_{air}	
ΔT_{sto}	-0.4
Q_{loss}	
Q_{ex}	
Q_{aux}	73,447
$Q_{loss\ max}$	
CFM max	
$Q_{aux\ max}$	11,100

NOTES:

PARAMETER 3 STUDY-
FLAT ROOF (20% GLASS)
NIGHT INSULATION

PROJECT: ______ TRIAL #: By:
LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	675.6	Ag	0	hour	value	hour	value
UAnight	373.0	Sday	0	8	21,538	1	68,816
MCsto	6715	Lday	9.0	9	44,525	2	57,024
UAsto	750	Tavg	32.7	10	57,024	3	44,525
fsto	0.81	Tswing	15.4	11	68,816	4	21,538
fair	0.07	Tmin	65	12	69,175		
Tsto	89	Tmax	80				
		Tvent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Qaux	Qex	Hour	Tair	Tsto	Qaux	Qex
1	68.2	86.8			13	71.6	99.7		
2	66.5	84.7			14	74.6	104.2		
3	65.1	82.6			15	76.6	107.1		
4	65.0	80.7	1,350		16	77.2	107.7		
5	65.0	79.1	2,440		17	76.2	105.6		
6	65.0	77.6	3,240		18	80.0	102.9		3,920
7	65.0	76.2	3,790		19	80.0	100.5		1,390
8	65.0	76.3	13,600		20	79.1	98.2		
9	65.0	78.9	10,700		21	77.0	96.0		
10	65.0	83.2	6,310		22	74.8	93.7		
11	65.0	88.5	1,030		23	72.7	91.5		
12	68.1	94.2			24	70.7	89.3		

DAILY TOTALS	
Tair	
ΔTsto	+0.3
Qloss	
Qex	5,310
Qaux	42,460
Qloss max	
CFM max	
Qaux max	13,600

NOTES:

PARAMETER 4 STUDY-
6" FLOOR SLAB FOR THERMAL MASS
SLOPED ROOF (41% GLASS)
R-4 NIGHT INSULATION

PROJECT: ________ TRIAL #: By:
LOCATION: ________ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	675.6	Ag	0	hour	value	hour	value
UAnight	373.0	Sday	0	8	21,538	1	68,816
MCsto	12,064	Lday	9.0	9	44,525	2	57,024
UAsto	1287	Tavg	32.7	10	57,024	3	44,525
fsto	0.81	Tswing	15.4	11	68,816	4	21,538
fair	0.07	Tmin	65	12	69,175		
Tsto	82	Tmax	80				
		Tvent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Qaux	Qex	Hour	Tair	Tsto	Qaux	Qex
1	69.5	80.7			13	70.6	86.3		
2	68.4	79.5			14	72.7	88.9		
3	67.4	78.3			15	74.1	90.6		
4	66.5	77.1			16	74.6	91.1		
5	65.8	75.9			17	73.9	90.1		
6	65.2	74.8			18	78.6	88.9		
7	65.0	73.8	562		19	77.4	87.7		
8	65.0	73.6	10,600		20	76.1	86.6		
9	65.0	74.9	8,100		21	74.8	85.4		
10	65.0	77.1	4,010		22	73.5	84.2		
11	65.5	79.9			23	72.1	82.9		
12	68.1	83.1			24	70.8	81.7		

DAILY TOTALS	
Tair	
ΔTsto	-0.3
Qloss	
Qex	
Qaux	23,272
Qloss max	
CFM max	
Qaux max	10,600

NOTES:

PARAMETER 4 STUDY -

FLOOR & BEARING WALL FOR THERMAL STORAGE

SLOPED ROOF (41% GLASS)

NIGHT INSULATION

PROJECT: ______ TRIAL #: By:

LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	675.6	Ag	0	hour	value	hour	value
UAnight	373.0	Sday	0	8	18,993	1	65,824
MCsto	15,311	Lday	9.0	9	39,388	2	52,462
UAsto	1645	Tavg	32.7	10	52,462	3	39,388
fsto	0.81	Tswing	15.4	11	65,824	4	18,993
fair	0.07	Tmin	65	12	69,175		
Tsto	78	Tmax	80				
		Tvent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Qaux	Qex	Hour	Tair	Tsto	Qaux	Qex
1	68.4	77.0			13	69.1	80.8		
2	67.6	76.1			14	70.8	82.8		
3	66.7	75.1			15	71.9	84.0		
4	66.0	74.2			16	72.2	84.3		
5	65.4	73.3			17	71.7	83.5		
6	65.0	72.4	144		18	75.2	82.6		
7	65.0	71.7	970		19	74.3	81.8		
8	65.0	71.5	11,100		20	73.3	80.9		
9	65.0	72.3	8,810		21	72.3	80.0		
10	65.0	73.9	5,060		22	71.2	79.1		
11	65.0	75.9	384		23	70.1	78.2		
12	67.0	78.4			24	69.1	77.3		

DAILY TOTALS	
Tair	
ΔTsto	-0.7
Qloss	
Qex	
Qaux	26,468
Qloss max	
CFM max	
Qaux max	11,100

NOTES:

PARAMETER 5 STUDY -
WING WALLS NORMAL TO FACADE
SLOPED ROOF (41% GLASS)
NIGHT INSULATION
MAXIMUM THERMAL MASS

PROJECT: ______ TRIAL #: By:
LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
				hour	value	hour	value
UAday	675.6	Ag	0	8	19,825	1	68,816
UAnight	373.0	Sday	0	9	41,100	2	54,743
MCsto	15374	Lday	9.0	10	54,743	3	41,100
UAsto	1655	Tavg	32.7	11	68,816	4	19,825
fsto	0.81	Tswing	15.4	12	69,175		
fair	0.07	Tmin	65				
Tsto	80	Tmax	80				
		Tvent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Qaux	Qex	Hour	Tair	Tsto	Qaux	Qex
1	68.5	77.0			13	69.4	81.2		
2	67.6	76.1			14	71.2	83.3		
3	66.8	75.1			15	72.4	84.6		
4	66.1	74.2			16	72.7	84.9		
5	65.5	73.3			17	72.2	84.1		
6	65.0	72.5	384		18	75.8	83.2		
7	65.0	71.7	877		19	74.9	82.4		
8	65.0	71.5	11,000		20	73.9	81.5		
9	65.0	72.4	8,610		21	72.8	80.6		
10	65.0	74.0	4,120		22	71.7	79.7		
11	65.1	76.2			23	70.7	78.8		
12	67.3	78.7			24	69.6	77.9		

DAILY TOTALS	
Tair	
ΔTsto	-0.1
Qloss	
Qex	
Qaux	25,245.4
Qloss max	
CFM max	
Qaux max	11,000

NOTES:

PARAMETER 5 STUDY-
WING WALLS 15° FROM NORMAL
SLOPED ROOF (41% GLASS)
NIGHT INSULATION
MAXIMUM THERMAL MASS

PROJECT: ______ TRIAL #: By:
LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	675.6	Ag	0	hour	value	hour	value
UAnight	373.0	Sday	0	8	20,657	1	68,816
MCsto	15,424	Lday	9.0	9	42,813	2	57,024
UA sto	1,662	T avg	72.1	10	57,024	3	42,813
f sto	0.81	T swing	15.4	11	68,816	4	20,657
f air	0.07	T min	65	12	69,175		
Tsto	78.5	T max	80				
		T vent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Q aux	Q ex	Hour	Tair	Tsto	Q aux	Q ex
1	68.9	77.5			13	69.8	81.7		
2	68.0	76.6			14	71.6	83.8		
3	67.2	75.6			15	72.8	85.2		
4	66.5	74.7			16	73.2	85.5		
5	65.9	73.8			17	77.7	84.7		
6	65.4	72.9			18	76.3	83.9		
7	65.0	72.1	64.2		19	75.4	83.0		
8	65.0	71.9	10,200		20	74.4	82.1		
9	65.0	72.8	7,840		21	73.3	81.2		
10	65.0	74.5	3,850		22	72.3	80.3		
11	65.4	76.7			23	71.2	79.4		
12	67.6	79.2			24	70.1	78.4		

DAILY TOTALS	
Tair	
ΔTsto	-0.1
Qloss	
Qex	
Qaux	21,954.2
Qloss max	
CFM max	
Q aux max	10,200

NOTES:

PARAMETER 5 STUDY-
WING WALLS 30° FROM NORMAL
SLOPED ROOF (41% GLASS)
NIGHT INSULATION
MAXIMUM THERMAL MASS

PROJECT: ______ TRIAL #: By:

LOCATION: ______ DATE:

PEGFIX PEGFLOAT User Worksheet

INPUT VALUES				Ihour (hourly radiation rate)			
UAday	700.1	Ag	0	hour	value	hour	value
UAnight	424.1	Sday	0	8	21,538	1	68,816
MCsto	6715	Lday	9.0	9	44,525	2	57,024
UAsto	750	Tavg	32.7	10	57,024	3	44,525
fsto	0.81	Tswing	15.4	11	68,816	4	21,538
fair	0.07	Tmin	65	12	69,175		
Tsto	88	Tmax	80				
		Tvent	0	Total Daily Sday			

HOURLY RESULTS									
Hour	Tair	Tsto	Qaux	Qex	Hour	Tair	Tsto	Qaux	Qex
1	65.7	85.6			13	70.9	99.2		
2	65.0	83.5	1,150		14	73.8	103.7		
3	65.0	81.5	2,840		15	75.7	106.6		
4	65.0	79.8	4,150		16	76.3	107.1		
5	65.0	78.2	5,110		17	75.2	105.0		
6	65.0	76.8	5,780		18	80.0	102.3		1,340
7	65.0	75.6	6,180		19	79.0	99.9		
8	65.0	75.7	14,900		20	76.8	97.4		
9	65.0	78.3	12,000		21	74.6	95.0		
10	65.0	82.7	7,460		22	72.4	92.6		
11	65.0	88.0	2,090		23	70.2	90.2		
12	67.3	93.7			24	68.1	87.9		

DAILY TOTALS	
Tair	
ΔTsto	- 0.1
Qloss	
Qex	1,340
Qaux	61,660
Qloss max	
CFM max	
Qaux max	10,200

NOTES:

ABOVE GROUND HOUSE (41% GLASS)
NIGHT INSULATION
SLOPED ROOF
EXPOSED 6" FLOOR SLAB

PROJECT: ______ TRIAL #: By:

LOCATION: ______ DATE:

VITA

Rekki Lynn Helms

Candidate for the Degree of

Master of Architectural Engineering

Thesis: PASSIVE SOLAR CONTRIBUTION TO EARTH SHELTER PERFORMANCE

Major Field: Architectural Engineering

Biographical:

Personal Data: Born in Lawton, Oklahoma, November 18, 1955, the son of Mr. and Mrs. Eugene E. Helms.

Education: Graduated from Lawton High School, Lawton, Oklahoma, in May, 1974; attended Cameron State University in 1974-76; received the Bachelor of Science in Architectural Studies degree from Oklahoma State University in July, 1979; completed requirements for the degree of Master of Architectural Engineering at Oklahoma State University in July, 1981.

Professional Experience: Graduate Teaching Assistant, Oklahoma State University, January, 1981, to May, 1981; Graduate Research Assistant, May, 1980, to December, 1980; Graduate Teaching Assistant, August, 1979, to May, 1980.

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