ENERGY ANALYSIS OF EARTH SHELTERED DWELLINGS

By

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1978

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, 1980

ENERGY ANALYSIS OF EARTH

SHELTERED DWELLINGS

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PREFACE

This study is concerned with the analysis of energy consumption in earth sheltered dwellings. The primary goal is to quantify the energy usage of six selected earth sheltered residences in Oklahoma. The process of examination includes presentation of actual metered energy consumption and predicted energy usage, which are compared, as well as comparisons of design space conditioning loads to estimated actual loads. Methodologies currently accepted are adapted to derive predictive heating and cooling loads for the earth covered dwellings.

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 in formulating and organizing this study. Appreciation is also expressed to Walter T. Grondzik, Assistant Professor of Architecture, for his assistance in this study. A note of thanks is given to all those associated with the Presidential Challenge Grant Project who organized and conducted the data collection used in this study.

Gratitude is expressed to Charles and Marge Bice for their support over the last three years. Finally, special appreciation is extended to my wife, Gayle, for typing the early draft of this manuscript, and for her encouragement and many sacrifices.

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CHAPTER I

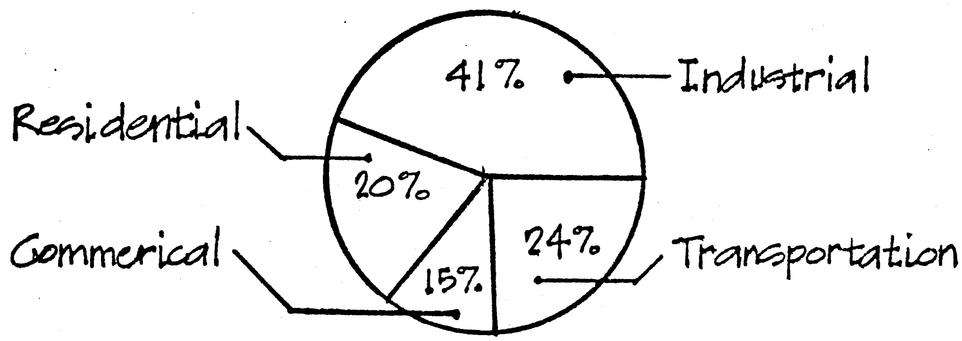
INTRODUCTION

The Energy Picture

The energy waste that developed in the early twentieth century, primarily in industrial societies, grew out of a seemingly endless supply of fossil fuels. Because deposits were large and inexpensive to obtain, production energy developed at such a rapid pace that all areas of human activity became affected. The period produced architecture which reflected this abundance of energy supplies. Mechanical systems capable of providing comfort inside spaces in any ambient conditions revolutionized building design. Architectural design had little regard for the performance of buildings with respect to the effects that location, climate, orientation, and physical site characteristics had on energy usage.

In recent years, as petroleum consumption has increased beyond production, the world has realized that the supply of petroleum resources is finite, and that the need for conservation is great. All sectors of society have been affected and severe economic setbacks have occurred because of a refusal to acknowledge the existence of an "energy crisis."

How is energy used in the United States? The percentage of energy consumed by each major use sector is shown in Figure 1. The commercial and residential sectors together comprise 35 percent of the total energy consumed. Building design can alter this percentage significantly.



Source: Energy Conservation in the Home, Department of Energy, EDM-1028, 1977, p. 253.

Figure 1. Total Energy Consumption by Major Use Sectors

Considering the residential sector alone, 70 percent of the energy expended goes toward space conditioning.[1] Although this percentage varies slightly from source to source, it clearly remains the largest component of energy consumption in residential applications, and accounts for almost 16 percent of the total raw energy used in the United States.[2]

The most recent federal energy program, the National Energy Plan II (NEP-II) estimates that an average residence will use 130 million BTUS per year costing the homeowner up to $1,000 a year.[3] The government energy plan advocates energy conservation, hoping that this will provide valuable time to develop new technologies, new energy sources, and new energy facilities. But as Dr. Charles Fairhurst at the University of Minnesota suggests:

> Experience to date suggests that we are unlikely to reach goals indicated. In some cases, the technology will not become available in time; in others the overall environmental cost of a particular technology may be considered too high a price to pay for the energy supply benefits of the technology. Certainly we must thoroughly explore the obvious complement to the development of new resources, i.e., finding ways to reduce energy consumption and conserve the reserves no available.[4]

An Alternative: Earth Sheltered Housing

Using underground space for human habitat is as old as mankind itself, dating back to prehistoric use of caves for protection from climate extremes. Underground space has continued to be used in contemporary time periods mostly for storage and specialized industrial processes. Now as energy conservation becomes a design priority, viable solutions for residential applications have emerged using earth sheltered concepts. As one source relates:

> It is inevitable that the search for architectural forms which respond to natural phenomena will lead us back to a reconsideration of the design techniques which characterized the historical periods preceding the industrial era; those which respond to sun and wind, heat and cold, and the natural features of the earth itself. Among these reconsiderations is the use of the earth's tempering qualities to dampen the effects of seasonal variations in air temperature.[5]

Those who advocate earth covered dwellings generally support the preservation of the natural environment as well. Perhaps the most adamant proponent of underground construction is architect Malcolm Wells. Almost twenty years ago, long before the energy problems surfaced, he voiced "that there just isn't any building as beautiful, or as appropriate, or as important, as the bit of forest it replaces."[6]

Viewed as a radical statement by most architects in that time period, the claims he made began to make more sense by 1974. He maintained then that "really great architecture remains, as it began, an earth art; an expression, fashioned in the earth's own materials . . ."[7] Although this back-to-nature theme made sense, few structures were built to conserve the natural environment. Wells contends "the idea of an underground architecture for the purpose of conservation isn't old. It is so new that after ten years of searching I have yet to find more than one or two examples of it."[8]

The aim of most subsurface designs prior to 1973, resulted from other nature-oriented reasons and not conservation. In midwestern states, Oklahoma included, residences in rural settings were built underground for weather protection from windstorms and tornadoes. Architect Ken Labs states this aspect "taken together with the argument for climatic efficiency (energy conservation) as well as nature conservation, . . . may restore the view of the subsurface as the 'natural' way to build."[9]

Energy Conservation Potential

"There is now no doubt that earth-sheltered buildings require less energy than equivalent conventional structures."[10]

This statement identifies the prime motive force behind the boom in earth sheltering. A recent Oklahoma State University study of current earth sheltered residence owners in Oklahoma singled out the desire for reduced heating and cooling requirements as the number one reason for building an earth covered home.[11]

The expected energy savings are due to the climate dampening effect of the soil mass covering the structures. The earth smooths the diurnal and seasonal temperature fluctuations. At depths below 8 inches, the wide diurnal surface temperature variance is negligible, which proves the advantageous effect of a sod roof.[12] The soil temperatures at greater depths respond to seasonal changes after a time lag. Heat from the summer sun reaches the underground space in the fall months whereas the cool winter temperatures are delayed until the early summer months. The NEP-II concludes that:

> If best current practices were used, the average new building could be heated and cooled with up to 50 percent less energy than existing buildings. Use of emerging technologies could boost that figure to as high as 60 to 70 percent.[13]

According to architect Frank Moreland, of Fort Worth, Texas, analysis suggests that reductions of 70 percent in heating and cooling loads for earth covered dwellings are possible.[14] This concept of substantial savings in energy consumption is held by many proponents of earth sheltered housing, but technical data supporting this claim remains scarce. Dr. Thomas Bligh at MIT says "a preliminary search indicated data little better than that available to Neanderthal man."[15] Without actual performance background, some owners and builders are mislead on the amount of energy savings that they can achieve with earth integrated construction.[16]

Future of Earth Sheltered Housing

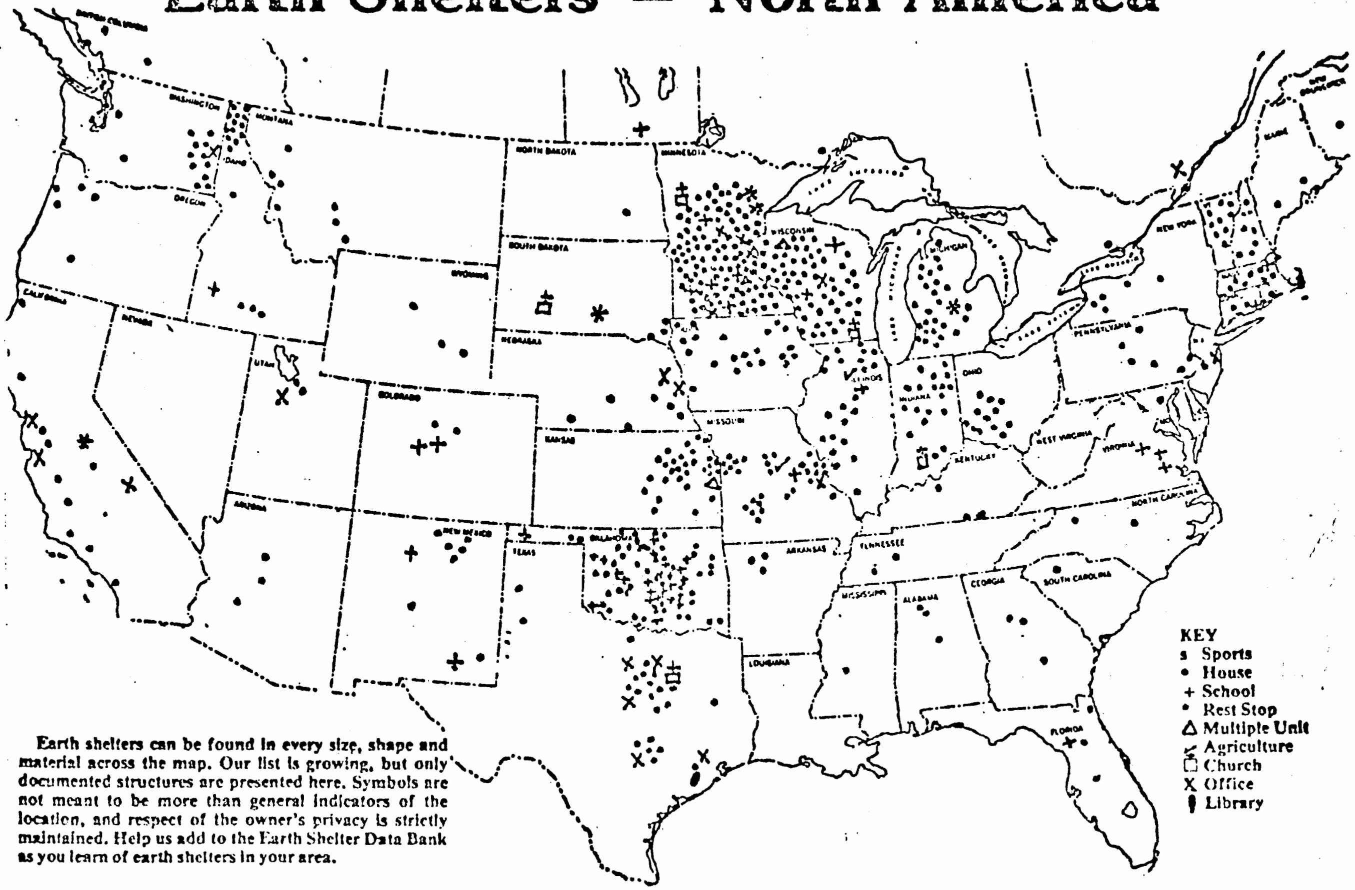
The aim of the earth sheltered housing alternative, as with any good architectural solution, is a living and working environment responding to the human need. It is an architectural solution that can provide a quality habitat, while at the same time preserving and conserving the natural environment which it addresses. It is an architectural solution that can work in concert with nature, the sun, and the seasonal changes, and in the process conserve the energy required to maintain human comfort.

> History reveals the subsurface alternative to be a time-honored response to climatic variation for the purpose of human comfort. With our current and often conflicting interests in meeting energy needs while maintaining environmental quality, it will serve us well to consider the heritage of underground development; it promises us a future of great potential.[17]

A recently published map locating approximately 450 earth sheltered projects is presented in Figure 2. The map identifies different building occupancy types with residences being in the clear majority. The two major regions of earth covered construction are easily recognized as the states of Minnesota, Wisconsin, and Oklahoma.

Large number of projects in Minnesota are a result of intense winters; those in Oklahoma are being built for year-round climate attenuation as well as storm protection. It is interesting to note that the projects indicated on the map for Oklahoma represent about half of the identified earth sheltered structures in the state as of May, 1980.

Earth Shelters — North America



Source: Earth Shelter Digest, No. 7 (Jan./Feb., 1980).

Figure 2. Map of Earth Sheltered Buildings in the Continental United States

END NOTES

[1]Thomas P. Bligh, "Energy Conservation by Building Underground," Underground Space, May/June, 1976, Vol. 1, No. 1, p. 22.

[2]Ibid.

[3]National Energy Plan II, A Report to the Congress Required by Title VIII of the Department of Energy Organization Act (Public Law 95-91) U.S. Department of Energy, May, 1979.

[4]Charles Fairhurst, "Energy, Conservation, and the Underground," (Editor's introduction), Underground Space, July/August, 1976. Vol. 1, No. 2, p. iii.

[5]David Bennett and Thomas P. Bligh, "The Energy Factor--A Dimension of Design," Underground Space, August, 1977, Vol. 1, No. 4, p. 325.

[6]Malcolm B. Wells, "Nowhere to Go But Down," Progressive Architecture, February, 1965, Vol. 46, No. 2, p. 175.

[7]Malcolm B. Wells, "Environmental Impact," Progressive Architecture, June, 1974, Vol. 55, No. 6, p. 60.

[8]Ibid.

[9]Kenneth Labs, "The Use of Earth Covered Buildings Through History," Alternatives in Energy Conservation: The Use of Earth Covered Buildings, F. L. Moreland (Ed.), University of Texas at Arlington, July, 1975, p. 10.

[10]Fairhurst, p. v.

[11]M. J. Weber, L. L. Boyer, and W. T. Grondzik, "Implications for Habitability Design and Energy Savings in Earth Sheltered Housing," Proceedings Earth Sheltered Building Design Innovations Conference, L. L. Boyer (Ed.), Oklahoma State University, Stillwater, April, 1980, p. vi-22.

[12]Bligh, 1976, p. 23.

[13]National Energy Plan II, p. 66.

[14]Frank Moreland, "Mildly Technical Considerations of Earth Covered Buildings: Appendix III," Alternatives in Energy Conservation: The Use of Earth Covered Buildings, F. L. Moreland (Ed.), University of Texas at Arlington, July, 1975, p. 197.

[15]Thomas P. Bligh and Richard Hamburger, "Conservation of Energy by Use of Underground Space," Legal, Economic, and Energy Considerations in the Use of Underground Space, National Academy of Engineering Report No. NSF/RA/S/4-002, 1973, p. 113.

[16]L. L. Boyer, W. T. Grondzik, and M. J. Weber, "Passive Energy Design and Habitability Aspects of Earth Sheltered Housing In Oklahoma," Proceedings of 2nd Annual Operational Results Conference on Solar Heating and Cooling Systems, Solar Energy Research Institute, Colorado Springs, November, 1979.

[17]Labs, p. 14.

CHAPTER II

PROBLEM STATEMENT

Goals of Study

This study will address the topic of energy consumption in earth covered buildings with an emphasis on quantifying the energy conservation potential. Actual energy performance data from selected existing earth sheltered residences in the state of Oklahoma will be presented and analyzed. In addition, comparisons of actual and predicted energy consumption with "energy conserving" above grade residences will provide a more accurate and realistic forecast of the energy conservation capabilities of earth sheltered housing.

Purpose of Study

As pointed out by Bligh in his paper "Conservation of Energy by Use of Underground Space,"[1] the data base of technical support for earth sheltered residences is limited. While the need for energy conservation escalates as energy costs soar, it is surprising to find that the great energy saving potential offered by many supporters of earth sheltered housing has been quantified by so few. The lack of documentation can be attributed to several reasons including the vernacular nature of most earth covered dwellings, the rapid growth of the earth sheltering movement, the complexity of current earth sheltered heat transfer analysis methods, and the disinterest of the government with respect to earth sheltered housing. In order to facilitate positive acceptance and implementation of this viable energy conserving building type, actual performance must be identifiable and predictable beyond the scope of rough estimates. Earth sheltered housing is especially of interest in Oklahoma where it not only provides storm protection and reduces heating requirements, but reduces an equally large requirement for cooling. This study is generated by the need to know more about this potential energy saver with use of documented performance, and the need for development of a simpler mathematical analysis method which gives an accurate energy consumption estimate.

Specific Objectives for Study

The specific objectives of this study attempt to quantify the energy design effectiveness of selected earth sheltered dwellings in Oklahoma using several methods of evaluation. The objectives are as follows:

1. Present the total energy consumption from metered billings for six dwellings.
2. Calculate specific space heating and cooling loads for the above dwellings using accepted methodologies adapted for this study. In addition, the appliance and domestic hot water loads will be estimated.
3. Determine the energy performance levels as specified in recently published energy standards for buildings.
4. Compare the actual metered energy usage with the calculated energy usage and then with published energy performance standards for contemporary buildings as presented above.

Limitations of Study

The most obvious limitation of this study is the sample size of six residences. Six sites were chosen in order that each case would be identifiable throughout the study. In addition, this small number of residences kept the study from becoming unworkable from the inclusion of all the extensive hand calculations. Although only six cases will be considered, the sample size still allows for multiple comparisons of actual and calculated energy consumption. No attempt is made to identify where the actual energy flows occur in each structure, but rather to present the total heating and cooling energy usage for each case. In order to identify the energy transfer modes, specific on-site monitoring would be required which is costly and beyond the resources of this study. Because of this lack of specific on-site data, many assumptions are made so that calculations can be performed. In the event that monitoring activities are initiated, the results of this study and the application of the calculation methods presented may be validated more conclusively. The lifestyle and habitability parameters of earth sheltered housing will not be specifically addressed in this study, but each is recognized as being of equal importance to the energy performance characteristics with respect to the acceptance of this mode of habitat.[2]

One limitation of the heating season calculations is the failure of the methodology used to assess solar contributions that reduce the heating load. A major limitation of the comparisons presented is the failure of current thermal comfort indicators to recognize the positive radiant wall effects of earth sheltered housing. Without a more sensitive comfort index, the comparisons with above grade construction standards can give misleading results as occupant comfort directly affects energy consumption.

END NOTES

[1]Thomas P. Bligh and Richard Hamburger, "Conservation of Energy by Use of Underground Space," Legal, Economic, and Energy Considerations in the Use of Underground Space, National Academy of Engineering Report No. NSF/RA/S74-002, 1973, p. 113.

[2]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, Oklahoma State University, Stillwater, March, 1980.

CHAPTER III

DESCRIPTION OF SAMPLES

Types of Underground Construction

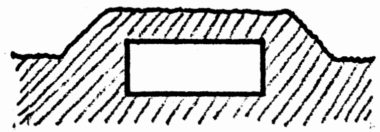
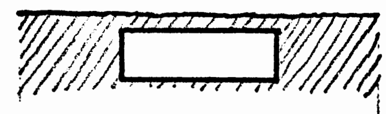
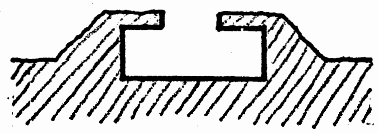
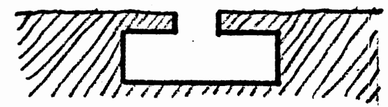
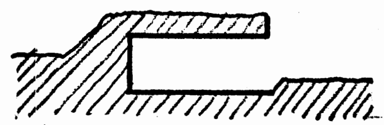
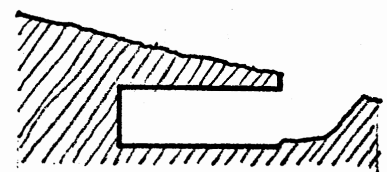
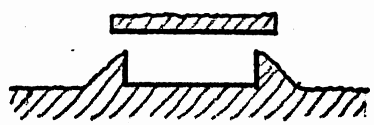
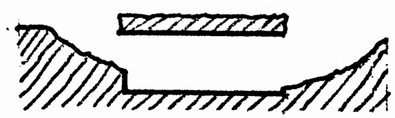
Table I presents a general overview of building types of earth sheltered construction. In lieu of including complete elevational drawings of exposed facades, building sections for each site, or photographs, the descriptions of each building type described in Table I will be used where applicable for each case. The building type generally used in Oklahoma is the elevational which adapts to the hilly topography of Oklahoma well, allows for substantial earth cover over and around the majority of the structure, and maintains good views to the outside.

Data Collection

The data assembled for each dwelling to be studied was gathered in a study of earth sheltered housing in Oklahoma funded as a Presidential Challenge Grant Project at Oklahoma State University. The project was conducted by the School of Architecture and the Department of Housing Design and Consumer Resources.[1, 2] The data collection process utilized an extensive survey questionnaire which was mailed to occupants of existing earth sheltered residences in the state of Oklahoma. The seventeen-page questionnaire asked respondents to consider aspects of their earth sheltered dwelling including size, cost of construction, materials of construction, passive energy design, mechanical systems, floor plan

TABLE I

UNDERGROUND CONSTRUCTION BUILDING TYPES

Type	Bermed New Earth Level Raised Above Existing Grade	Chamber Building Excavated Beneath Existing Grade
1. "TRUE UNDERGROUND" internally similar to deep space by its isolation		
2. ATRIUM or COUNTRYARD used for entry, for light and air, for outdoor rooms		
3. ELEVATION windows, doors, out-side courts to accomodate slopes		
4. SIDE WALL PENETRATIONS, for light, air, access, view, expansion poten-tial		

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

layout, maintenance, habitability factors, lifestyle parameters, and energy performance indications and documentation.

Method of Selection

The six residences chosen represent approximately fifteen percent of the currently identified earth sheltered dwellings in Oklahoma for which data have been collected and which have been occupied for a year or longer. The six houses are all located in the Central and South Central regions of the state as shown in Figure 3. The dwellings were not chosen because of unusual or outstanding energy performance, but were selected on the basis of three criteria: 1) availability of a detailed record of energy consumption for a one year cycle, 2) no on-site utilization of complex interactive energy systems, and 3) the accessibility of technical construction and design data for each structure.

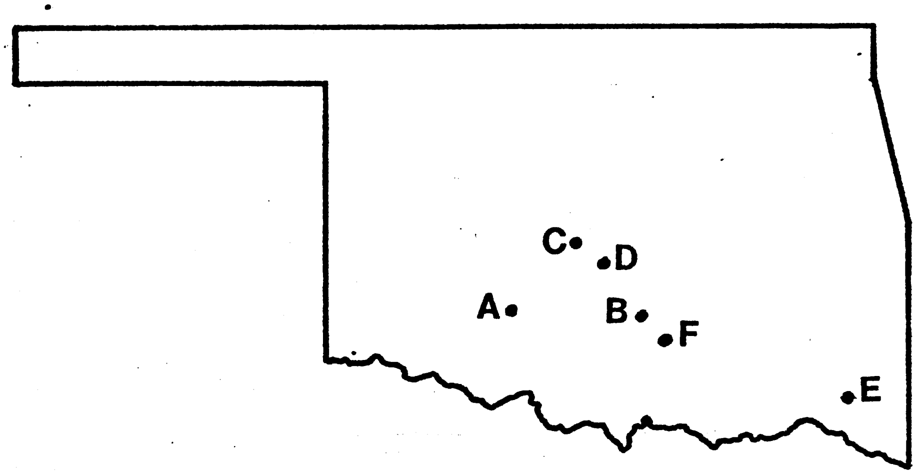


Figure 3. Site Location of Samples in Oklahoma

Originally, the sample selection included other criteria, but due to size constraints of the sampling frame, they were abondoned. These other considerations were building orientation, extent of insulation, and use of thermal mass in the structure.

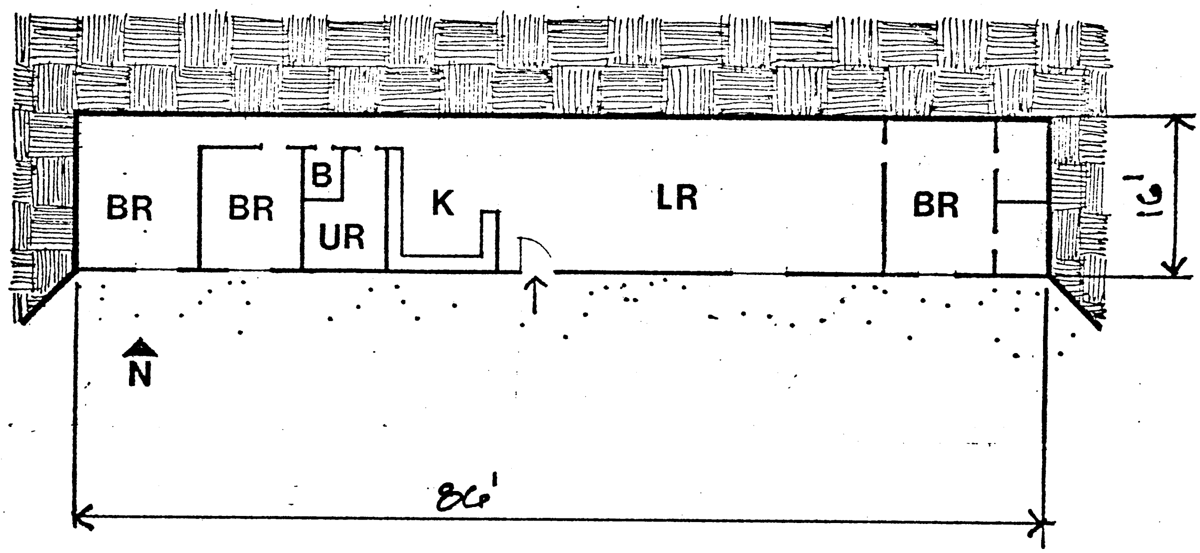
Building Floor Plans

The schematic floor plans for each dwelling are presented in Figures 4 through 9. In order to maintain occupant confidentiality, the sites will be identified as sites A through F and will be associated with their respective county locations. The assortment of construction types is typical of Oklahoma earth sheltered residences in general, and all are recent installations.

Technical Data for Each Site

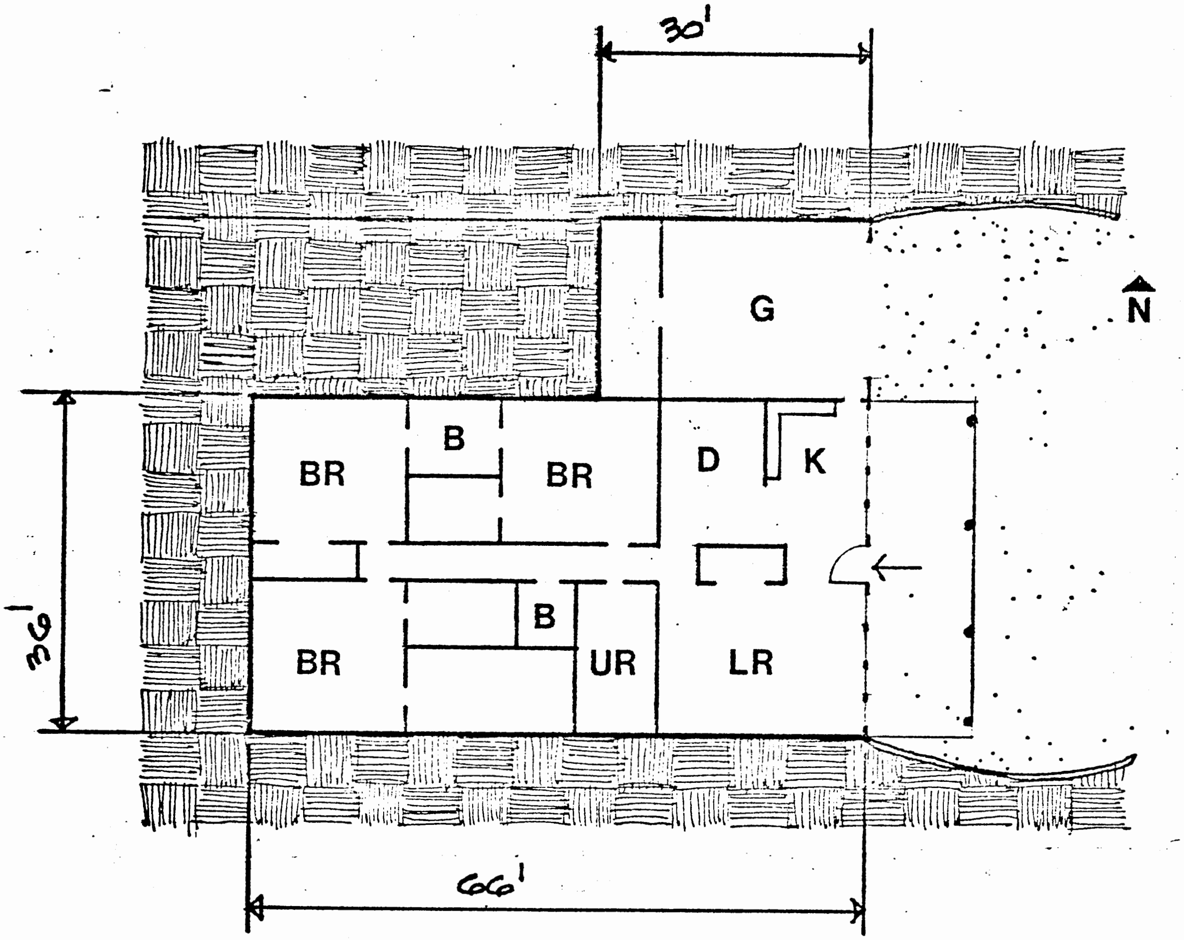
General background information for each sample dwelling is compiled and presented in Table II. The building floor areas shown represent gross conditioned living floor area. For sites B, D, and F, the gross floor area shown does not include the garage. Sites A, C, and E do not have Garages. Table III summarizes data concerning the extent and depth of earth cover for each residence as well as building orientation. All six sites can be considered as substantially earth sheltered structures.

The insulation characteristics of each residence are presented in Tables IV and V, as compiled from questionnaire data. Examination of Table IV points out the general deliberate ommission of insulation at earth backed walls, and the absence of roof insulation for sites B and F. All six sites indicate uninsulated floor slabs which from field



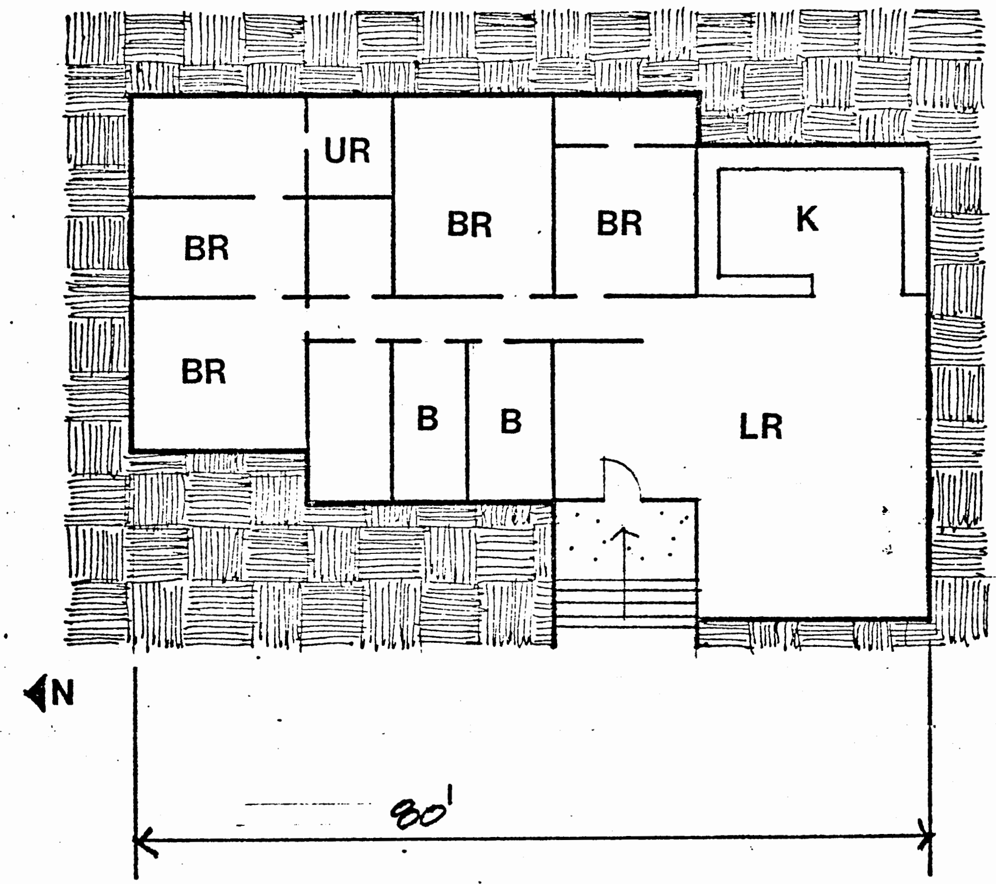
Designed by Owner
Floor Area--1370 sq ft
Wall Construction--Poured Concrete
Roof Construction--Poured Concrete
Building Type--Chamber Elevational

Figure 4. Floor Plan of Site A Located in Comanche County.



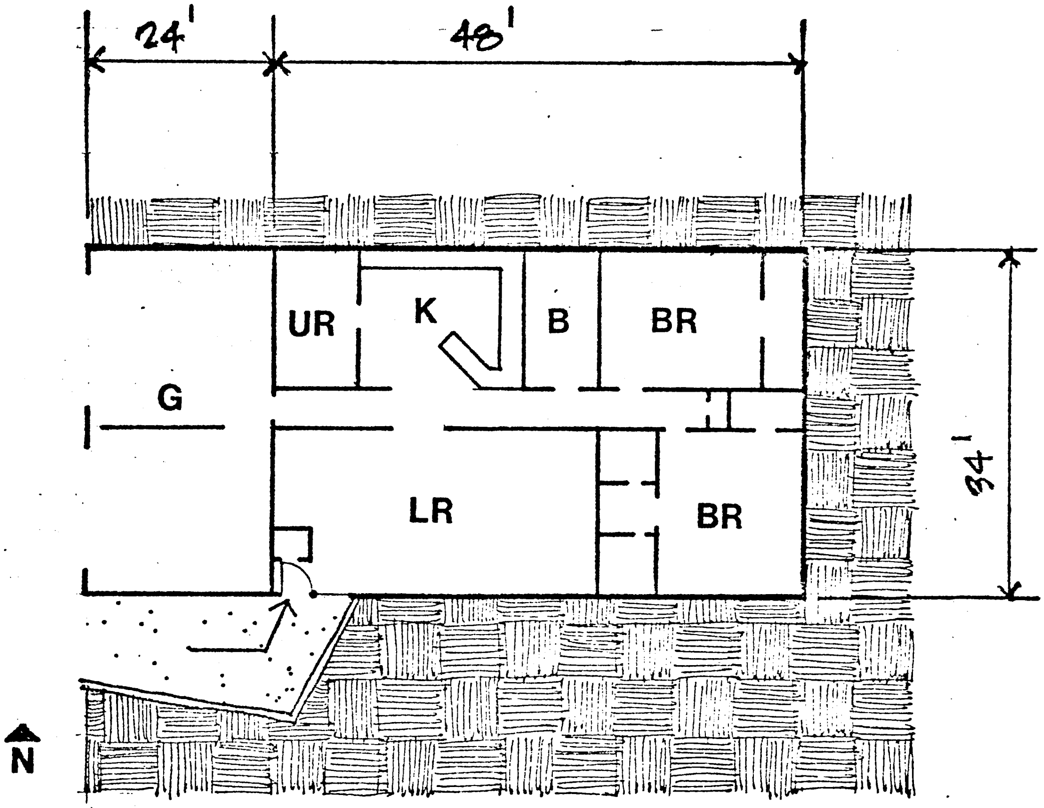
Designed by Owner
Floor Area--2800 sq ft
Wall Construction--Concrete Block
Roof Construction--Poured Concrete
Building Type--Chamber Elevational

Figure 5. Floor Plan of Site B Located in Garvin County.



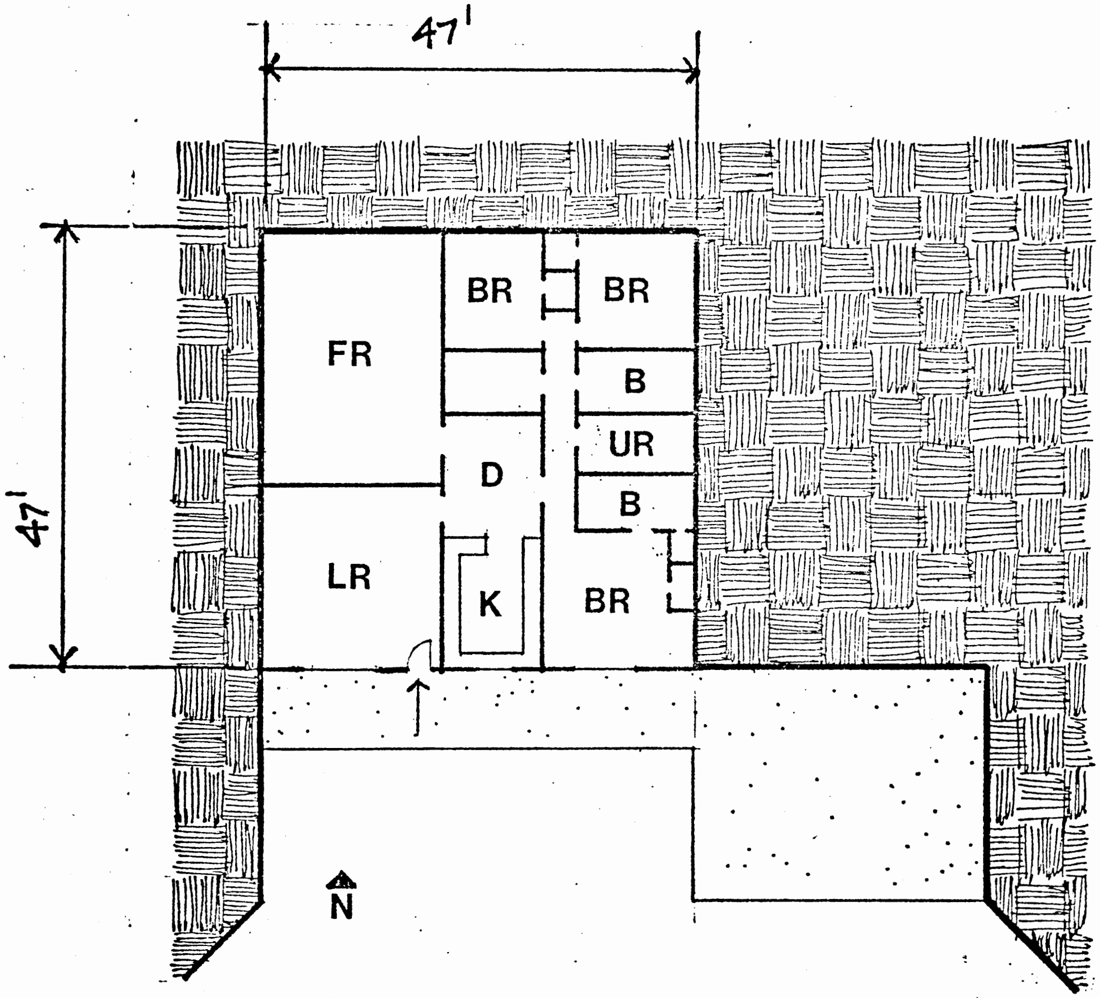
Designed by Owner
Floor Area--2700 sq ft
Wall Construction--Concrete Block
Roof Construction--Conventional Wood
Building Type--Chamber "True" Underground With
Non-Earth Roof

Figure 6. Floor Plan of Site C Located in Grady County



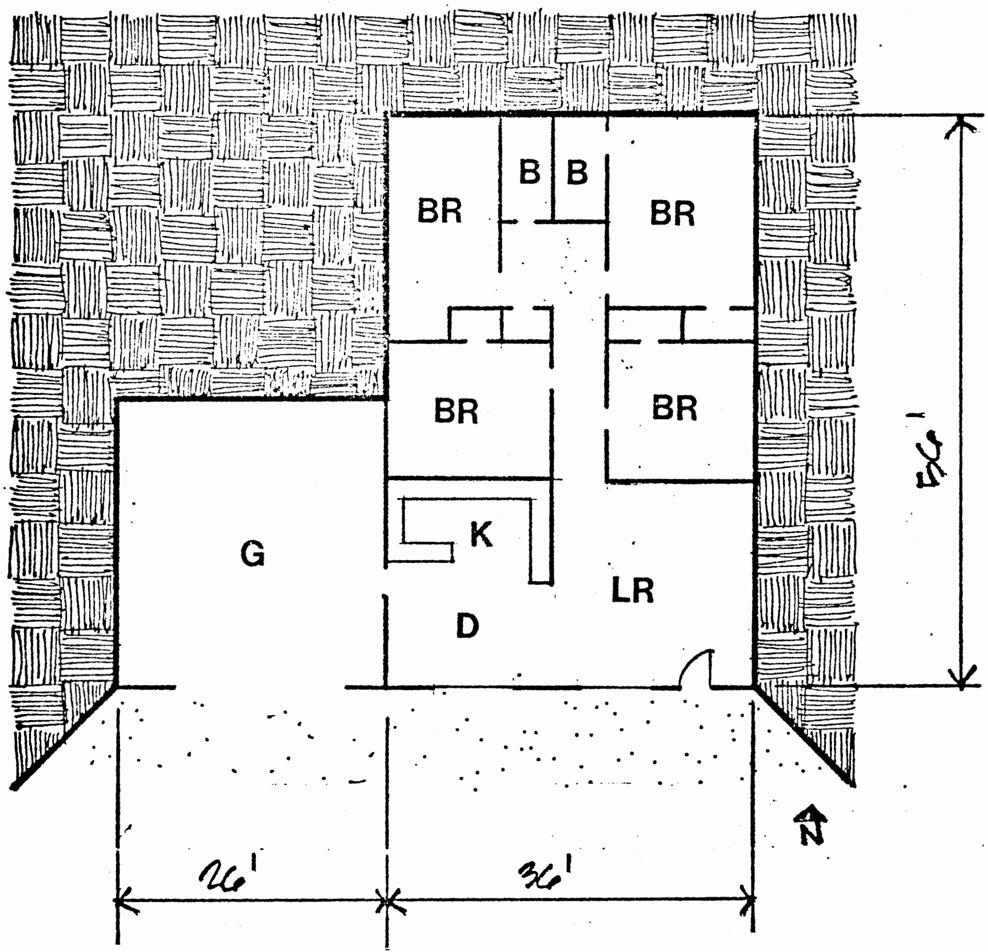
Designed by Owner, Engineer, Contractor
Floor Area--1700 sq ft
Wall Construction--Poured Concrete
Roof Construction--Bar Joist With Concrete Slab
Building Type--Bermed "True" Underground

Figure 7. Floor Plan of Site D Located in McClain County



Designed by Owner
Floor Area--2200 sq ft
Wall Construction--Poured Concrete
Building Type--Chamber Elevational

Figure 8. Floor Plan of Site E Located in McCurtain County



Designed by Owner
Floor Area--2000 sq ft
Wall Construction--Poured Concrete
Roof Construction--Bar Joist With Concrete Slab
Building Type--Chamber Elevational

Figure 9. Floor Plan of Site F Located in Murray County

TABLE II

GENERAL INFORMATION ON SAMPLE DWELLINGS

Sample	Location, County	Floor Area Sq. Ft.	Wall Construction	Roof Construction	Date Occupied	Number of Occupants
Site A	Comanche	1370	Poured Concrete	Poured Concrete	12-77	2
Site B	Garvin	2800	Concrete Block	Poured Concrete	1-78	4
Site C	Grady	2700	Concrete Block	Conventional Wood	12-77	5
Site D	McClain	1700	Poured Concrete	Bar Joist with Slab	12-77	2
Site E	McCurtain	2200	Poured Concrete	Poured Concrete	7-77	4
Site F	Murray	2000	Poured Concrete	Bar Joist with Slab	4-78	3

TABLE III

EARTH COVERING OF SAMPLE DWELLINGS

	Earth Cover - Roof		Earth Cover - Walls*							
			Front		Rear		Right		Left	
Sample	Extent	Depth	Or	Extent	Or	Extent	Or	Extent	Or	Extent
Site A	100%	1' - 10"	S	None	N	100%	E	100%	W	100%
Site B	100%	1' - 0"	E	None	W	100%	N	100%	S	100%
Site C	None Conventional Roof	0"	W	75%	E	75%	S	75%	N	75%
Site D	All Except Skylights	0' - 8"	SW	None (Garage)	NE	100%	SE	100%	NW	100%
Site E	100%	1' - 6"	S	None	N	100%	E	100%	W	100%
Site F	All Except Skylights	2' - 0"	S	None	N	100%	E	100%	W	100%

*OR: Orientation of wall; front wall is defined as major facade, right wall is with reference to exterior view of house - facing facade.

TABLE IV

INSULATION INSTALLED ON SAMPLE DWELLINGS

Sample	Insulation Details							
	Roof		Front Wall		Other Walls		Floor	
	Material	Thick	Material	Thick	Material	Thick	Material	Thick
Site A	Expanded Urethane	1½"	Expanded Urethane	1½"	Expanded Urethane	1"	None	---
Site B	None	---	Sytrofoam	1"	None	---	None	---
Site C	Polyurethane Fiberglass	1" 4"	Polyurethane (3' down)	1"	Polyurethane (3' down)	1"	None	---
Site D	Fiberglass	10"	None	---	None	---	None	---
Site E	Styrofoam	4"	Rock Wool	?	None	---	None	---
Site F	None	---	None	---	None	---	None	---

TABLE V

IMPLICIT INSULATION OF SAMPLE DWELLINGS

Sample	Construction Details		
	Ceiling System	Floor System	Earth Contact Walls: Finishes
Site A	Plaster Applied to Roof Slab	Slab on Grade	Plaster Applied Directly to Structure
Site B	Suspended Drywall Ceiling	Slab on Grade	Surface Bonding Cement
Site C	Suspended Tile Ceiling	Slab on Grade	Surface Bonding Cement
Site D	Suspended Tile Ceiling	Slab on Grade	Plaster Applied Directly to Structure
Site E	Plaster Applied to Roof Slab	Slab on Grade	Plaster and Drywall Applied Directly to Structure
Site F	Suspended Tile Ceiling	Slab on Grade	Drywall on Furring Strips

experience implies a lack of perimeter slab insulation as well. All insulation is externally applied to the structure except for the fiberglass roof insulation at sites C and D, which is internally installed.

Table V presents the interior finishes used. In most cases, a suspended ceiling is used which decouples the radiant effect of the earth covered ceiling by providing a dead air space of insulation. A majority of the samples have wall finishes that are directly applied to the structure, which maintain better thermal contact with the earth heat sink as compared to furred paneling. Slab on grade floors are used in all cases.

END NOTES

[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, Oklahoma State University, Stillwater, March, 1980.

[2]Walter T. Grondzik and Lester L. Boyer, "Performance Evaluation of Earth Sheltered Housing in Oklahoma," Proceedings of International Solar Energy Society 25th Annual Meeting, Phoenix, Arizona, June, 1980.

CHAPTER IV

METERED ENERGY CONSUMPTION

Data From Monthly Billings

The actual metered energy consumption for each residence studied was obtained from the questionnaire response. All six of the sample residences are total electric installations and are located on rural sites. Table VI presents the monthly consumption, expressed in KWH, for each site as it was received from each respondent. Due to the limited availability of metered records, portions of the annual cycle for half of the sample dwellings are non-coincident with each other. Sites A, B, and C have energy performance data for winter-spring 1977, while sites D, E, and F are documented for winter-spring 1978. Examination of weather records shows that climatic conditions for these two periods were quite similar. Therefore, any apparent inconsistency between the tabulated values would be attributed to factors not related to weather conditions. Energy consumption plots are shown in Figure 10 on a monthly basis for each site normalized as a function of gross building area (less garage), and all six sites are considered as experiencing coincident data occurrences.

A few comments on the data presented in Table VI are in order. For Site A, the high variance in energy usage could be attributed to the configuration of the building. Since it has a large exposed facade, it loses

TABLE VI

ANNUAL CYCLE SITE ENERGY CONSUMPTION

Site	Metered Electrical Consumption (KWH)												Time Period Covered
	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	
A	1130	1710	2760	1830	540	330	480	1380	1080	1050	690	900	12/77-11/78
B	1783	8338	11503	4730	2534	2701	3370	3875	3419	3383	2372	2402	12/77-11/78
C	2750	3500	5010	5000	3700	2000	2500	3340	3450	3450	2550	2500	12/77-11/78
D	1422	1933	2222	2432	2590	1038	1155	1706	1347	1484	1265	732	6/78-5/79
E	2374	2487	2851	2657	2181	1801	2070	2314	2800	2814	2651	1981	7/78-7/79
F	2323	2571	2342	1737	1622	1259	2198	2272	1819	1889	929	1757	6/78-5/79

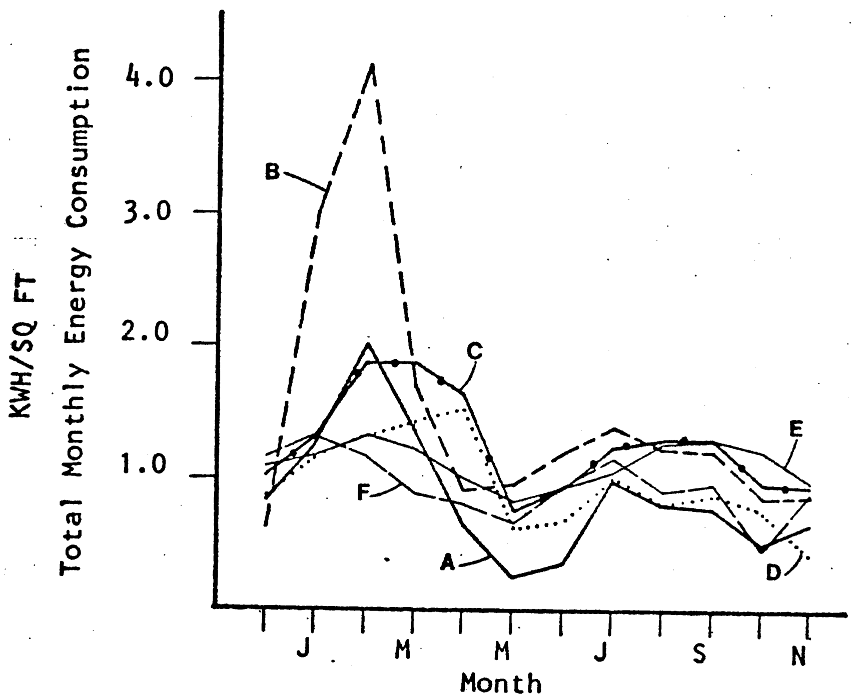


Figure 10. Metered Energy Consumption, Sites A-F.

heat at a much higher rate than the other samples, as reflected in the mid-winter readings. The data for Site B appears very suspect as the mid-winter readings are two to five times as great as the others. Site C has consistent high metered readings that could be attributed to both high appliance use (with five occupants) and a non-earth roof. The remaining sites, D, E, and F, have energy consumption patterns typical of Oklahoma earth shelters.[1]

Elements of Total Consumption

The energy consumption shown for each site is a total energy expenditure comprised of the requirements for summer and winter space conditioning, domestic hot water heating, and all appliances. The respondents for each dwelling indicated on the questionnaire features of their residence and behavior which could account for a higher than average energy usage, i.e., two hot water heaters, kitchen appliance usage, power tool appliances, stereo usage, etc. Four of the six sites use a private well equipped with a pumping system for a water supply source. On the average, for the projects examined, the appliance and domestic water heating energy usage is estimated to account for approximately 60 percent of the total annual metered usages.

Occupant Evaluation of Energy Use

Several questions pertaining to energy consumption were included in the questionnaire. One item requested respondents to compare the actual energy consumption of their earth sheltered home to their expectations. One respondent indicated actual usage was lower than the expected usage, two respondents indicated their expectations were met, while three respondents of the six cases expressed an energy consumption greater than the expected energy usage. Reasons why actual energy consumption exceeded occupant expectations could include poor thermal mass design, no conscious attempt to implement passive solar design, and no apparent lifestyle changes to save energy. For most samples, the appliance load was increased from the previously owned residence which indicates an actual improvement in lifestyle.

Another item asked respondents to compare their present energy consumption to the energy usage of their previous home. Five of the six cases studied indicated a lower energy consumption by an average of 45 percent over their previous residence with the remaining case, Site A, expressing an energy consumption level equal to their prior home which was a house trailer the same shape as their earth sheltered house. Of considerable interest here is the fact that the earth sheltered dwellings are, on the average, 67 percent larger than the previously owned dwellings, but still maintain a lower total energy consumption level. According to the homeowners, this substantial energy savings has been achieved along with an increase in the comfort, livability, and habitability aspects of their residences.[2]

END NOTES

[1] L. L. Boyer, W. T. Grondzik, and M. J. Weber, "Passive Energy Design and Habitability Aspects of Earth Sheltered Housing in Oklahoma," Proceedings 2nd Annual Operational Results Conference on Solar Heating and Cooling Systems, Solar Energy Research Institute, Colorado Springs, November, 1979.

[2] Ibid.

CHAPTER V

PREDICTED ENERGY CONSUMPTION

Heating Season Heat Loss Calculations

Formulation of Method

The design heat loss for each site is derived using the ASHRAE heat loss values for below grade walls and floors, and the standard heat loss method found in the ASHRAE 1977 Fundamentals.[1] For earth sheltered construction, the heat loss through roofs and upper portions of walls will be greater than the heat loss experienced by the floors and the lower wall areas. This loss through roofs can be twice as great[2] as that for the floor because of the shorter heat transfer paths.

The data tabulated for heat loss from below grade basement walls and floors was found through full scale modeling and therefore are empirical values. These values are limited to standard basement depths of seven feet and floor widths between 20 and 32 feet. Applying this method to earth sheltered construction, which is typically 10 feet below grade and between 12 to 40 feet wide, requires that the tables be expanded. For this study, graphical extrapolation shown in Figure 11 was used to determine the wall heat loss values which are presented in Table VII. The values for the floor losses, presented in Table VIII, were extrapolated mathematically. It is interesting to note in Figure 11 that at depths below 6 feet the curves for insulated and non-insulated walls

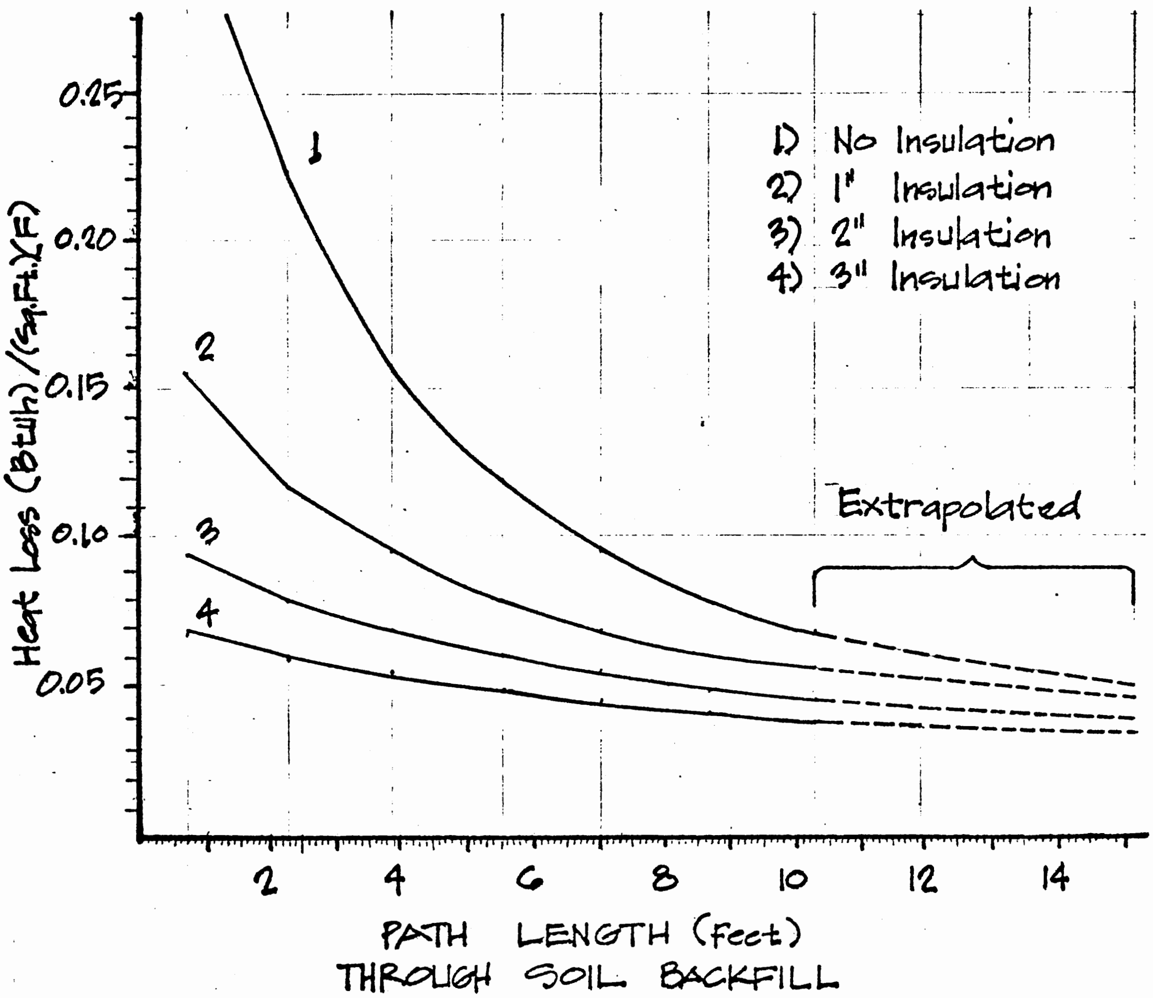


Figure 11. Heat Loss Through Below Grade Walls

TABLE VII

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

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

Note: Values above dashed line from Table I, Chapter 24, ASHRAE 1977 Fundamentals, p. 24.4.

TABLE VIII

FLOOR HEAT LOSS (BTU/(H)(SQ FT)(F))

Depth of Foundation Wall Below Grade (ft)	Width of House									
	12 ft	16 ft	20 ft	24 ft	28 ft	32 ft	36 ft	40 ft	44 ft	48 ft
7	.035	.032	.029	.026	.023	.021	.019	.017	.095	.013
8	.030	.030	.027	.024	.021	.019	.017	.095	.013	.010
9	.032	.029	.026	.023	.020	.018	.016	.014	.012	.009
10	.030	.027	.024	.021	.018	.016	.014	.012	.010	.008

Note: Values above dashed line from Table 2, Chapter 24, ASHRAE 1977 Fundamentals, p. 24.4.

begin converging to the same point indicating nearly identical heat loss characteristics regardless of applied insulation thickness. Since cooling is such a major concern in Oklahoma, removing insulation at certain locations to enhance the passive cooling effects of direct earth contact would not significantly increase the heating load.

The heat loss through the earth covered roof is calculated in the same manner as a basement wall. Because the soil modulates the diurnal temperature swing, the tables for below grade heat loss through walls are adapted to calculate the heat flow through the roof. This involves interpolation using the actual transfer path length and extrapolation for insulation thicknesses greater than three inches.

Selection of the appropriate temperature difference to use for below grade heat loss is still a controversial matter. For this paper, the interior design temperature is taken to be 70°F, while the external design temperature is an estimate of the earth temperature near the structure. The ASHRAE _1977 Fundamentals_ indicates that the amplitude of fluctuation, A, of the ground surface temperature at a four inch depth is approximately 20°F for Oklahoma. This value is subtracted from the actual mean annual air temperature, $\bar{t}_a$, for each site. The mean temperatures were calculated from climatological records for the time periods coinciding with the metered energy data.

Variables Used in Calculations

This section defines all variables used in heat loss calculations.

Q_1 = Heat loss through earth backed walls, Btuh/F

Q_2 = Heat loss through floor slab, Btuh/F

Q_3 = Heat loss through earth covered roof, Btuh/F

Q_4 = Total heat loss through earth backed surfaces, Btuh

Q_5 = Heat loss through exposed construction, Btuh

Q_6 = Heat loss through slab on grade edge, Btuh

Q_7 = Heat loss due to infiltration, Btuh

H_L = Heat loss value, Btuh/sq ft/°F

Amp = Amplitude of fluctuation, °F

A_1 = Floor area, sq ft

A_2 = Ceiling area, sq ft

A_5 = Area of exposed facade component, sq ft

L_1 = Perimeter length of earth backed walls, ft

L_6 = Length of exposed slab edge, ft

F = Heat loss value for slab edge, Btuh/ft

t_{ext} = External design temperature, °F

t_a = Actual mean annual air temperature, °F

t_i = Inside design temperature, °F

t_o = Outside design temperature, °F (97.5% value)

U = Air-to-air heat transfer coefficient, Btuh/sq ft °F

Procedure

The procedure for determining design heat loss consists of summing up the heat losses that occur through the different building components. Determination of these heat losses is described below:

Step 1:

Incremental heat loss through the earth backed walls, Q_1, is found by summing the tabulated incremental heat loss values of the wall according to its depth below grade to determine an aggregate heat loss value, HL, per lineal foot of wall. This value is then multiplied by the perimeter length of earth backed wall, L_1:

$$Q_1 = (HL)(L_1) \tag{5.1}$$

Step 2:

Heat loss through the floor slab, Q_2, is a function of the floor depth below grade and the least dimension width of the floor. This value, HL, is multiplied by floor area, A_1:

$$Q_2 = (HL)(A_1) \tag{5.2}$$

Step 3:

Heat loss through an earth covered roof is found by interpolating or extrapolating the tabulated values for below grade walls, and multiplying by the ceiling or roof area:

$$Q_3 = (HL)(A_2) \tag{5.3}$$

Step 4:

The external design temperature, t_{ext}, is found:

$$t_{ext} = (\bar{t}_a - Amp) \tag{5.4}$$

Step 5:

The total heat loss through surfaces in contact with the earth, Q_4, is found by combining the values determined above, and then multiplying by the design temperature difference:

$$Q_4 = (Q_1 + Q_2 + Q_3)(t_i - t_{ext}) \tag{5.5}$$

Step 6:

Heat loss by conduction through the exposed wall, glass, and door areas is found using the standard heat flow equation for each component:

$$Q_5 = (U)(A_5)(t_i - t_o) \tag{5.6}$$

Step 7:

Slab on grade exposed edge heat loss, Q_6, is found using tabulated values, F, multiplied by the length of exposed edge:

$$Q_6 = (F)(L_6) \tag{5.7}$$

Step 8:

Infiltration losses are estimated from the air requirements of exhaust fans in bathrooms, kitchens, and hallways, as noted by sample respondents. Combustion make-up air is normally not required with all-electric homes, except perhaps for fireplaces:

$$Q_7 = (t_i - t_o)(CFM)(1.08) \tag{5.8}$$

The design heat loss is the total of values found in steps five through eight.

Cooling Season Heat Gain Calculations

Formulation of Method

Since the conduction of heat by earth backed walls provides a cooling mechanism during the cooling season, calculations for determining the design cooling load must be sensitive to this factor. Methods of calculation currently used to find design cooling loads in buildings do not address this cooling effect.

A chapter on Environmental Control for Survival, containing a procedure referred to as the deep earth shelter method, appears in the ASHRAE 1978 Applications.[3] By using an energy balance equation, the method predicts resulting environmental conditions inside survival shelters during a specific time interval. By assuming the interior space conditions, the energy required of an air conditioning system to maintain these conditions can be found using the heat balance equation.

Although normally applied to completely buried shelters experiencing a sudden load input, i.e., occupants, support lighting, and support ventilation, the method is tentatively utilized here for earth sheltered residences. The primary load for these structures which have a limited amount of external exposure, is the dynamic solar heat gain. The total design summer cooling load is comprised of the following heat gain components: unscreened solar gain, convectional gains due to high external air temperatures, heat from ventilation and infiltration air, and internal gains from occupants and heat-producing equipment.

The heat dissipation mechanism provided by the earth heat sink is dependent upon soil properties. An accurate average temperature for the soil surrounding the earth covered dwelling must be established to estimate the heat sink effect. This factor is very important and requires site-specific research in order to have realistic values for each project.

Another factor related to the earth cooling effect concerns the amount of interior surface area which can be considered effective in providing heat conduction away from the structure. If only a small net heat dissipation is expected, as with earth covered roofs and front sidewalls exposed to solar radiation, the areas should not be included in calculations of earth cooling. To reduce the possibility of net heat gain, thick vegetation on all earth covered surfaces and external shading, either man-made or natural, is essential.[4]

For earth covered dwellings, two modes of cooling are considered: heat conduction through earth backed surfaces and mechanical cooling.

The method of calculation presented uses the plane semi-infinite model of case three.[5] Case three considers a ventilated underground shelter from which heat is removed by the combined effects of ventilation (or mechanical cooling) and heat conduction. By adapting this particular case of the deep shelter method, reasonably accurate values for expected energy consumption for a cooling season can be found. The air-conditioning energy required is calculated only for a 24-hour period, since the dynamic sun load is repeated during that cyclic period. When using the method, all load inputs must be expressed as a function of the number of occupants in Btuh per person for the time period being considered.

Variables Used in Calculations

This section defines all the variables required in the adaptation of the deep earth shelter method.

Q_a = Convective heat gain through glass, Btuh

Q_b = Radiant heat gain through glass, Btuh

Q_c = Heat gain through opaque facade elements, Btuh

Q_d = Design cooling load, Btuh

Q_e = Heat gain from lights, appliances, and equipment, Btuh

Q_o = Heat gain from occupants, Btuh

Q_f = Heat gain from unconditioned spaces, Btuh

Q_i = Combined external and internal heat gain input, Btuh/person

Q_r = Heat rejected by mechanical refrigeration, Btuh/person

t_a = Average monthly temperature, °F

t_i = Design inside temperature, °F

t_o = Wall temperature at earth-backed surfaces, °F

k = Thermal conductivity of soil, Btu/h * sq ft * F

α = Thermal diffusivity of soil, sq ft/h

θ = Elapsed time; for this method adaptation always 24 hours

a = Equivalent radius of the shelter, ft

S_i = Total effective inner surface area of earth-backed surfaces, sq ft

S_p = Effective inner surface area of earth-backed surfaces per person (sq ft)/person

h = Surface heat transfer coefficient, Btu/h * sq ft * F

T = Dimensionless time function

ϕ = Temperature rise function

N = Dimensionless parameter used in determination of ϕ

G = Infiltration rate, CFM/person

u_o = Value of temperature rise as function of heat transfer at earth-backed walls, °F

n = Dimensionless parameter used in determination of u_o.

Procedure

Before using the adapted deep shelter method, values of several variables must be identified either from actual site data or by assuming values typical of the location in general. These variables are α, h, k, G, t_i, and t_o.

In addition to the above items, the variable Q_i must be determined before proceeding to the steps of the deep shelter adaptation. This value Q_i is the total heat gain averaged for the 24-hour period divided by the number of occupants. It is comprised of heat gains throught the fenestration, opaque walls, roofs, heat gains of metabolic heat from occupants, and heat gains from equipment. The procedure for finding these heat gain components is described in the following steps.

Step 1:

Heat gain through building components exposed to exterior conditions.

Glass (Convective):

$$Q_a = (U)(A)(t_a - t_i) \tag{5.9}$$

Glass (Radiant):

$$Q_b = (A)\ (\overline{SHGF})(SC) \tag{5.10}$$

Opaque:

$$Q_c = (U)(A)(\overline{CLTD}) \tag{5.11}$$

where

$\overline{SHGF}$ = sum of the solar heat gain factor averaged over the 24-hour period, Btuh;

SC = shading coefficient (constant); and

$\overline{CLTD}$ = sum of the cooling load temperature difference values averaged over the 24-hour period, °F.

Step 2:

Heat gain from the occupants, Q_o, is the total metabolic heat released inside the structure averaged for the 24-hour period. In determining this value, expected time period of occupancy and activity levels of those periods are assumed. For example, consider a person who works outside of the home during a typical day. The heat gain from this occupant occurs only in the evening, at night, and in the early morning with metabolic heat output corresponding to normal activities during those periods of the day. Values for heat gain according to degree of activity are found in the ASHRAE 1977 Fundamentals.[6]

Step 3:

Heat gain from appliances, lights, and equipment, Q_e, is found by assuming a unit heat gain per unit floor area:

$$Q_e = [(\text{Btuh})/(\text{sq ft})](\text{sq ft}) \tag{5.12}$$

Step 4:

Heat gain from convection through party walls, adjacent to unconditioned spaces, Q_f, such as garages. This gives a conservative value when the garage is earth sheltered also:

$$Q_f = (U)(A)(t_a - t_i) \tag{5.13}$$

Step 5:

Determine Q_i, the heat gain load input, by combining the values calculated in steps 1, 2, and 3, and dividing by the number of occupants:

$$Q_i = \frac{Q_a + Q_b + Q_c + Q_o + Q_e + Q_f}{\text{Number of Occupants}} \tag{5.14}$$

After determining the load input, Q_i, the remainder of the calculation procedure is adapted from case three of the deep shelter method.

Step 6:

Calculate the total effective inner surface area of earth-backed surfaces, S_i, using only the surface areas that can reasonably be expected to maintain heat conduction away from the structure.

Step 7:

Divide S_i by the number of occupants which then defines the parameter S_p.

Step 8:

Determine the equivalent radius of the shelter, a, using the following equation:

$$a = \sqrt{S_i} \tag{5.15}$$

Step 9:

Evaluate the dimensionless parameter N solving the following expression:

$$N = (h)\,\frac{(a)}{(k)}\left[\frac{1.08G + 10}{1.08G + 10 + (h)/(S_p)}\right] \tag{5.16}$$

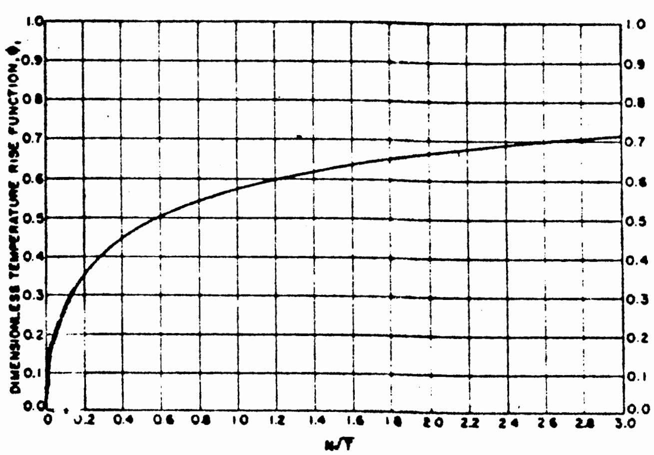
Step 10:

Using the values of soil thermal diffusivity, elapsed time, and equivalent radius of the shelter, find the dimensionless time function T, where

$$T = \frac{\alpha\theta}{(a)^2} \tag{5.17}$$

Step 11:

Calculate $N\sqrt{T}$ and determine the value of the temperature rise function, ϕ, from the chart presented in Figure 12.



Source: ASHRAE 1978 Applications, pp. 12, 15.

Figure 12. Temperature Rise Chart

This parameter ϕ takes into account the warming of soil in contact with the building as it is a function of N and T, which are determined using the soil properties.

Step 12:

Solve for dimensionless parameter n, where

$$n = \frac{hS_p}{1.08G + 10 + hS_p} \tag{5.18}$$

Step 13:

Find temperature rise u_o from Equation (5.19):

$$U_o = \frac{1}{[(1-n) + n\phi]} \tag{5.19}$$

Step 14:

Determine Q_r, the heat carried away by the cooling equipment:

$$Q_r = Q_i + [10(100 - t_o)] + [1.08G(t_a - t_o)] - (1.08G + 10)U_o \tag{5.20}$$

Step 15:

Multiply Q_r, determined above, by the number of occupants to find the design cooling load in Btuh:

$$Q_d = (Q_r)(\text{No. of Occupants}) \tag{5.21}$$

Assumptions

For this study, actual specific on-site data were not available, so with inside design conditions set at 75°F and 50% RH, the following assumptions are made.

1. The soil properties for every case were assumed for heavy, damp soil.[7]

$$K = 0.75 \text{ Btu/(h)(ft)(F)}$$

$$\alpha = 0.025 \text{ (sq ft)/(h)}$$

2. The soil temperature equals 62°F, based on the estimated well water isotherm for Oklahoma.[8]

3. The inside wall surface temperature is assumed to be 70°F with a surface convection heat transfer coefficient assumed.

$$h = 1.5\text{(Btu)/(hr)(sq ft)(F)}$$

The temperature of 70°F was assumed because condensation on walls was not indicated as a problem by sample occupants, so it allows for a high dewpoint target. If the wall temperature was near earth temperature, assumed 62°F, then condensation would occur frequently with Oklahoma humidity levels. But alternately, the temperature would not be at room temperature, 75°F, due to earth heat sink cooling effects, enhanced by good thermal contact.

4. The infiltration rate, G, was determined by estimating the air requirements of exhaust fans in each case. Each fan was assumed to require 60 CFM when in use, and running time was generously set at 10 minutes per hour, so each fan provides an equivalent constant rate of 10 CFM per fan. All homes were all-electric; therefore, combustion makeup air is not required.

5. Loads from equipment, lights, and appliances were estimated using 2 Btuh to 3 Btuh per square foot of living area, depending on degree of appliance use indicated in the questionnaire on a 5-point scale with less than average (1), average (3), and more than average (5).

6. Thermal characteristics of the glass equal to the following, assuming double glazing:

$U = 0.58$ (Btuh)/(sq ft)(F), $SC = 0.88$

7. The cooling effect of the earth is not considered for the ceiling area and the first five feet of the front side walls and floor area extending back from the exposed facade due to the exposure to solar radiation. This portion of surface area also served as a transition area due to increased outdoor air temperature. The five foot setback was arbitrary and somewhat conservative since some of the residences received no direct radiation on the exposed wall because of porch overhangs. These areas are not included in the value of S_i or S_p, are are assumed to provide no net gain.

Annual Cycle Energy Estimation Procedures

Space Heating

The Heating Degree Day Method[9] is used to calculate the values of expected energy consumption required for space heating. In order to make comparisons between the predicted and actual metered energy consumption, actual monthly degree days for each site are compiled from weather bureau records for the months for which metered data are available.

Space Cooling

Since cooling degree day methods are not well defined or accepted, the energy estimates for space cooling are based on logic and field experience.

By using a 24-hour average unit running time of 15 minutes per hour, which field experience suggests as typical of earth sheltered installations, the daily energy usage is found by multiplying the design cooling load, Q_d, by 6. The monthly energy consumption is then derived simply by multiplying by 30. The design cooling loads are determined separately for each month.

Appliances and Domestic Hot Water

In order to compare predictive energy consumption with the actual metered consumption which is presented as total usage, the appliance and water heating requirements are estimated. This combined estimate of appliance and water heating consumption is then added to the space conditioning energy expenditure to provide a total energy consumption prediction. The estimates of energy used per month were compiled from two sources, Energy Conservation in the Home[10] and Alternative Natural Energy Sources.[11] The respondents for each site evaluated their own appliance use as less than average (1), average (3), or more than average (5) on a 5-point rating scale. The predicted appliance usage was estimated considering this evaluation and the age, sex, and number of occupants. It is realized that appliance usage varies from day to day and month to month, but in order to predict the total consumption on an annual basis, the monthly average consumption estimated will be assumed for all months.

Example Energy Calculations: Site F

In order to illustrate the methods described, example calculations for Site F will be presented. The exposed wall area and U-factors are determined from questionnaire responses. The procedure will include derivation of the design heat loss, design cooling load, space conditioning energy consumption, and estimation of appliance and domestic hot water energy usage.

The exposed wall construction assumed is:

Typical frame construction: U = 0.07, A = 144 sq ft

Double pane windows: U = 0.58, A = 144 sq ft

Door, S.C. 1¼ in.: U = 0.34, A = 42 sq ft

Concrete block at garage party wall: U = 0.18, A = 240 sq ft

No insulation installed on earth-backed walls, earth covered roof

Roof earth cover = 2' - 0"

3 occupants, 3 exhaust fans.

Heat Loss

The design heat loss calculations are determined for the month of December. The procedure steps sequence follows the outline presented in the heating season calculation section of this chapter. The mean annual air temperature is the actual value for this site.

Month: December

Outside design temperature = 13°F

Inside design temperature = 70°F

Mean annual air temperature = 61.2°F

Amplitude of fluctuation = 20°F

1. Heat loss through earth-backed walls, using Table VII:

Depth Below Grade (ft)	(Btuh)/(Ft)(F)
2-3	0.155
3-4	0.119
4-5	0.096
5-6	0.079
6-7	0.069
7-8	0.059
8-9	0.049
9-10	0.045
	0.671

Total per foot length of wall = 0.671 (Btuh)(ft)(F)

Length of wall = 118' - 0"

Total wall heat loss = (118)(0.671) = 79.18 (Btuh)/(F).

2. Heat loss through floor slab using Table VIII:

36' wide

Average heat loss per sq ft = 0.014 (Btuh)/(ft)(F)

Floor area = 2000 sq ft

Total floor loss = (2000)(0.014) = 28.00 (Btuh)/(F).

3. Loss through roof, 2'0" transfer path:

Suspended ceiling construction with 12" air space, R = 5.87

Interpolating between R values, in Table VIII provides heat value = 0.10 (Btuh)/(sq ft)(F)

Ceiling area = 2000 sq ft

Total ceiling heat loss (0.1)(2000) = 200.0 (Btuh)/(F).

4. Total loss through earth-backed surfaces:

(79.18) + (28.00) + (200.0) = 307.2 (Btuh)/(F).

5. External design temperature = (61.2 - 20) = 41.2°F

Design temperature difference = (70 - 41.2) = 28.8°F

(307.2)(28.8) = 8847.4 Btuh.

6. Exposed facade losses (construction assumed):

Garage assumed 50°F

Walls:	(0.07)(144)(57) =	575
	(0.18)(240)(20) =	864
Windows:	(0.58)(144)(57) =	4760
Doors:	(0.34)(21) (57) =	407
	(0.34)(21) (20) =	143
	Total heat loss =	6749 Btuh

7. Slab edge loss:

   36'-0" exposed, uninsulated

   R = 3.75, F = 31 Btuh/sq ft

   (36)(31) = 1116 Btuh.

8. Infiltration loss:

   3 exhaust fans @ 60 CFM each = 180 CFM, (.5) for diversity

   (0.5)(180)(1.08)(57) = 5540 Btuh

Totals for Site F:	Btuh
(5) Earth-backed surfaces	8,847
(6) Exposed construction	6,749
(7) Slab edge	1,116
(8) Infiltration	5,540
Design heat loss:	22,252 Btuh (December).

Heat Gain

The design heat gain for August is found using the method described in the section on heat gain calculations of this chapter. The average monthly temperature used is the actual value for this site.

Month--August

Outside design temperature = monthly average temperature

= 81.1°F

Inside design temperature = 75°F

G = 10 CFM/person

$\overline{SHGF}$ = 13.96 Btuh/sq ft

$\overline{CLTD}$ = 9.2°F

Reference Appendix B for determination of $\overline{SHGF}$ and $\overline{CLTD}$.

1. Heat gain through building components:

   Glass: Convective gain using Equation (5.9):

   $$Q_a = (0.58)(144)(81.1 - 75) = 509.5 \text{ Btuh}$$

   Radiant gain using Equation (5.10):

   $$Q_b = (144)(13.96)(.88) = 1769.0 \text{ Btuh}$$

   Wall: Heat gain using Equation (5.11):

   $$Q_c = (0.07)(144)(9.2) = 92.7 \text{ Btuh.}$$

2. Occupant heat gain for 24-hour test period:

   2 males, 1 female

   Activity: Time, (Hrs)(Heat Gain)(Occupant Number)

   Sleeping: (8 hrs)(350)(2.85) = 7980

   Light Work: (6 hrs)(420)(2.85) = 7182

   Gone: (10 hrs)

   $\overline{15162}$

   15162/24 = 632 Btuh.

3. Occupant indicates average (3) appliance use, so using Equation (5.12):

   $$Q_e = (2000 \text{ sq ft})(2.5 \text{ Btuh/sq ft}) = 5000 \text{ Btuh.}$$

4. Heat gain from garage using Equation (5.13):

   $$Q_f = (0.18)(240)(81.1 - 75) = 263.5.$$

5. Using Equation (5.14), the heat gain input Q_i is:

   $$Q_i = \frac{(509.5) + (1769) + (92.7) + (632) + (5000) + 263.5}{3}$$

   $$= 2755.4 \text{ Btuh/person.}$$

6. $S_i = (408) + (288) + (240) + (1836) = 2772$ sq ft.

7. $S_p = (2772)/(3) = 924$ (sq ft)/(person).

8. Determine a using Equation (5.15):

   $$a = \sqrt{2772} = 53 \text{ ft.}$$

9. Find N solving Equation (5.16):

$$N = (1.5)\ \frac{(53)}{(0.75)}\ \frac{(1.08)(10) + (10)}{(1.08)(10) + (1.5)(924)} .$$

$$= 1.57$$

10. Solving Equation (5.17):

$$T = \frac{(0.025)(24)}{2772} = 0.0002.$$

11. $N\sqrt{T} = (1.57)(0.0002)^{0.5} = 0.022.$ Using the chart in Figure 12,

$\phi \cong 0.10.$

12. From Equation (5.18):

$$n = \frac{(1.5)(924)}{(1.08)(10) + 10 + (1.5)(924)} = 0.985.$$

13. Using Equation (5.19):

$$u_o = \frac{1}{(1 - 0.985) + (0.985)(0.1)} = 8.81\ F$$

14. Find Q_r using Equation (5.20):

$$Q_r = (2755.4) + 10\ (100 - 70)$$

$$+ (1.08)(10)(81.1 - 70)$$

$$- (1.08)(10) + (10)(8.81)$$

$$= (2755.4) + (300) + (119.88) - (183.2)$$

$$= 2992 \text{ Btuh/person.}$$

15. Design cooling load, Q_d, using Equation (5.21):

$Q_d = (2992)(3) = 8976$ Btuh (August).

Energy Consumption Estimation

The actual heating degree days for December, 1978, 750, along with the design heat loss, are used for the energy usage estimation. Inserting these values into the heating degree day approximation below,

$$KWH = \frac{(22,252)(750)(24)}{(57)(3413)} = 2059 \text{ KWH (December)}$$

the expected energy consumption for spacing heating is found.

To find the expected energy consumption for August, 1978, the month considered in the cooling load calculations, the daily energy usage is first found:

$$(6 \text{ hrs/day})(8,976 \text{ Btuh}) = 53,856 \text{ Btuh/day}$$

All months are considered as having 30 days, so monthly consumption is found by multiplying by 30. Assuming typical residential air conditioning unit sizes of 2 to 3 tons, the conversion to KWH is found using the EER value typical of this size, 6.5 Btu/watt:

$$\frac{(30)(53,856)}{(6500)} = 249 \text{ KWH (August)}$$

The appliance and domestic water heating consumption is estimated by a compilation of statistically determined empirical energy consumption values describing the average monthly usage in a typical residence. The appliances chosen are assumed typical of latter-day households. These data are presented in Table IX. On the questionnaire, the respondent indicated a higher than average (5) number of appliances; therefore, to insure consideration of items not included above, like power tools or a microwave oven, the total is increased by 25 percent:

$$(1.25)(1025) = 1282 \text{ KWH}$$

Combining this value with the respective space conditioning energy usage estimates provides an expected total energy consumption in the months indicated for site F:

December, 1978: (2059) + (1282) = 3341 KWH

August, 1978: (249) + (1282) = 1531 KWH.

TABLE IX

APPLIANCE AND DOMESTIC WATER HEATING USAGE FOR SITE F

Appliance/Water Heating	KWH/Month
Range Self-Cleaning Oven	100.4
Coffee Maker	8.8
Dishwasher	30.3
Mixer	1.0
Frying Pan	15.5
Broiler	8.3
Toaster	3.3
Garbage Disposal	2.5
Refrigerator/Freezer (Frostless, 14 cu ft)	152.4
Clothes Dryer	82.7
Washing Machine (Automatic)	8.6
Water Heater	351.6
Fan Exhaust	3.6
Iron	12.0
Hair Dryer	1.2
Television (Color)	42.0
Radio/Record Player	9.1
Vacuum	5.0
Lighting	40.0
Total	1025.1

Predicted Values for All Sites

The expected energy consumption for all samples was found in the same manner for each month, as the total consumption for December, 1978, and August, 1978, for Site F was determined above. The calculations for the heating season, cooling season, and appliance and domestic water heating estimates for each site are included in Appendixes A, B, and C, respectively. For each site, the calculations predicted the total energy consumption for the months corresponding to months of actual metered billings for the full year cycles indicated. These data are compiled and presented in Table X.

New Methods

Because of the dynamic nature of heat transfer in earth covered buildings, methods utilizing computer modeling are being developed and tested against actual data. At the Ames Laboratory, D.O.E., Ames, Iowa, Richard Szydlowski and Thomas Kuehn have developed a mathematical model which analyzes the transient heat loss in earth sheltered structures.[12] The model solves the two-dimensional transient Fourier heat conduction equation in cartesian coordinates using an alternating direction implicit finite difference technique. The model can consider variable soil properties, different building configurations, and varying thicknesses and locations of external and internal insulation.

Some preliminary findings using this model found that seasonal wall and ceiling losses in Iowa, with approximately 6.5 feet of soil cover, were not reduced to values typical of conventional construction unless insulation was added. It also identified the trade-offs encountered by the installation of insulation. Although the winter season heat losses

TABLE X

PREDICTED ANNUAL CYCLE ENERGY CONSUMPTION

Site	Electrical Consumption (KWH)												Time Period Covered
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	
A	2518	3308	3110	2048	1005	980	987	1017	1026	1076	1117	1916	12/77-11/78
B	4069	5789	5045	3325	1717	1740	1771	1790	1766	1753	1699	2876	12/77-11/78
C	4230	5703	5004	3285	1968	1968	1967	1991	1993	2015	1990	3091	12/77-11/78
D	2480	3087	2593	1742	1038	1057	1089	1123	1104	1090	1033	1747	6/78-5/79
E	3038	3809	3112	2281	1672	1694	1717	1726	1714	1696	1658	2087	7/78-7/79
F	3341	4393	3596	2375	1428	1464	1515	1540	1501	1490	1404	2233	6/78-5/79

are reduced, the passive cooling heat transfer of the wall in summer is retarded with added insulation. Floor insulation reduces the heat conduction away from the structure more in the cooling season, so it actually increases annual energy requirements.[13]

A simpler method for determining the heat flow through earth covered roofs has been developed by Dr. Edward Blick at the University of Oklahoma. The method is generated by the temperature dampening effect of the first eight inches of soil at the earth's surface. Because the diurnal oscillations of surface air temperature are not felt below eight inches, the average monthly surface air temperature is used in the heat flux equation. When considering an earth covered composite roof, the total R-value of the roof assembly is calculated in the normal manner and combined with the R-value of the soil. The Blick approximation equation[14] of heat flux through earth covered roofs is expressed as

$$q = \frac{\bar{T}_o - T_i}{R_e + R^*} \tag{5.22}$$

where

$\bar{T}_o$ = mean monthly air temperature;

T_i = internal room temperature;

R_e = thermal resistance of the earth; and

R^* = thermal resistance of the composite roof minus soil.

END NOTES

[1] ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 24, Heating Load, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1977.

[2] Earth Sheltered Housing Design--Guidelines, Examples, and References, American Underground-Space Association, Dept. of Civil and Mineral Engineering, University of Minnesota, Minneapolis, Minnesota, 1978, p. 55.

[3] ASHRAE Handbook and Product Directory--1978 Applications, Chapter 12, Environmental Control for Survival, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1978.

[4] Ibid., p. 12.17.

[5] Ibid., p. 12.9.

[6] ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 25, Air-Conditioning Cooling Load, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1977.

[7] ASHRAE Handbook and Product Directory--1978 Applications, Chapter 12, p. 12.5.

[8] Kenneth Labs, "Underground Building Climate," Solar Age, Vol. 4, No. 10 (October, 1979), p. 44.

[9] ASHRAE Handbook and Directory--1976 Systems, Chapter 43, Energy Estimating Methods, Amer. Soc. Heating, Refrigerating and Air-Conditioning Engineers, New York, 1976.

[10] Energy Conservation in the Home, Department of Energy, EDM-1028, 1977, p. 254.

[11] A. J. Davis and R. P. Schubert, Alternative Natural Energy Sources in Building Design, Van Nostrand Reinhold Company, New York, 1974, p. 236.

[12]Richard Szydlowski and Thomas Kuehn, "Transient Analysis of Heat Flow in Earth Sheltered Structures," Proceedings of Earth Sheltered Building Design Innovations Conference, L. L. Boyer (Ed.), Oklahoma State University, Stillwater, Oklahoma, April, 1980, p. III-27.

[13]Ibid., p. III-36.

[14]Edward 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.), Oklahoma State University, Stillwater, Oklahoma, April, 1980, p. III-19.

CHAPTER VI

BUILDING ENERGY STANDARDS

Building Energy Performance Standards

The proposed Department of Energy Building Energy Performance Standards (BEPS)[1] has been developed to establish energy performance standards for new buildings in an effort to achieve the maximum practicable improvements in energy efficiency and increases in the use of renewable annual energy budget for space conditioning in Btuh/sq.ft./year, and a separate budget for hot water heating for all residences.

BEPS identifies 78 Standard Metropolitan Statistical Areas (SMSA) for which energy budget values have been determined. When considering specific sites, the nearest SMSA is chosen for evaluation of the space conditioning energy budget. At this time, the two SMSA locations in Oklahoma available to choose from are Tulsa and Oklahoma City. The value for Oklahoma City will be appropriate for all sites in this study. The building type, and fuel type must also be identified in order to choose the correct annual energy target. In this investigation these are single family detached and electricity, respectively.

The allowable space conditioning energy consumption for Sites A through F is 34.3 MBtu/sq. ft./year. For all single family dwellings, regardless of size or number of occupants, a constant energy budget of

54,600 MBTU/year has been specified for water heating, with no identified budget for appliance usage.

Minimum Property Standards

The Minimum Property Standards (MPS)[2] developed by the Department of Housing and Urban Development are building standards that outline requirements for special types of new construction. They define the minimum level of acceptability of design and construction for low rent public housing and housing approved for government mortgage insurance programs. Considering MPS provides one level of building energy performance for equivalent above grade dwellings that can be compared with the six earth sheltered sites. The equivalent above grade dwellings are the same size, configuration, and orientation as the earth sheltered counterpart.

The design loads for the equivalent dwellings are derived using the calculation procedure used in finding design loads for "Arkansas" House construction,[3] to be discussed in a later section. The most recent 1979 edition of MPS identifies the required construction features that are assigned to the equivalent residences for the determination of building heat loss and heat gain loads. These features include; 6" fiberglass batts (R = 19) in the ceiling, 3 1/2" fiberglass batts in 2x4 stud exterior walls, single pane weather-stripped windows with area limited to 15 percent of gross exterior wall area enclosing heated spaces, hollow core uninsulated doors, and perimeter slab insulation (R = 3.5). The design heating load and cooling loads calculated are presented in Table XI. The calculations of the loads are included in Appendix D.

TABLE XI

DESIGN LOADS FOR EQUIVALENT MPS
ABOVE GRADE SWELLINGS

Site	Winter Heat Loss Btuh	Summer Heat Gain Btuh
A	54,073	34,330
B	61,636	39,051
C	66,861	41,847
D	39,148	25,737
E	56,016	35,463
F	47,945	30,568

ASHRAE Standard 90-75

ASHRAE Standard 90-75, Energy Conservation in New Building Design,[4] is a current standard which is generally accepted as a guide to energy efficient design of new buildings. Although the performance section offers an option for evaluation of earth covered structures, the commonly used envelope prescription section, Section 4.0, does not specifically address earth sheltered construction and the potential energy conservation benefits. In an effort to gauge the effectiveness of the earth covered residences in this analysis, winter and summer design loads are derived for equivalent above grade residences of sample dwellings which meet the requirements of Section 4.0 of 90-75.

The design heating and cooling loads of these above grade duplicate dwellings are found using the required envelope U factors and perimeter insulation identified in Section 4.0. The design heating loss for the equivalent structures is found using the method described in Chapter 24, ASHRAE 1977 Fundamentals.[5] Design heat gain is determined using Heat Transfer Multipliers[6] corresponding to U-factors required by 90-75. The infiltration component for both design heat loss and heat gain is estimated identically to the load in the predictive heat loss calculations in Chapter V at a rate of 60 CFM per exhaust fan. To estimate solar gains in heat gain calculations, the window area is assumed 10 percent of the total exposed wall area. The predictive design loads of these equivalent 90-75 dwellings are tabulated in Table XII. Detailed calculations are in Appendix D.

TABLE XII

DESIGN LOADS FOR EQUIVALENT 90-75 ABOVE GRADE DWELLINGS

Site	Winter Heat Loss Btuh	Summer Heat Gain Btuh
A	45,650	25,015
B	42,672	30,233
C	48,599	34,612
D	35,977	23,936
E	42,326	32,110
F	40,461	28,840

The "Arkansas" House

In the climate of today's energy crisis, energy conserving concepts for the building community have started being developed. Professional engineers, architects, and building contractors have all been attempting to provide homes that would cost less to build and less to operate. Frank Holtxclaw, a construction design analyst for HUD, has developed a residential construction method which saves framing lumber, provides installation of more insulation, and reduces construction time. His scheme was realized in several prototype dwellings erected in Little Rock, Arkansas, where they have shown a savings of energy costs in excess of \$200 per year.[7] Stated as the main objective of the design was the desire "to gain maximum control over the interior environment of the home . . . , to isolate the interior environment from the variable exterior environment."[8]

The inclusion of the "Arkansas" House in this analysis provides another energy design parameter against which earth sheltered design may be measured. Design winter and summer loads are calculated for above grade equivalent dwellings constructed with the energy-saving elements of the "Arkansas" House using the Heat Transfer Factor method presented in the paper "Energy Saving Homes."[9] As with the MPS and 90-75 equivalent dwellings, the above grade duplicates are the same size, shape, and orientation as their earth sheltered "twins."

The construction characteristics of the "Arkansas" House include the following; 12" fiberglass batts in ceiling (R = 38), 6" fiberglass batts in 6" exterior stud walls (R = 10.7), insulated doors, double pane windows with area restricted to 8 percent of gross living area, and a ventilation controlled attic space. The design loads for the above grade equivalent dwellings, having these construction characteristics are present in Table XIII, and the calculations appear in Appendix D.

TABLE XIII

DESIGN LOADS FOR EQUIVALENT "ARKANSAS" HOUSE
ABOVE GRADE DWELLINGS

Site	Winter Heat Loss Btuh	Summer Heat Gain Btuh
A	20,210	16,199
B	30,573	27,061
C	31,280	27,006
D	18,919	17,662
E	22,273	22,518
F	22,894	20,605

Thermal Integrity Factor

A new concept has been developed by Dr. Ray Sterling at the University of Minnesota which addresses the energy consumption performance of residences with respect to primarily the heating season. A single number rating called the Thermal Integrity Factor[10] is derived using the heating season energy usage, in Btus, divided by the conditioned, living floor area of the dwelling, and the heating degree day total for that location. Dr. Sterling has determined that Thermal Integrity Factors of one or less are extremely good, with poor ratings beginning at values of eight. One example of a Minnesota earth sheltered dwelling is the Jones

House which has a rating of 1.67 Btu/sq. ft./HDD. This 1500 sq. ft. residence used 1.75 cords of oak wood at 12 MBtu/cord for the heating source.

Applying the Thermal Integrity Factor rating system to the Oklahoma earth covered dwellings in this study, shows that with the predicted heating energy consumption of all-electric heating the ratings are fairly good. For example, the Thermal Integrity Factors for Sites D and E are 3.43 Btu/sq. ft./HDD and 3.39 Btu/sq. ft./HDD, respectively. The actual Thermal Integrity Factors would be lower, as the actual metered energy consumption is less than predicted usage. The Thermal Integrity Factors of actual metered usage (minus the estimated appliance and hot water consumption) for Sites D and E are 1.93 Btu/sq. ft./HDD and 2.41 Btu/sq. ft./HDD respectively.

Although this concept seems to have some value when applied to the heating season cycle, it does not comfortably address the cooling season. To achieve a similar rating for the cooling cycle a new component must be used in place of heating degree days, which could logically be called "cooling degree days" (CDD). Because the formulation of an accurate measure which would be a cooling degree day would appear to be the subject of an extensive study by itself, a possible basis for evaluation is briefly discussed here.

Since heating degree days are based on a referent base of 65°F a simple logical approach for cooling degree days would be to identify a reference point, which might possibly be 80°F. The use of accurate and complete weather data would be required in order to calculate a value for daily and monthly cooling degree days. Because the cooling required results from a combination of solar radiation effects and increased air temperature, the CDD value would also need modification to include the radiation component. Realizing that the amount of solar radiation is dependent on latitude, using the Solar Heat Gain Factors tabulated in the ASHRAE 1977 Fundamentals[11] along with the 80°F reference could conceivably produce a close approximation of "cooling degree days" that might be used in calculating the Thermal Integrity Factor for cooling season.

END NOTES

[1]"Energy Performance Standards for New Buildings; Proposed Rule," Department of Energy, Federal Register, Washington, D. C., Vol. 44, No. 230, 28 Nov. 1979, p. 68120.

[2]Minimum Property Standards for One and Two Family Dwellings, Vol. 1, U.S. Department of Housing and Urban Development, Washington, D.C. 1979.

[3]M. J. McGuinness, B. Stein, and J. S. Reynolds, Mechanical and Electrical Equipment for Buildings, John Wiley and Sons, Inc., New York, 1980, p. 144.

[4]Energy Conservation in New Building Design, ASHRAE Standard 90-75, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1975.

[5]ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 24, Heating Load, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1977.

[6]McGuinness/Stein, p. 85.

[7]"Energy Saving Homes: The Arkansas Story," Report No. 1: Energy Conservation Ideas to Build On, Owens-Corning Fiberglass Corporation, Toledo, Ohio, 1975, p. 1.

[8]Ibid., p. 5.

[9]McGuinness/Stein, p. 144.

[10]Stu Campbell, The Underground House Book, Garden Way Publishers, Charlotte, Vermont, 1980, Appendix 3, p. 194.

[11]ASHRAE Handbook and Product Directory--1977 Fundamentals, Chapter 25, Cooling Load, Amer. Soc. Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1977.

CHAPTER VII

COMPARISONS

Total Energy Consumption

Actual Metered vs. Predicted

Calculated mean values of the predicted total energy consumption presented in Table X, Chapter V, and mean values of the actual metered usage presented in Table VI, Chapter IV, are plotted for an annual cycle, shown in Figure 13.

Although the lines representing the predicted and actual usage do not coincide directly, there appears to be good agreement between the calculated and actual values. As noted in Figure 13, Site B was not included in the averages in this comparison mainly due to questionable values of metered energy which substantially varied from all five other cases, as seen in Figure 10, Chapter IV, where the mid-winter usage/sq. ft. is more than twice as great as the next highest value, Site A.

The months of February and May, for which the highest and lowest energy consumption recorded for the earth sheltered dwellings occur one billing period later thant the respective peaks indicated by predictive calculations; this phase shift is most likely attributed to the time lag of the earth mass. A probable explanation for the wide variance in mid-winter values is the inadequacy of the modified basement and degree day methods, which do not consider passive solar gains on the roof areas or

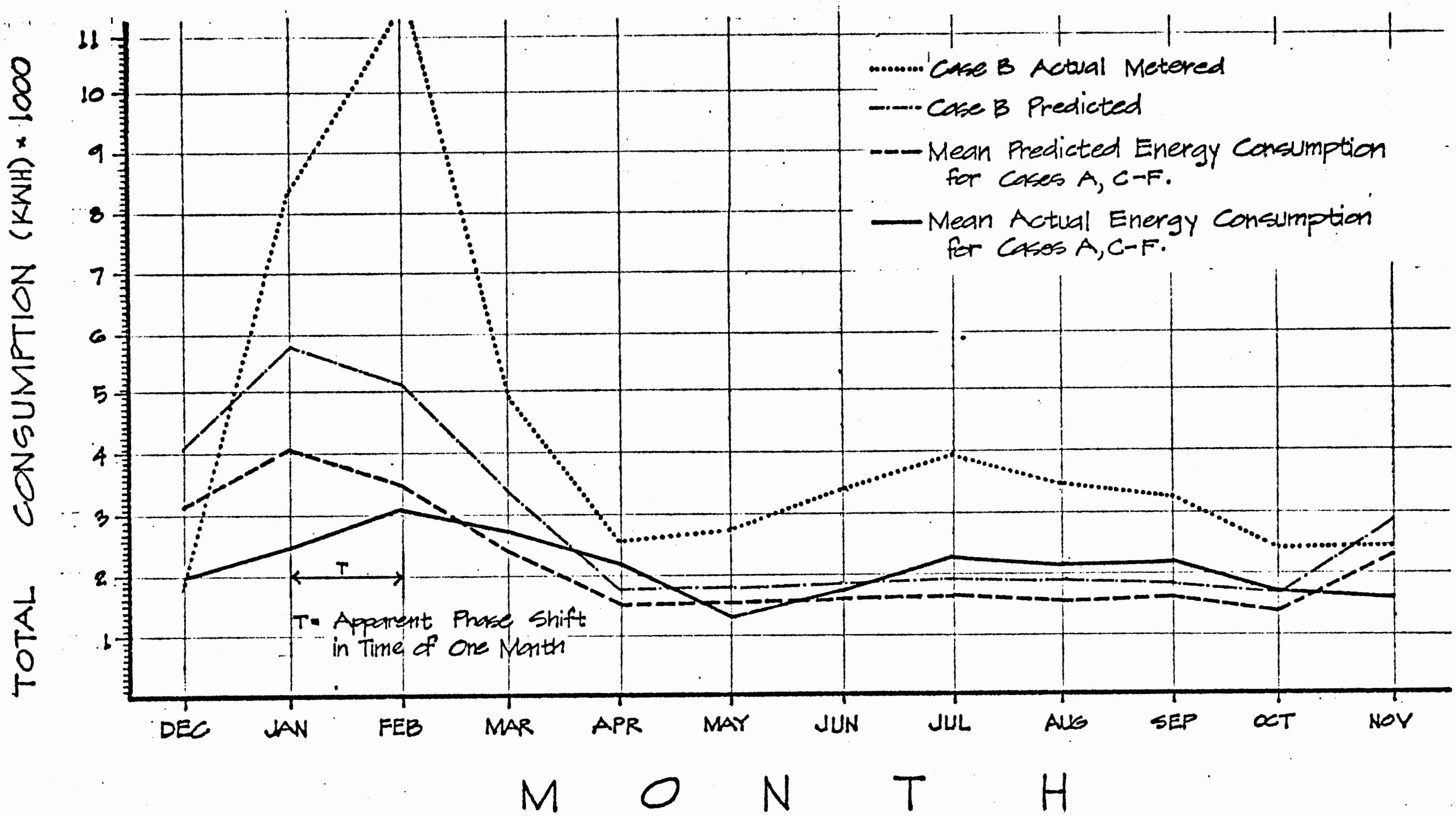


Figure 13. Average Total Energy Consumption for the Annual Cycle

glazing. The difference in calculated and predicted values for the summer could be due to net solar gains through the roof and ceiling assembly and through unshaded exposed glazing. In most cases the glazing faces south in contrast to isolated cases of well shaded non-south glass.

It should be restated that to achieve values of total energy usage, estimates of appliance and domestic water heating energy were combined with the predicted energy consumption values of space heating and cooling. Annual totals of the mean values for the predicted and actual energy consumption are as follows:

Predicted: 25,397 KWH
Actual: 24,931 KWH

These totals reveal that, on the average, for a yearly energy usage, the predictive values are 98 percent correct for this limited sample of Oklahoma case studies.

Actual Metered vs. BEPS

Figure 14 compares the actual annual site energy consumption to the BEPS (November, 1979) energy budget determined for each site. The BEPS energy budget is a combination of the space conditioning componet (34.3 MBtu/sq. ft./year) and the water heating component (54,600 MBtu/year) divided by the respective gross floor area of each site. The actual annual energy consumption is represented by this same block of energy, space conditioning and water heating, as one component, and the appliance energy usage as a separate component. The appliance energy estimates are identical to the approximations previously used in calculation of total predicted energy consumption.

For all samples, except Site B (where mid-winter readings are

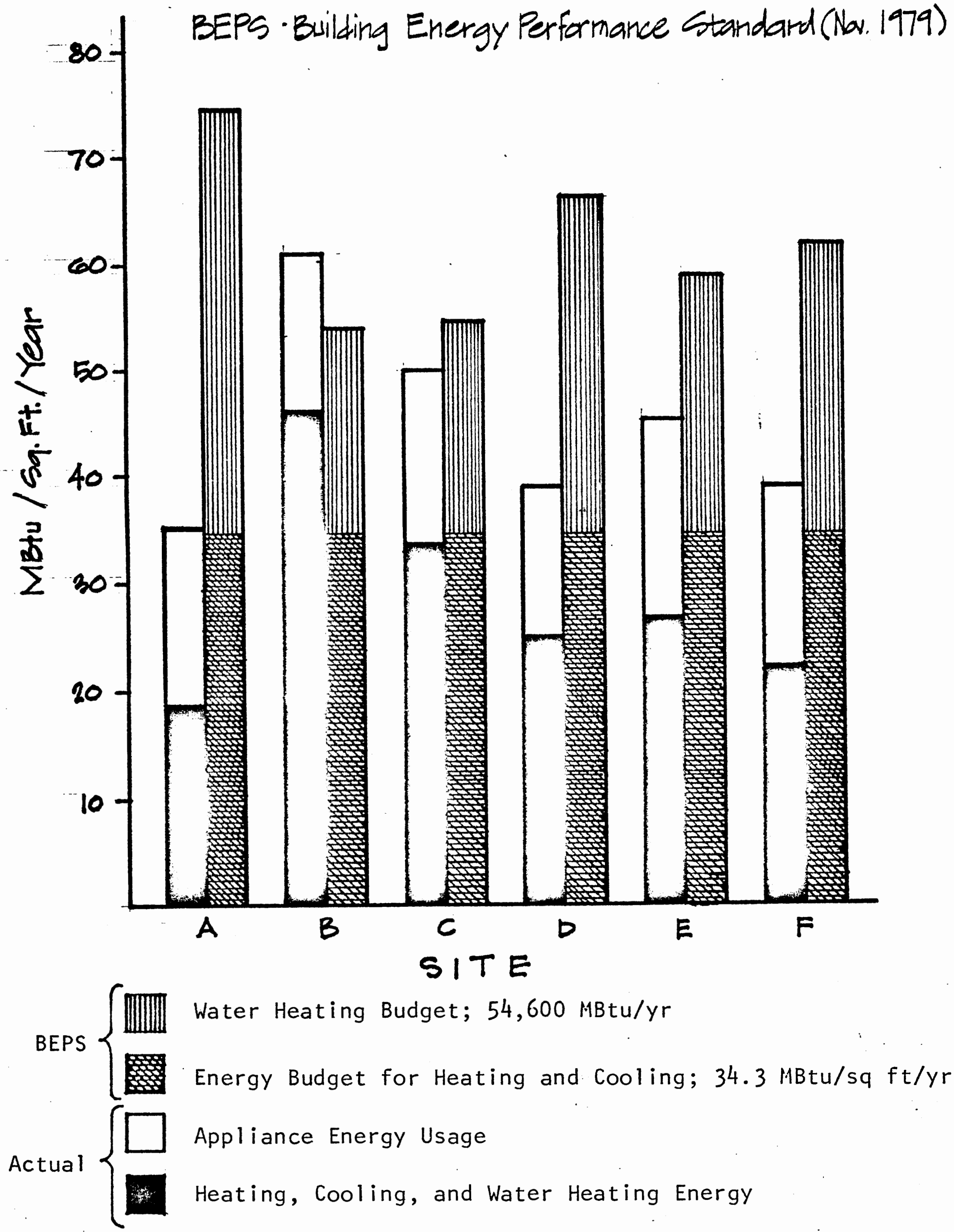


Figure 14. Comparison of Metered Energy Consumption to BEPS Energy Budget

suspect), the total gross metered annual energy consumption which includes appliance usage is less than the BEPS energy budget for space conditioning and water heating alone. By deleting the appliance energy consumption of the samples, the benefits of earth sheltering are further demonstrated. A question arises as to the validity of the BEPS energy allocation for domestic water heating. The amount budgeted appears extremely large for all single family dwellings, since dwelling size and number of occupants are not considered.

Design Loads

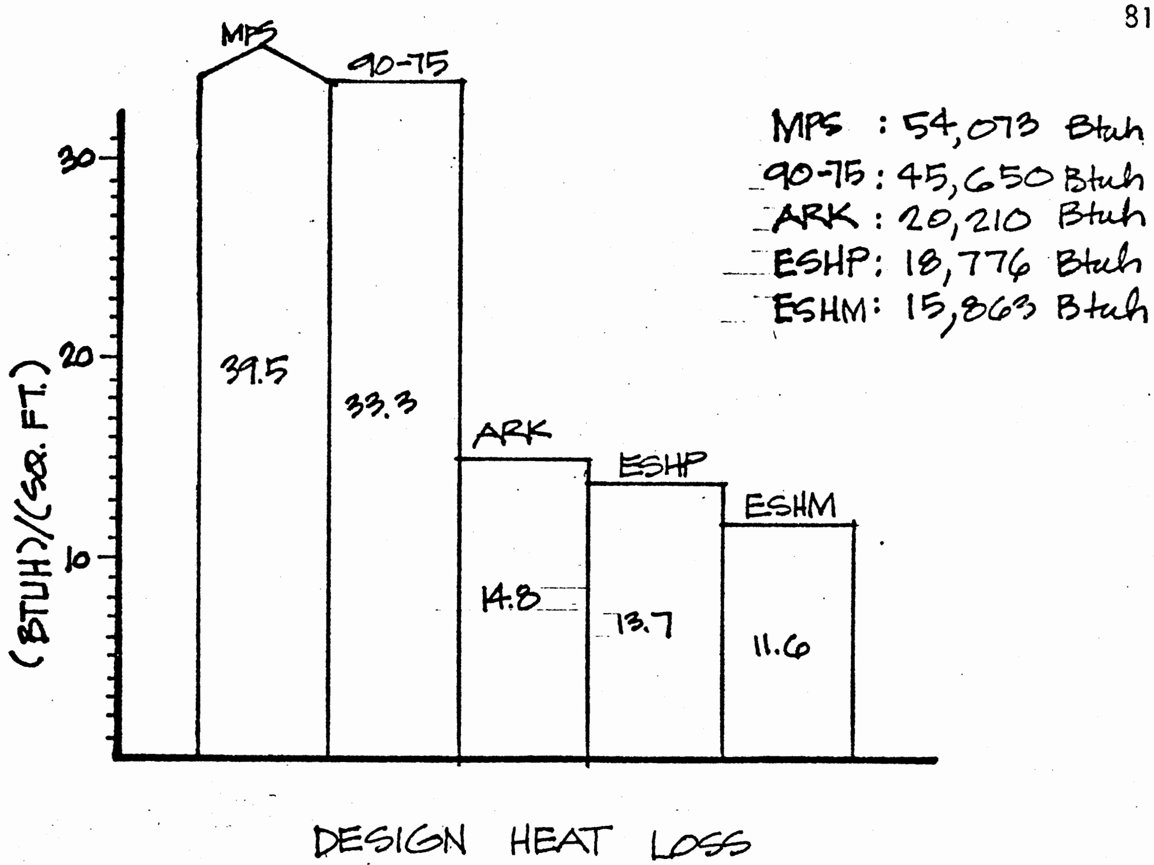
Projected design loads for equivalent above grade dwellings meeting construction requirements of MPS, ASHRAE 90-75, and the "Arkansas" House are compared to the design heating and cooling loads of their earth sheltered counterpart. Figures 15 through 20 present the comparisons of design loads for Sites A through F respectively, as a function of gross floor area.

The predicted loads for the earth sheltered dwellings, ESHP, are the design heat loss and the design cooling load found using the methods described in Chapter V. The "metered" heat loss and heat gain of each site, ESHM, are estimated by subtracting the appliance and water heating energy from the metered value of total consumption. The appliance and water heating energy used is identical to the amount added to the calculated loads, ESHP, when determining the predictive total energy consumption. The "metered" heat loss is found by reversing the degree day method using the February degree day total, and the "actual" cooling load is derived by reversing the energy estimation method outlined in Chapter V using the July energy usage. The values of ESHA for case B should probably be discounted, as meter readings appear extremely unusual when compared to all the other samples. The loads for the MPS, 90-75, and Arkansas equivalent dwellings are those determined in Chapter VI.

Figure 15 shows the design loads for Site A. The unusually high heat loss rate can be attributed to the building configuration as it is long and narrow, with a large exposed wall. The relationship between the different loads is typical of earth sheltered and above grade dwellings, with MPS being the highest and ESHA being lowest.

The comparison of design loads for Site B is presented in Figure 16. This is the only case where the predicted heat loss for the earth covered structure is higher than the load determined for the "Arkansas" equivalent dwelling. The main reason for the higher value is the lack of insulation on the 2800 sq. ft. roof. Calculations indicate that 58 percent of the ESHP value is heat loss through the roof. Passive solar heating is impossible due to the well-shaded east-facing exposure. Because of this lack of insulation and east-facing exposure, passive cooling strategies could be used in the summer, if the moisture content of the soil overhead is maintained at a high level, and solar radiation is shaded.

In Figure 17, the design heat loss rate and the "metered" heat loss rate are shown as nearly identical for Site C. In all the other cases (excluding B), the "metered" load is less than the predicted heat loss. One reason for the departure for Site C, could be due to the non-earth conventional roof construction. This would also be cause for the high "metered" cooling load shown on the cooling season graph, where exposure to direct solar radiation would make the roof temperature rise above that of an earth sheltered roof.



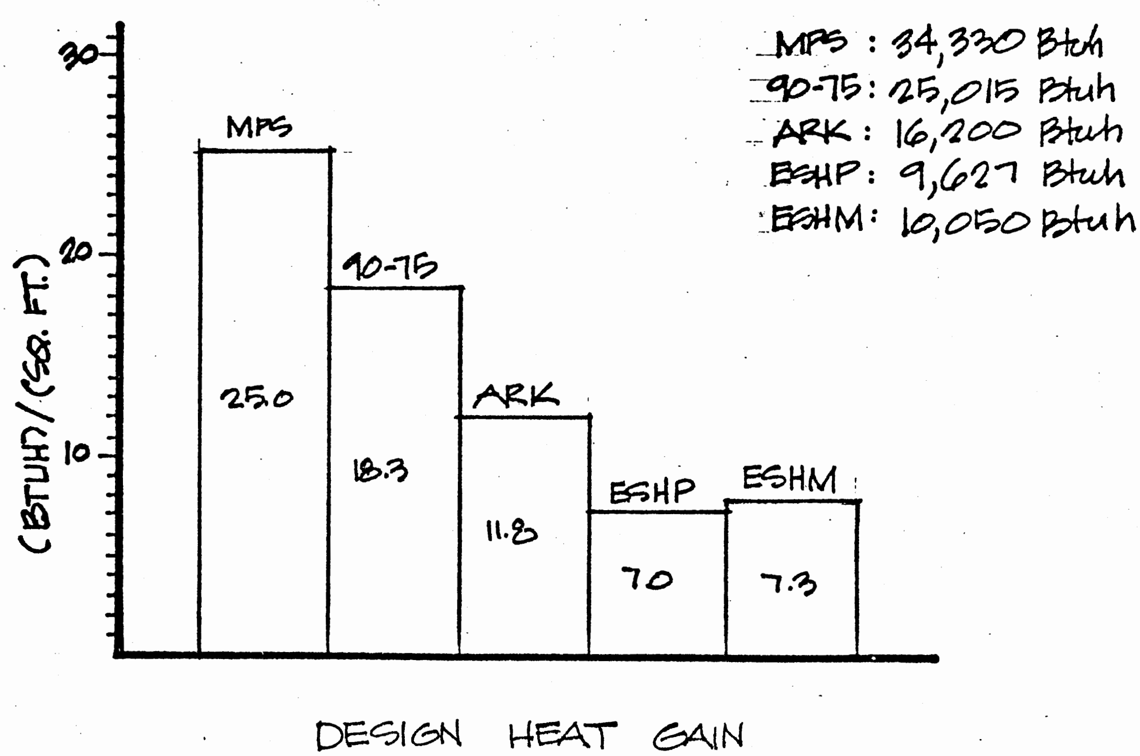
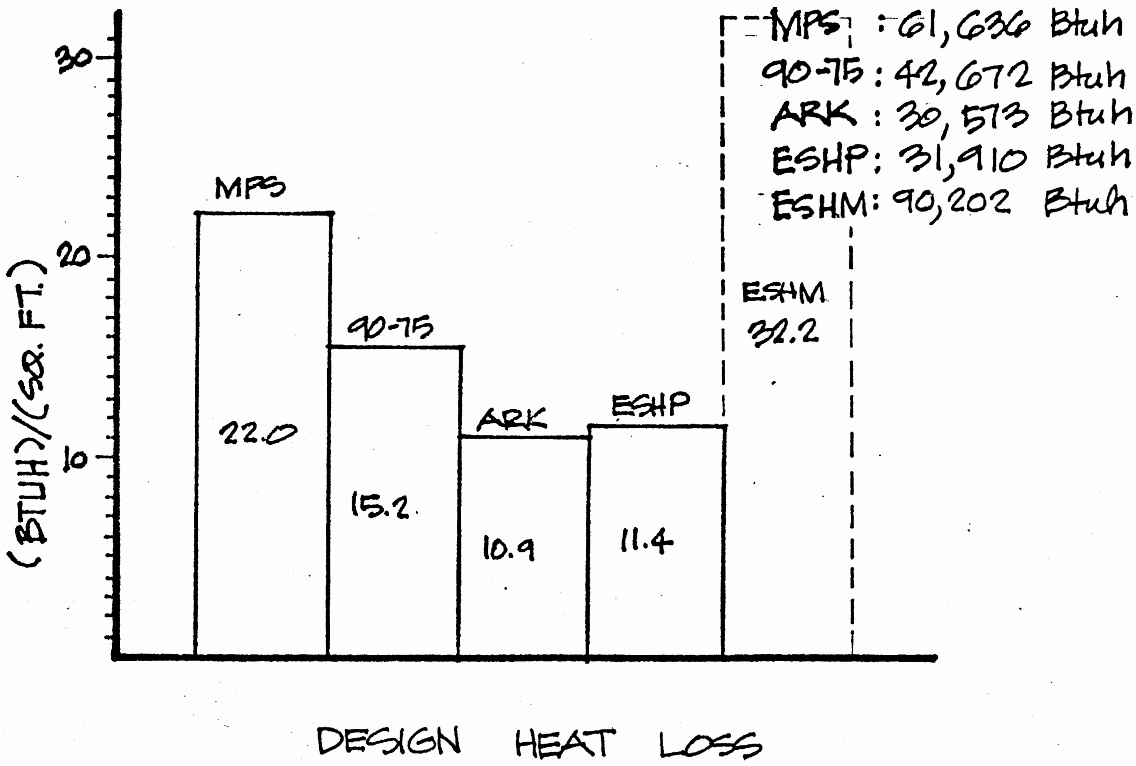


Figure 15. Comparison of Design Loads for Site A.



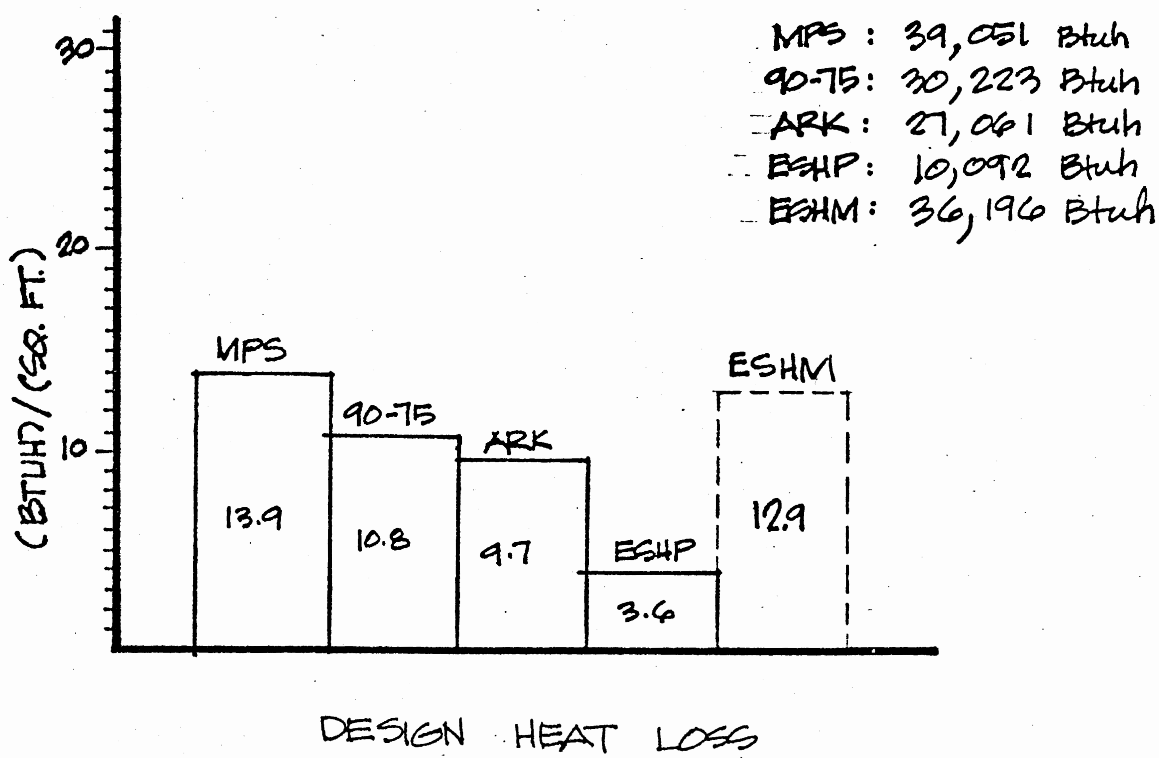
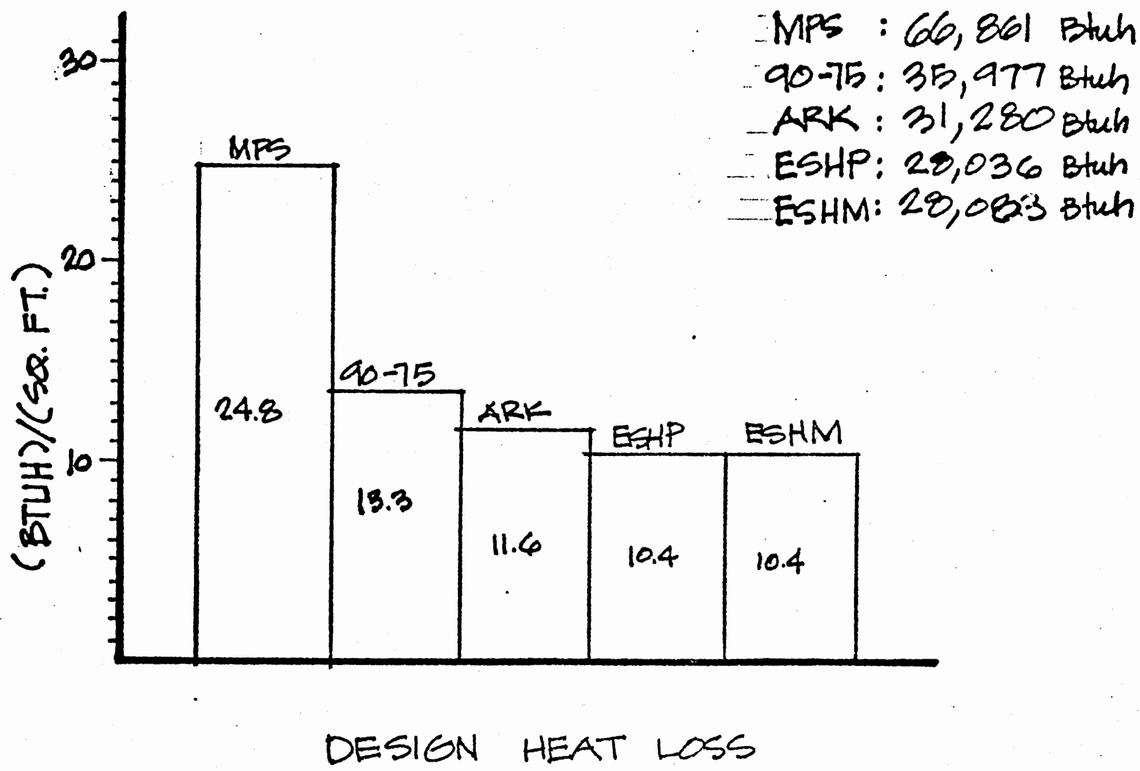


Figure 16. Comparison of Design Loads for Site B.



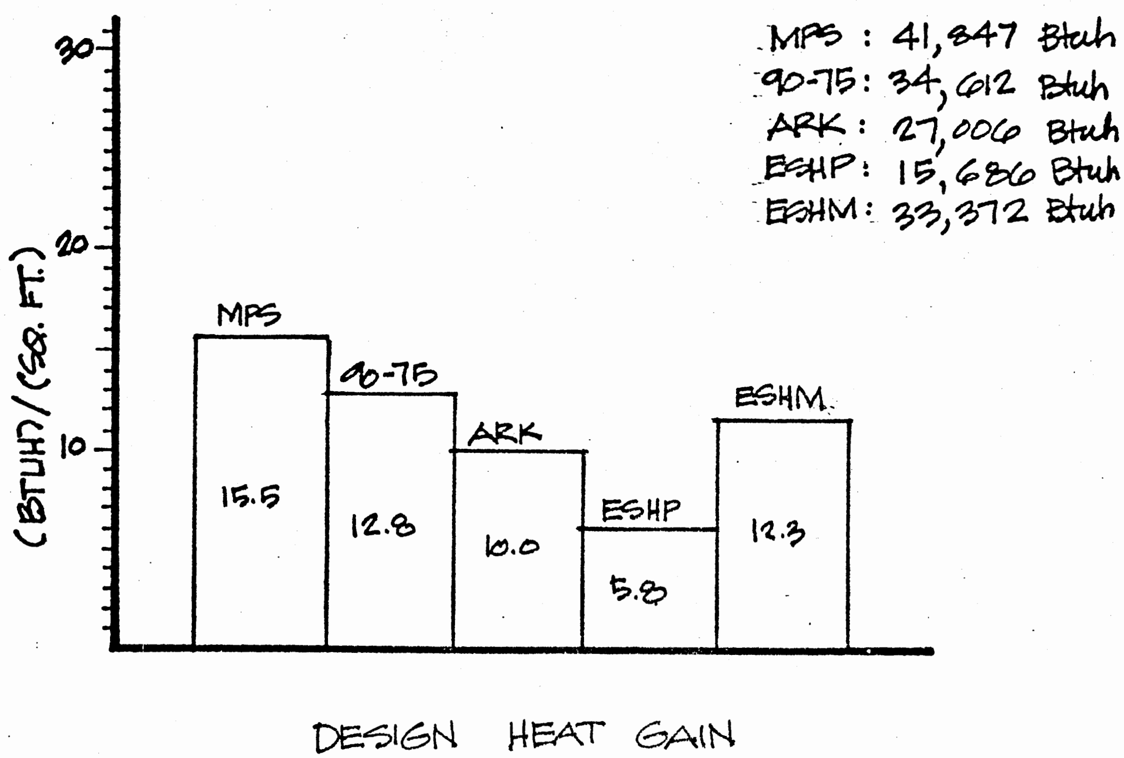
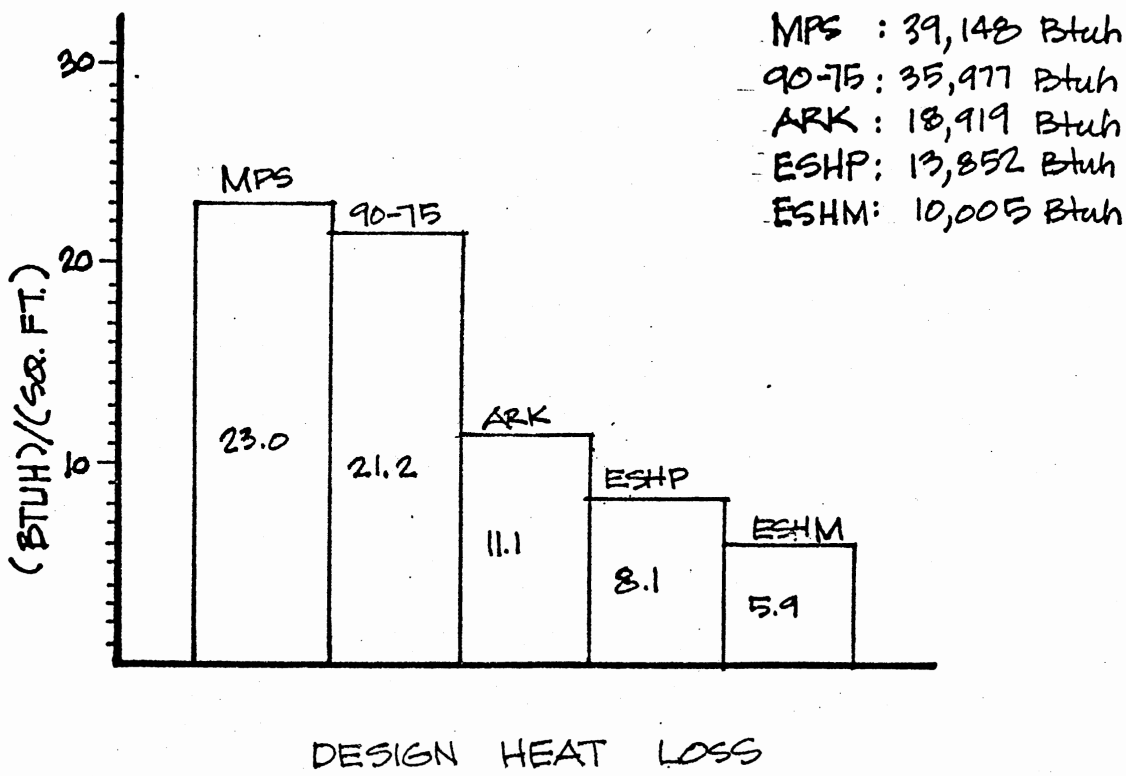


Figure 17. Comparison of Design Loads for Site C.

The pattern of the relationship between design loads and actual loads is typical for Sites D and E, shown in Figures 18 and 19. On the heating cycle, the design heat loss is considerably lower than the design loads of above grade construction, with the actual loss being even lower. For Site D, a probable explanation for this relationship is the small exposed wall area, which minimizes the typically largest portion, next to infiltration, of heat loss. For Site E, the deliberate use of passive solar radiation on the south facing windows and roof might account for the considerable improvement in the actual heating season design load. Although the actual cooling load is significantly larger than the design load for both Sites D and E, the actual values are still considerably less than the next best values of the "Arkansas" equivalent dwellings.

The same basic relationship for the heating and cooling season design loads exists for Site F, shown in Figure 20. The predicted heat loss is again lower than any of the other predicted values, and the estimated "metered" heat loss is lowest on the comparative scale. The "metered cooling season load is greater than the predicted value, but still remains better than any of the other design cooling loads.

The graphs presented in Figure 21 indicate the relative mean values of the various standards of construction considered for Sites A, C, D, E, and F. Site B was not included because of questionable metered readings. When compared to the worst case, MPS, the percentage of savings in design heating load for 90-75, Arkansas House, predicted earth sheltered and estimated actual earth sheltered, are 22 percent, 57 percent, 63 percent, and 72 percent respectively. Reasons for a lower actual value as compared to the predicted value would be attributed to passive solar input and



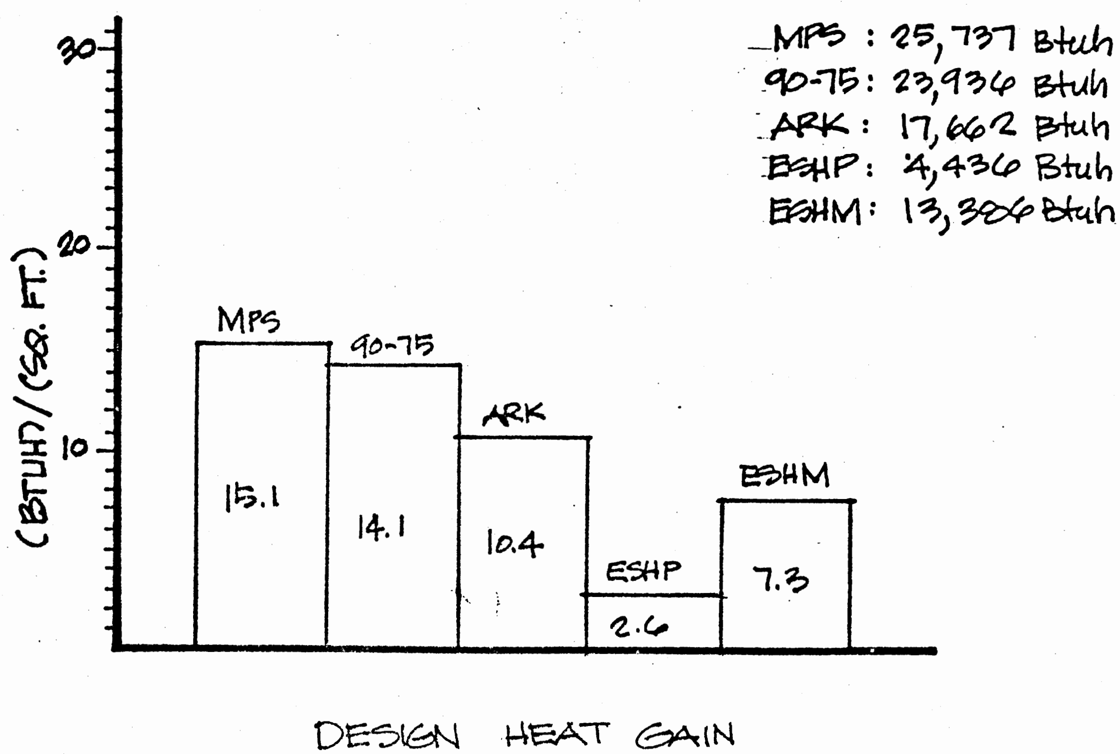
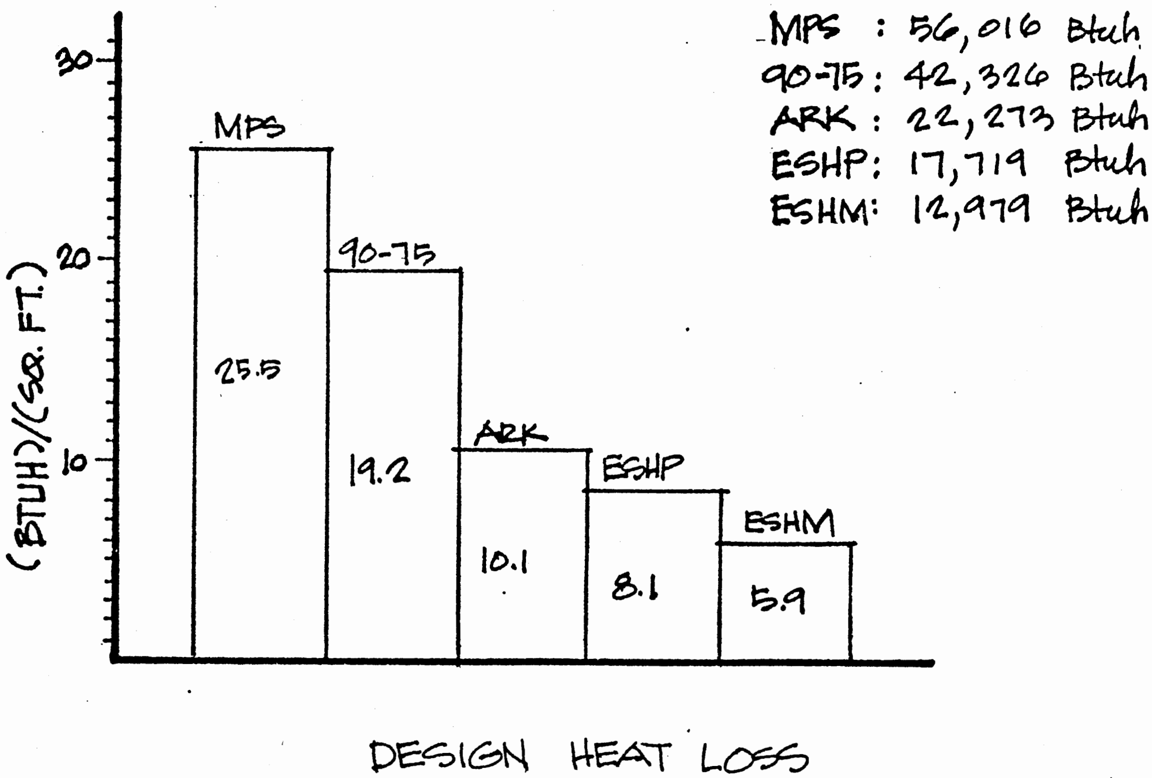


Figure 18. Comparison of Design Loads for Site D.



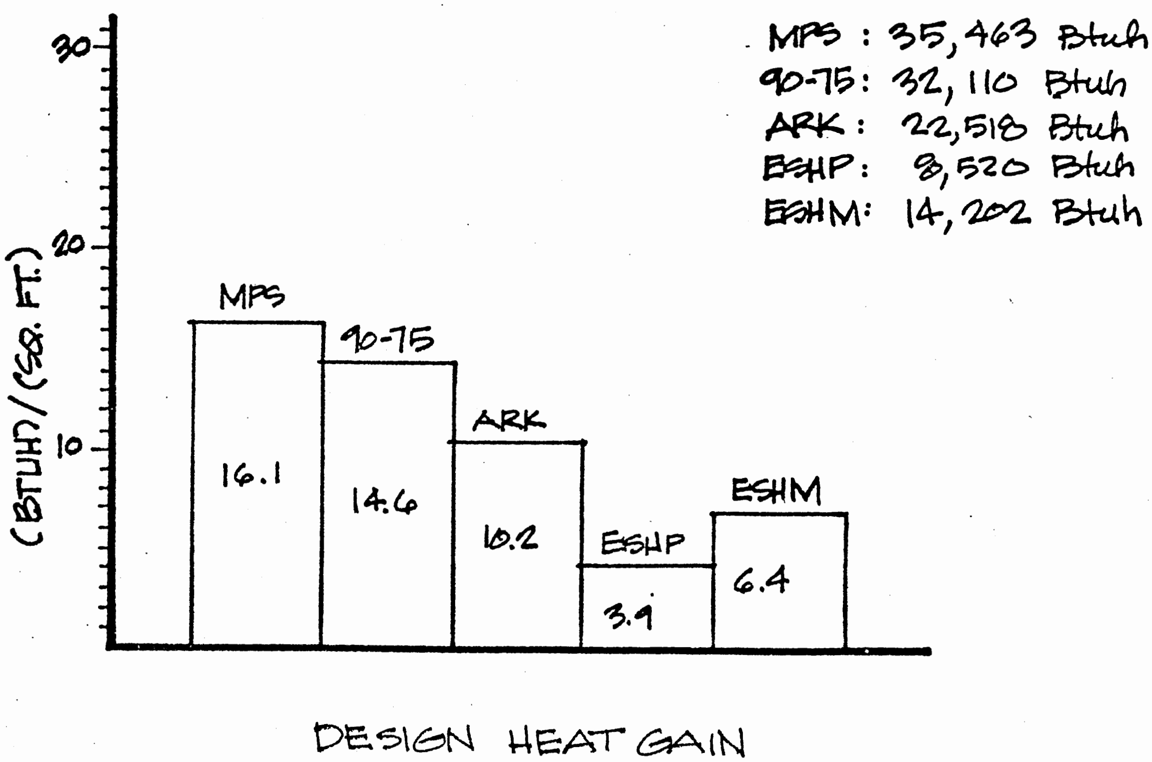
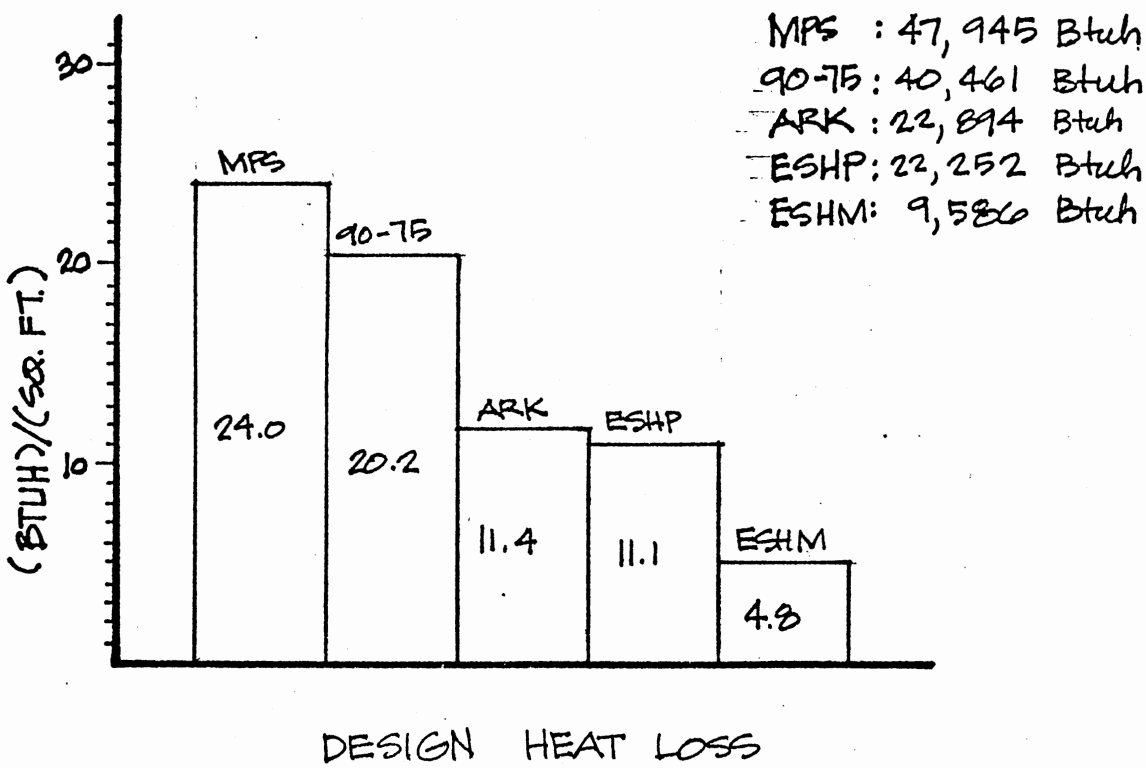


Figure 19. Comparison of Design Loads for Site E.



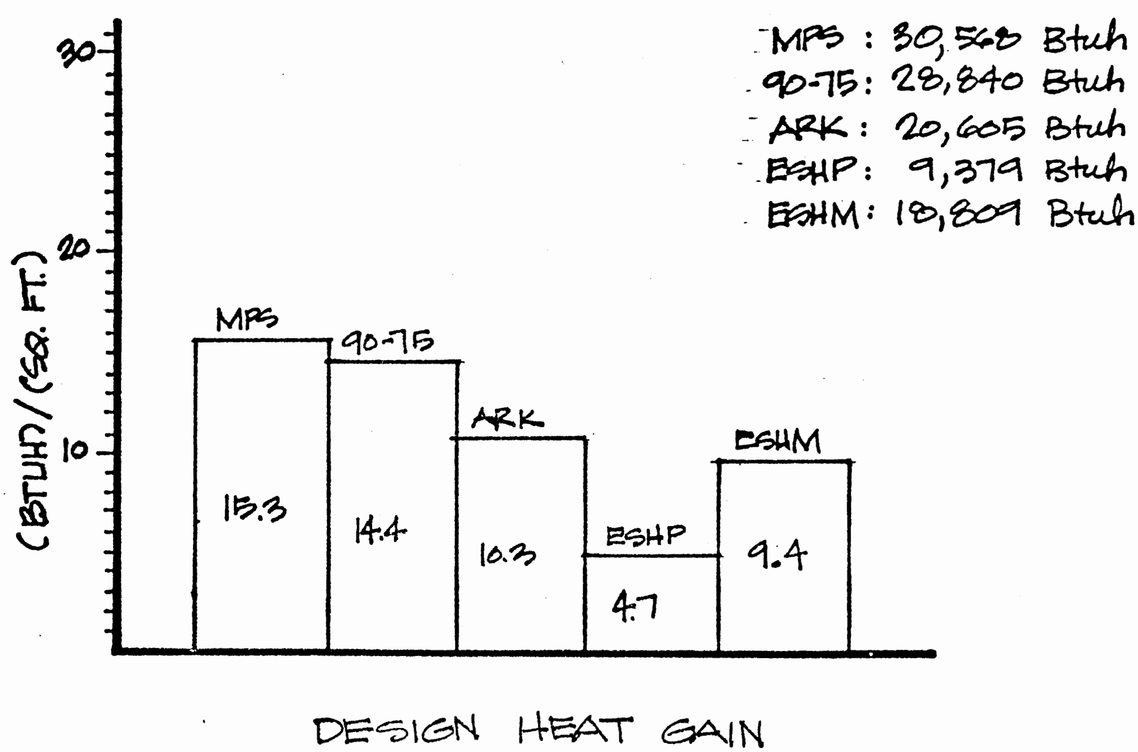
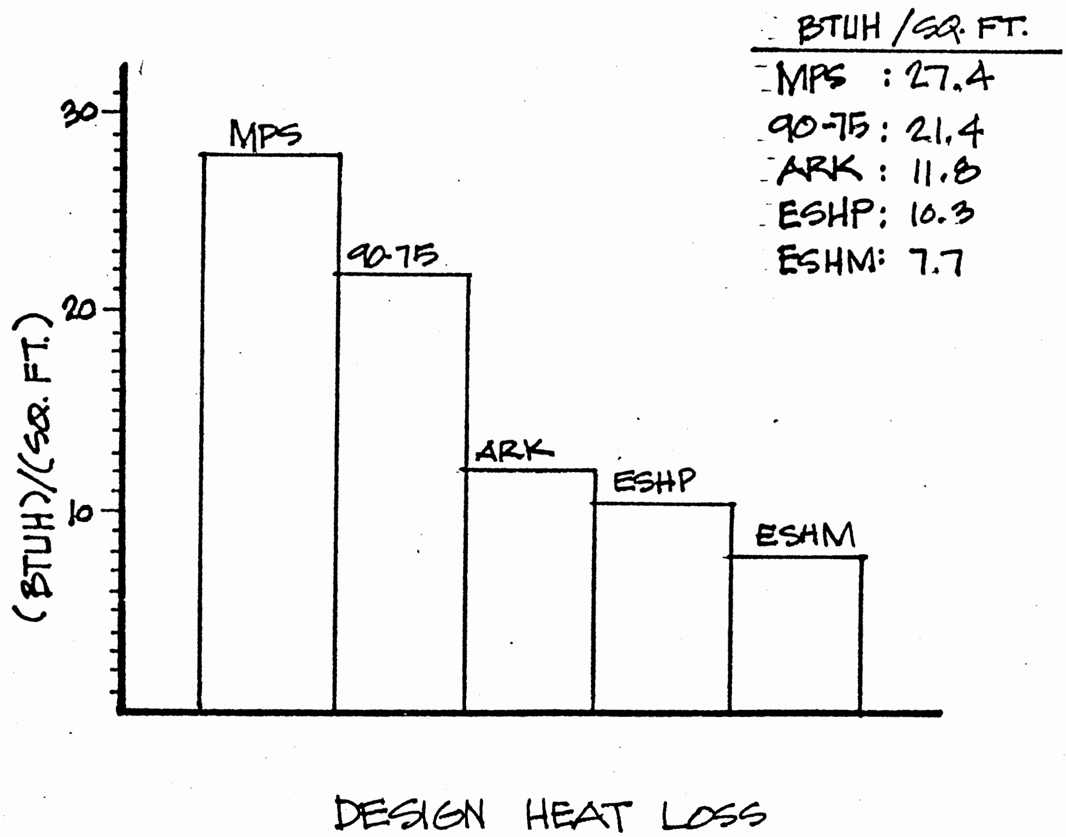
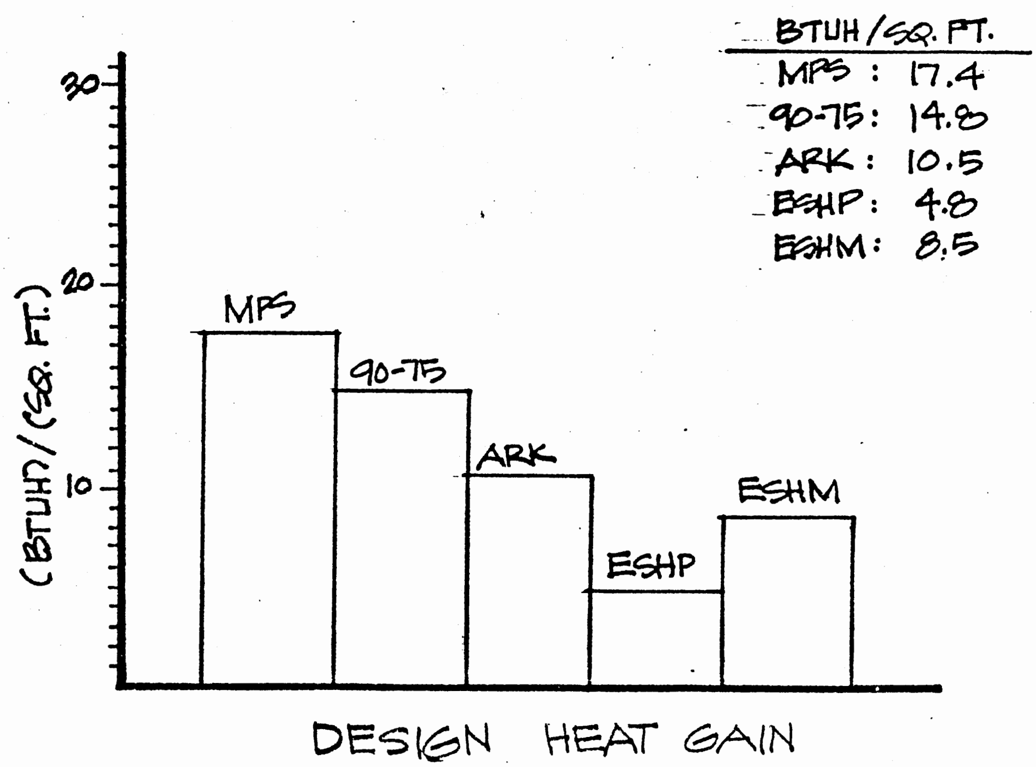


Figure 20. Comparison of Design Loads for Site E.





NOTE: Site B omitted due to abnormal meter readings as compared to other cases.

Figure 21. Comparison of Mean Design Loads.

the enhanced wall temperature effects on comfort discussed in the next section.

For the summer cooling instantaneous design predictions, when compared to the worst case, MPS again, the percentage of savings for 90-75, Arkansas House, predicted earth sheltered, and estimated actual earth sheltered, are 15 percent, 40 percent, 72 percent, and 51 percent respectively. One probable reason for the higher actual value than predicted is the presence of unshielded passive solar gain to earth covered surfaces.

Comfort and Energy Consumption

The previous comparisons of design loads indicate that the earth sheltered dwellings in this study and their "Arkansas" House counterparts are both extremely good energy conserving alternatives. But, these comparisons are static, point measures, whereas actual energy consumption is directly related to thermal comfort of the occupants.

Typically, thermal comfort has been identified by air temperature alone, without consideration of the radiant effect of room surfaces.[1] When occupants in above grade dwellings occupy a space adjacent to an exterior wall, they can become uncomfortable due to cool downdrafts in winter, and hot radiant walls in summer. To counteract these impacts and increase their comfort level, occupants will modify the space temperature by changing the thermostat setting. Because this normally occurs, the actual energy consumption increases beyond expected levels.

In earth sheltered dwellings, this adverse radiant effect of surfaces is significantly reduced which directly affects the comfort level of occupants. The average temperature of the surrounding surfaces is known as the mean radiant temperature (MRT). By most estimates, if the MRT is reduced by $1^{o}F$, and the air temperature rises $1^{o}F$, then the same level of comfort is maintained. In pre-1975 air conditioning design, the MRT was assumed to be equal to the inside air temperature, which is not the case in earth sheltered structures. Because of the passive cooling effect of earth backed walls, ceilings, and floors, the air temperature can be allowed to rise, thermostats can be allowed to rise, thermostats can be set higher, and occupants will still maintain a normal feeling of thermal comfort. It is important to maintain good thermal contact between the deep underground and the living space in order to take advantage of the earth heat sink.[2] Significant comfort improvements can occur with this deliberate MRT design enhancement even with relatively high air temperatures.[3]

The same benefits of MRT occur in the heating season, only in an opposite way. In winter, the air temperature can be permitted to go lower than the $72^{o}F$ comfort region, and occupants will still be comfortable. The energy stored in the earth from summer months reduces heat losses from the space to the surrounding earth. Because of this phenomenon, the relative MRT will be higher than in summer, while the air temperature is lower in order to save energy. Another very significant winter strategy that enhances the MRT effect is the use of passive solar heating.

When comparing earth sheltered designs to above grade designs with respect to energy usage, this MRT aspect is not typically considered. Because of this MRT effect of earth backed walls (and passive solar heating in winter), the thermostats can be lowered in winter and raised in summer and occupants will experience the same level of comfort while saving energy. Taking this fact into account, and re-examining the previous comparisons, it is likely that although the design loads for the "Arkansas" House equivalent dwellings and earth sheltered structures are about the same, the energy consumption would differ significantly. As shown by the mean values in Figure 21, the "metered" heat loss experienced is lower than predicted values, probably due to this MRT effect primarily, which combined with the marginal passive solar gains result in a lower than normal thermostat setting in winter. Although the metered heat gain value is greater than the predicted value, probably due to unshaded passive gain and lack of evaporative cooling effects on the roofs, in summer, it still remains lower than the "Arkansas" House values. In an actual case, the energy consumption indicated by the Arkansas cooling load would be expected to increase, as occupants would, more than likely, turn down the thermostat in order to maintain comfort when adverse MRT conditions exist.

END NOTES

[1]L. L. Boyer, "Radiant Panel Effects of Floor/Ceiling Assemblies Incorporating Static, Return, and Supply Plenums," ASHRAE Transactions, Vol. 74, (Part II), 1968.

[2]S. J. Raff, "Ground Temperature Control," Underground Space, July/August, 1978, Vol. 3, No. 1, p. 35.

[3]D. L. Smith, "Mean Radiant Temperature and its Effects on Energy Consumption," Proceedings of the 4th National Passive Solar Conference, G. Franta (Ed.) American Section/International Solar Energy Society, 1979, p. 431.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Restatement of Study

As presented in Chapter I, the need for energy conserving solutions in the building community has contributed to the rise of earth sheltering in recent years. Because earth integrated structures have been proven to be an energy saving alternative to above grade construction, earth covered buildings have begun to be built at an almost exponential rate. The goals of this study, as stated in Chapter II, were to quantify the energy performance of selected earth sheltered dwellings, and compare the expected and actual energy levels with several energy standards currently used. It was out of a personal interest in this mode of habitat that this study was initiated.

Procedure and Findings

Six dwellings located in the state of Oklahoma were analyzed in this study. Actual metered energy consumption for each dwelling was presented exactly as received from monthly utility billings. Heating and cooling loads were calculated using adaptations of currently available methodologies. In order to make comparisons with the total metered energy, appliance and water heating estimates were added to the calculated energy required for space conditioning. Comparison of the actual total to the predicted total energy usage indicates that the predicted values are in fairly good agreement with the actual values.

In an approach to measure the energy effectiveness of earth sheltered housing, the design loads of above grade equivalent dwellings were calculated and then compared to the predicted design loads and estimated actual loads of the six residences in this study. The annual actual total consumption for the residences is compared to allowable energy budget currently proposed by federal law.

Conclusions

Due to the complex nature of heat transfer from earth sheltered dwellings, there is a general feeling that available hand calculation methods are not adequate when dealing with underground construction. The methodologies used in this study have been shown to predict with reasonable accuracy the total annual energy consumption. Although the comparison might indicate that the predictive methods could be used, more actual performance data from detailed on-site monitoring is needed in order to accept the validity of the findings presented. The bases used for numerous assumptions should also be substantiated.

As comparisons with good, energy conscious above grade design point out, the earth sheltering alternative is a viable answer to the energy crisis at a residential level.

The comparisons substantiate what was expected. The particular earth sheltered residences examined cut down on the space conditioning requirements by as much as 72 percent in the winter and 51 percent in the summer. The comparisons are of a classical nature, but consideration of above grade dwellings and below grade structures in the same comparison is not really a fair appraisal. Because of the dissimilar boundary conditions, thermal comfort is perceived differently for each case, and the energy consumption patterns would be expected to differ from below grade to above grade conditions. Energy savings beyond those identified could be expected due to the ramifications of this comfort aspect. Development of a more sensitive comfort indicator, or index, for earth sheltered housing would also increase the accuracy of energy consumption analyses.

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APPENDIX A

HEATING SEASON CALCULATIONS

HEAT LOSS CALCULATIONS

Heating Season : Nov, Dec, Jan, Feb, Mar

ACTUAL DEGREE DAYS

Month	Site					
	A	B	C	D	E	F
Nov	460	347	436	437	273	347
Dec	720	650	767	866	708	750
Jan	1061	1087	1192	1221	1061	1134
Feb	976	898	990	932	742	844
Mar	517	461	493	434	362	399
Other*	230	213	155	300	312	336
TOTAL	3964	3656	4033	4190	3458	3810

*Other = D.D. Total in other Months

Presented as Coincident data; actual time period identical to metered data.

Sites A, B, C, : Dec 1977 to Nov 1978
Sites D, F : Jun 1978 to May 1979
Site E : Jul 1978 to Jun 1979

Source: Enviromental Data and Information Service, National Oceanic and Atmospheric Administration, National Climatic Center, Ashenville, N.C., Vol. 87, Vol. 88, № 1-7.

CONSTRUCTION U-FACTORS: Assumptions *

ALL SITES: Windows; Double Pane U=0.58
Doors; 1¼" w/ Storm Dr. U=0.34

EXPOSED ASSEMBLIES:

SITE A: Frame Construction U=0.085

SITE B: Masonry construction w/ Insulation in Sandwich U=0.11

@ Garage Party Wall; 8" Conc. Blk. w/ Furred Gyp. Bd. U=0.176

SITE C: Conc. Blk. Construction w/ R-12 Polyurethane U=0.07

Roof: U=0.066

SITE D: Conc. Blk. Construction w/ Stucco Finish, Brick U=0.377

@ Garage, 8" Conc. Blk U=0.367

SITE E: Frame Construction w/ Brick Veneer U=0.07

SITE F: Frame Construction w/ Brick Veneer U=0.07

@ Garage; Conc. Blk w/ Furred Gyp. Bd. U=0.18

SOURCE: M.J. McGuinness & B. Stein, Mechanical and Electrical Equipment for Buildings, John Wiley & Sons, Inc. New York, 1971, p. 155.

* Based on data shown on questionnaires.

Outside Design Temp, t_o = 13°F

Inside Design Temp, t_i = 70°F

HEAT LOSS CALCULATIONS: SITE A

Mean Annual Air Temperature = 59.7, ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.498 Btuh/ft °F)
Length of Wall = 115'
Total Wall Heat Loss = (115)(0.498) = 57.27 Btuh/F

2) Heat Loss Through Floor Slab: Table VIII, Area = 1370
Width: (16); (0.029 Btuh/ft² °F)(1370) = 39.73 Btuh/F

3) Heat Loss Through Roof: 1½" Insulation, 2' Soil cover
(0.035 Btuh/ft²°F)(1370) 47.95 Btuh/F

4) Total Loss @ Earth Backed Surfaces: 144.95 Btuh/F
Ext. Design Temp = ($\bar{t}_a$ - A) = (59.7 - 20) = 39.7°F
Design Temp Difference = (70 - 39.7) = 30.3°F
(144.95)(30.3) = 4391.9 Btuh

5) Exposed Facade Losses:

Walls: (0.085)(577 ft²)(57)	=	2795.57
Windows: (0.58)(90 ft²)(57)	=	2975.40
Doors: (0.34)(21 ft²)(57)	=	406.98
		6177.95 Btuh

6) Slab Edge Loss: Exposed Length = 86', F = 31
(86)(31) = 2666 Btuh

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each
(0.5)(180 CFM)(1.08)(57) 5540 Btuh

8) TOTALS:

Earth Backed Surfaces	=	4391.9
Exposed Construction	=	6177.9
Slab Edge	=	2666.0
Infiltration	=	5540.0

DESIGN HEAT LOSS 18,775.8 Btuh

HEATING ENERGY ESTIMATION: SITE A

NOVEMBER

$$\frac{(18{,}776)(460)(24}{(57)(3413)} = \underline{1065.5 \text{ KWH}}$$

DECEMBER

$$\frac{(18{,}776)(720)(24)}{(57)(3413)} = \underline{1667.7 \text{ KWH}}$$

JANUARY

$$\frac{(18{,}776)(1061)(24)}{(57)(3413)} = \underline{2457.6 \text{ KWH}}$$

FEBRUARY

$$\frac{(18{,}776)(976)(24)}{(57)(3413)} = \underline{2260.7 \text{ KWH}}$$

MARCH

$$\frac{(18{,}776)(517)(24)}{(57)(3413)} = \underline{1197.5 \text{ KWH}}$$

HEAT LOSS CALCULATIONS: SITE B

Mean Annual Air Temperature = 60.2°F, ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.67) Btuh/ft °F

Length of Wall = 138'

Total Wall Heat Loss = (138)(0.67) = 92.46 Btuh/F

2) Heat Loss Through Floor Slab: Table VIII, Area = 2800

Width: (36'); (0.014 Btuh/ft² °F)(2800) = 39.2 Btuh/F

3) Heat Loss Through Roof: - Insulation, 2' Soil cover

(2800)(0.222 Btuh/ft² °F) = 621.6 Btuh/F

4) Total Loss @ Earth Backed Surfaces: 753.26 Btuh/F

Ext. Design Temp = ($\bar{t}_a$ - A) = (60.2 - 20) = 40.2 °F

Design Temp Difference = (70 - 40.2) = 29.8 °F

(29.8)(753.26) = 22,447 Btuh

5) Exposed Facade Losses: $\Delta T_{Garage} = 20$

Walls:	(231 ft²)(0.11)(57)	=	1448.4
	(219 ft²)(0.176)(20)	=	770.9
Windows:	(57 ft²)(0.58)(57)	=	1884.4
Doors:	(21 ft²)(0.34)(57)	=	407.0
	(21 ft²)(0.34)(20)	=	142.8
			4653.5 Btuh

6) Slab Edge Loss: Exposed Length = 36', F = 31

(36)(31) = 1116 Btuh

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each

(60)(1.08)(57) = 3693

8) TOTALS:

Earth Backed Surfaces	=	22,447
Exposed Construction	=	4654
Slab Edge	=	1116
Infiltration	=	3693
DESIGN HEAT LOSS		31,910 Btuh

HEATING ENERGY ESTIMATION: SITE B

NOVEMBER

$$\frac{(31,910)(347)(24)}{(57)(3413)} = \underline{1366.0 \text{ KWH}}$$

DECEMBER

$$\frac{(31,910)(650)(24)}{(57)(3413)} = \underline{2558.8 \text{ KWH}}$$

JANUARY

$$\frac{(31,910)(1087)(24)}{(57)(3413)} = \underline{4279.1 \text{ KWH}}$$

FEBRUARY

$$\frac{(31,910)(898)(24)}{(57)(3413)} = \underline{3535.1 \text{ KWH}}$$

MARCH

$$\frac{(31,910)(461)(24)}{(57)(3413)} = \underline{1814.8 \text{ KWH}}$$

HEAT LOSS CALCULATIONS: SITE C

Mean Annual Air Temperature = 58.5°F, ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.892 Btuh/ft °F)
Length of Wall = 220'
Total Wall Heat Loss = (220)(0.892) = <u>196.24 Btuh/F</u>

2) Heat Loss Through Floor Slab: Table VIII, Area = 2700
Width: (27'); (0.019 Btuh/°F ft²)(2700) = <u>51.3 Btuh/F</u>

3) Heat Loss Through Roof: 10" Insulation, 0" Soil cover
(0.066)(2700)(57) = <u>10,192 Btuh</u>

4) Total Loss @ Earth Backed Surfaces:

Ext. Design Temp = ($\bar{t}_g$ - A) = (58.5 - 20) = 38.5 °F
Design Temp Difference = (70 - 38.5) = 31.5°F
(247.54 Btuh/F)(31.5) = <u>7797.5 Btuh</u>

5) Exposed Facade Losses:

Walls: (0.07)(534 ft²)(57) = 2130.7

Windows: (0.58)(16 ft²)(57) = 528.9

Doors: –

<u>2659.6 Btuh</u>

6) Slab Edge Loss: Exposed Length = 0, F = 0

<u>0</u>

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each
(120)(1.08)(57) = <u>7387.2 Btuh</u>

8) TOTALS:

Earth Backed Surfaces	=	7797.5
Exposed Construction	=	12,852.0
Slab Edge	=	–
Infiltration	=	7387.2
<u>DESIGN HEAT LOSS</u>		<u>28,036.7 Btuh</u>

HEATING ENERGY ESTIMATION: SITE C

NOVEMBER

$$\frac{(28,036)(436)(24)}{(57)(3413)} = 1508.0 \text{ KWH}$$

DECEMBER

$$\frac{(28,036)(767)(24)}{(57)(3413)} = 2652.8 \text{ KWH}$$

JANUARY

$$\frac{(28,036)(1192)(24)}{(57)(3413)} = 4122.8 \text{ KWH}$$

FEBRUARY

$$\frac{(28,036)(990)(24)}{(57)(3413)} = 3424.1 \text{ KWH}$$

MARCH

$$\frac{(28,036)(493)(24)}{(57)(3413)} = 1705.2 \text{ KWH}$$

HEAT LOSS CALCULATIONS: SITE D

Mean Annual Air Temperature = 59.2°F, ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.67 Btuh / ft °F)
Length of Wall = 122'
Total Wall Heat Loss = (122)(0.67) = **81.74 Btuh/F**

2) Heat Loss Through Floor Slab: Table VIII, Area = 1700
Width: (34'); (0.015 Btuh/ft² °F)(1700) = **25.5 Btuh/F**

3) Heat Loss Through Roof: 10" Insulation, 2' Soil cover
(0.015 Btuh/ft² F)(1700) = **25.5 Btuh/F**

4) Total Loss @ Earth Backed Surfaces: 132.74 Btuh/F
Ext. Design Temp = ($\bar{E}_q$ − A) = (59.2 − 20) = 39.2 °F
Design Temp Difference = (70 − 39.2) = 30.8 °F
(132.74)(30.8) = **4088.4 Btuh**

5) Exposed Facade Losses: ΔT_{Garage} = 20

Walls:	(46 ft²)(0.377)(57)	=	988.5
	(251 ft²)(0.367)(20)	=	1842.3
Windows:	(18 ft²)(0.58)(57)	=	595.2
Doors:	(21 ft²)(0.34)(57)	=	407.0
	(21 ft²)(0.34)(20)	=	142.8
			3975.8 Btuh

6) Slab Edge Loss: Exposed Length = 8', F = 31
(8)(31) = **248 Btuh**

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each
(.5)(180)(57)(1.08) = **5540 Btuh**

8) TOTALS:

Earth Backed Surfaces	=	4088.4
Exposed Construction	=	3975.8
Slab Edge	=	248.0
Infiltration	=	5540.0
DESIGN HEAT LOSS		**13,852.2 Btuh**

HEATING ENERGY ESTIMATION: SITE D

NOVEMBER

$$\frac{(13{,}852)(437)(24)}{(57)(3413)} = 746.8 \text{ KWH}$$

DECEMBER

$$\frac{(13{,}852)(866)(24)}{(57)(3413)} = 1479.9 \text{ KWH}$$

JANUARY

$$\frac{(13{,}852)(1221)(24)}{(57)(3413)} = 2086.5 \text{ KWH}$$

FEBRUARY

$$\frac{(13{,}852)(932)(24)}{(57)(3413)} = 1592.7 \text{ KWH}$$

MARCH

$$\frac{(13{,}852)(434)(24)}{(57)(3413)} = 741.7 \text{ KWH}$$

HEAT LOSS CALCULATIONS: SITE E

Mean Annual Air Temperature = 60.5°F, ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.67 Btuh/ft °F)

Length of Wall = 141'

Total Wall Heat Loss = (141)(0.67) = 94.6 Btuh/F

2) Heat Loss Through Floor Slab: Table VIII, Area = 2200

Width: (48'); (0.008) Btuh/ft²F (2200) = 17.6 Btuh/F

3) Heat Loss Through Roof: 4" Insulation, 2' Soil cover

(0.035 Btuh/ft² °F) (2200) 77.0 Btuh/F

4) Total Loss @ Earth Backed Surfaces: 189.2 Btuh/F

Ext. Design Temp = ($\bar{t}_a$ − A) = (60.5 − 20) = 40.5 °F

Design Temp Difference = (70 − 40.5) = 29.5°F

(189.2)(29.5) = 5581.4 Btuh

5) Exposed Facade Losses:

Walls:	(305 ft²)(0.7)(57) =	1234.3
Windows:	(50 ft²)(0.58)(57) =	1653.0
Doors:	(21 ft²)(0.34)(57) =	407.0
		3294.3 Btuh

6) Slab Edge Loss: Exposed Length = 47', F = 31

(47)(31) = 1457 Btuh

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each

(2)(60)(57)(1.08) = 7387 Btuh

8) TOTALS:

Earth Backed Surfaces	=	5581.4
Exposed Construction	=	3294.3
Slab Edge	=	1457.0
Infiltration	=	7387.0
DESIGN HEAT LOSS		17,719.7 Btuh

HEATING ENERGY ESTIMATION: SITE E

NOVEMBER

$$\frac{(17,720)(273)(24)}{(57)(3413)} = \underline{596.8 \text{ KWH}}$$

DECEMBER

$$\frac{(17,720)(708)(24)}{(57)(3413)} = \underline{1547.7 \text{ KWH}}$$

JANUARY

$$\frac{(17,720)(1061)(24)}{(57)(3413)} = \underline{2319.4 \text{ KWH}}$$

FEBRUARY

$$\frac{(17,720)(742)(24)}{(57)(3413)} = \underline{1622.1 \text{ KWH}}$$

MARCH

$$\frac{(17,720)(362)(24)}{(57)(3413)} = \underline{791.4 \text{ KWH}}$$

HEAT LOSS CALCULATIONS: SITE F

Mean Annual Air Temperature = 61.2 , ΔT = 57°F

1) Heat Loss Through Earth Backed Walls: Table VII

Loss per foot length of Wall = (0.67 Btuh/ft °F)
Length of Wall = 118'
Total Wall Heat Loss = (118)(0.67) = 79.2 Btuh/F

2) Heat Loss Through Floor Slab: Table VIII, Area = 2000
Width: (36'); (0.014 Btuh/ft² F)(2000) 28.0 Btuh/F

3) Heat Loss Through Roof: Insulation, 2' Soil cover
(0.10 Btuh / ft² F)(2000) 200 Btuh/F

4) Total Loss @ Earth Backed Surfaces: 307.2 Btuh/F

Ext. Design Temp = $(\bar{t}_a - A)$ = (61.2 − 20) = 41.2°F
Design Temp Difference = (70 − 41.2) = 28.8°F
(28.8)(307.2) = 8847.4 Btuh

5) Exposed Facade Losses: ΔT_{Garage} = 20

Walls:	(144 ft²)(0.07)(57)	=	575
	(240 ft²)(0.18)(20)	=	864
Windows:	(144 ft²)(0.58)(57)	=	4760
Doors:	(21 ft²)(0.34)(57)	=	407
	(21 ft²)(0.34)(20)	=	143
			6749 Btuh

6) Slab Edge Loss: Exposed Length = 36', F = 31
(31)(36) = 1116 Btuh

7) Infiltration Loss: Exhaust Fan(s) @ 60 CFM each
(180)(1.08)(57)(.5) = 5540 Btuh

8) TOTALS:

Earth Backed Surfaces	=	8847.4
Exposed Construction	=	6749.0
Slab Edge	=	1116.0
Infiltration	=	5540.0

DESIGN HEAT LOSS 22,252.4 Btuh

HEATING ENERGY ESTIMATION: SITE F

NOVEMBER

$$\frac{(22{,}252)(347)(24)}{(57)(3413)} = \underline{952.6 \quad \text{KWH}}$$

DECEMBER

$$\frac{(22{,}252)(750)(24)}{(57)(3413)} = \underline{2058.9 \quad \text{KWH}}$$

JANUARY

$$\frac{(22{,}252)(1134)(24)}{(57)(3413)} = \underline{3113.0 \quad \text{KWH}}$$

FEBRUARY

$$\frac{(22{,}252)(844)(24)}{(57)(3413)} = \underline{2316.9 \quad \text{KWH}}$$

MARCH

$$\frac{(22{,}252)(399)(24)}{(57)(3413)} = \underline{1095.3 \quad \text{KWH}}$$

APPENDIX B

COOLING SEASON CALCULATIONS

COOLING SEASON CALCULATIONS

Cooling Season Months: Apr, May, Jun, Jul, Aug, Sep, Oct.

AVERAGE MONTHLY TEMPERATURES

MONTH 1978	SITE					
	A	B	C	D	E	F
APR	64.7	65.5	64.5	64.5	62.9	65.5
MAY	69.5	69.2	68.1	68.1	68.5	69.2
JUN	77.5	77.9	77.5	77.5	77.1	77.9
JUL	88.8	85.8	87	87	83.6	85.8
AUG	79	81.1	82.6	82.6	81.7	81.1
SEP	76	79.3	79.7	79.7	76.4	79.3
OCT	62.6	64.7	64.7	64.7	61.8	64.7

SOURCE: Environmental Data and Information Service, National Oceanic and Atmospheric Administration, National Climatic Center, Ashenville, N.C., Vol. 87.

AVERAGE SOLAR HEAT GAIN FACTORS

Values for SHGF found in Chapter 26, ASHRAE 1977 Fundamentals. Half day totals added & then Averaged for 24-hour period. Interpolated between 40° & 32° N. Lat.

MONTH	SHGF		$\overline{\text{SHGF}}$	
	South	North	South	North
APR	848	315	35.3	13.13
MAY	608	437	25.8	18.21
JUN	540	514	22.5	21.42
JUL	600	454	25	18.92
AUG	826	335	34.4	13.96
SEP	1246	249	51.9	10.38
OCT	1544	191	64.3	7.96

$\overline{\text{CLTD}}$ for SUNLIT WALLS

Wall Construction Groups: Frame Wall - G
Masonry - E

Tables found in ASHRAE 1977 Fundamentals, Ch. 25.

CLTD's summed up for whole day & averaged for 24-hour period. Found that $\overline{\text{CLTD}}$ for G & E were same for July, which the table is set up for.

To find $\overline{CLTD}$ for other months & latitudes, use equation below;

$$\overline{CLTD}_{July} + \left[\frac{(SHGF_{Month})}{(SHGF_{July})} - 1 \right] (95 - t_{avg_{month}}) = \overline{CLTD}_{month}$$

where the SHGF values are the daily totals, and $t_{avg_{month}}$ is the average temp. of the month in question.

This equation adapted from correction shown in Note 4, Table 7, Chapter 25.

$\overline{CLTD}$

MONTH	South	North	East/West
APR	29.6	2.5	31.9
MAY	17.5	11.0	32.5
JUN	15.5	13.6	32.5
JUL	17.2	12.0	22.
AUG	22.5	8.3	31.6
SEP	35.5	4.3	30.5
OCT	65.9	-6.0	29

For Both Wall Construction Types, E & G

COOLING LOAD CALCULATIONS: SITE A

Heat Gain Through Exposed Facade: Exposure,

$Q_a + Q_b + Q_c$ Glass Area = 90 sq. ft., U = 0.58
Wall Area = 577 sq. ft., U = 0.085

APRIL: t_a = 64.7, $\overline{SHGF}$ = 35.3, $\overline{CLTD}$ = 29.6

Glass: Convective (0.58)(90)(64.7-75) = -537.66

Radiant (90)(35.3)(0.88) = 2795.76

Wall: (0.085)(577)(29.7) = 1456.64

TOTAL 3714.74 Btuh

MAY: t_a = 69.5, $\overline{SHGF}$ = 25.3, $\overline{CLTD}$ = 17.5

Glass: Convective (0.58)(90)(69.5-75) = -287.10

Radiant (90)(25.3)(0.88) = 2003.76

Wall: (0.085)(577)(17.5) = 858.29

TOTAL 2574.95 Btuh

JUNE: t_a = 77.5, $\overline{SHGF}$ = 22.5, $\overline{CLTD}$ = 15.5

Glass: Convective (0.58)(90)(77.5-75) = 130.50

Radiant (90)(22.5)(0.88) = 1782.0

Wall: (0.085)(577)(15.5) = 760.19

TOTAL 2672.69 Btuh

JULY: $t_a = 88.8$, $\overline{SHGF} = 25$, $\overline{CLTD} = 17.2$

Glass: Convective $(0.58)(90)(88.8-75) = 720.36$

Radiant $(90)(25)(0.88) = 1980.0$

Wall: $(0.085)(577)(17.2) = 843.57$

TOTAL 3543.93 Btuh

AUGUST: $t_a = 79$, $\overline{SHGF} = 34.4$, $\overline{CLTD} = 22.5$

Glass: Convective $(0.58)(90)(79-75) = 208.80$

Radiant $(90)(34.4)(0.88) = 2724.48$

Wall: $(0.085)(577)(22.5) = 1103.51$

TOTAL 4036.79 Btuh

SEPTEMBER: $t_a = 76$, $\overline{SHGF} = 51.9$, $\overline{CLTD} = 35.5$

Glass: Convective $(0.58)(90)(76-75) = 52.20$

Radiant $(90)(51.9)(0.88) = 4110.48$

Wall: $(0.085)(577)(35.5) = 1741.09$

TOTAL 5903.77 Btuh

OCTOBER: $t_a = 62.6$, $\overline{SHGF} = 64.3$, $\overline{CLTD} = 65.9$

Glass: Convective $(0.58)(90)(62.6-75) = -647.28$

Radiant $(90)(64.3)(0.88) = 5092.56$

Wall: $(0.085)(577)(65.9 = 3232.06$

TOTAL 7677.34 Btuh

COOLING LOAD CALCULATIONS: SITE A

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

(2 Btuh/ft^2)(1370 ft^2)(.5) = 1370 Btuh

PEOPLE

2 occupants; 1 male, 1 female

Sleeping (8 hrs)(1.85)(350 = 5180

Occupied (6 hrs)(1.85)(420) = 4662

(9842)/(24) = 410 Btuh

UNCONDITIONED SPACES none

COOLING LOAD CALCULATIONS: SITE A

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

$S_i = 1657$ sq. ft.

$S_p = 1657/2 = 828.5$ sq. ft.

$a = \sqrt{1657} = 40.7$

$$N = (1.5)\frac{(40.7)}{(0.75)}\left[\frac{(1.08)(10)+(10)}{(1.08)(10)+(10)+(1.5)(828.5)}\right] = 1.34$$

$$T = \frac{(0.6)}{(1657)} = .0004 \quad , N\sqrt{T} = 0.027 \quad , \phi = 0.14$$

$$n = \frac{(1.5)(828.5)}{(1.08)(10)+(10)+(1.5)(828.5)} = 0.984$$

$$U_o = \frac{1}{\left[(1-0.984) + (0.984)(0.14)\right]} = 6.5$$

APRIL: $t_a = 64.7$, $Q_i = 2747.4$ Btuh/person

$$Q_r = (2747.4) + \left[10(100-70)\right] + \left[(1.08)(10)(64.7-70)\right]$$
$$-\left[(1.08)(10)+(10)\right](6.5)$$
$$= 2801.96$$

$Q_d = (2802)(2) = 5604$ Btuh

MAY: $t_q = 69.5$, $Q_i = 2177.48$

$Q_r = (2177.48) + (300) + (10.8)(69.5-70) - (20.8)(6.5)$

$= 2336.8$ Btuh/person

$Q_d = (2336.8)(2) = 4673.76$ Btuh

JUNE: $t_q = 77.5$, $Q_i = 2226.35$

$Q_r = (2226.35) + (300) + (10.8)(77.5-70) - (135.2)$

$= 2472.15$ Btuh/person

$Q_d = (2472.15)(2) = 4944.3$ Btuh

JULY: $t_q = 88.8$, $Q_i = 2661.97$

$Q_r = (2661.97) + (300) + (10.8)(88.8-70) - (135.2)$

$= 3014.77$ Btuh/person

$Q_d = (3014.77)(2) = 6029.53$ Btuh

AUGUST: $t_q = 79$, $Q_i = 2908.4$

$Q_r = (2908.4) + (300) + (10.8)(79-70) + (-135.2)$

$= 3170.4$ Btuh/person

$Q_d = (3170.4)(2) = 6340.8$ Btuh

SEPTEMBER: $t_q = 76$, $Q_i = 3841.89$

$Q_r = (3841.89) + (300) + (10.8)(76-70) - (135.2)$

$= 4071.5$ Btuh/person

$Q_d = (4071.5)(2) = 8143$ Btuh

OCTOBER: $t_q = 62.6$, $Q_i = 4728.67$

$Q_r = (4728.67) + (300) + (10.8)(62.6-70) - (135.2)$

$= 4813.55$ Btuh/person

$Q_d = (4813.55)(2) = 9627.1$ Btuh

COOLING ENERGY ESTIMATION: SITE A

(6 hrs / day) × (30 day / month) = 180 hrs / month

APRIL

$$\frac{(180)(5604)}{(6.5\ \text{Btu/watt})(1000)} = \underline{155.2\ \text{KWH}}$$

MAY

$$\frac{(180)(4674)}{(6500)} = \underline{129.4\ \text{KWH}}$$

JUNE

$$\frac{(180)(4945)}{(6500)} = \underline{136.9\ \text{KWH}}$$

JULY

$$\frac{(180)(6030)}{(6500)} = \underline{167.0\ \text{KWH}}$$

AUGUST

$$\frac{(180)(6341)}{(6500)} = \underline{175.6\ \text{KWH}}$$

SEPTEMBER

$$\frac{(180)(8143)}{(6500)} = \underline{225.5\ \text{KWH}}$$

OCTOBER

$$\frac{(180)(9627)}{(6500)} = \underline{266.6\ \text{KWH}}$$

COOLING LOAD CALCULATIONS: SITE B

Heat Gain Through Exposed Facade: Exposure,

$Q_a + Q_b + Q_c$ Glass Area = 57 sq. ft., U = 0.58
Wall Area = 235 sq. ft., U = 0.12

APRIL: $t_a = 65.5$, $\overline{SHGF} = 13.13$, $\overline{CLTD} = 2.5$

Glass:	Convective	(0.58)(57)(65.5-75) =	-314.07
	Radiant	(57)(13.13)(0.88) =	657.09
Wall:		(0.12)(235)(2.5) =	70.50
		TOTAL	413.53 Btuh

MAY: $t_a = 69.2$, $\overline{SHGF} = 18.2$, $\overline{CLTD} = 11.0$

Glass:	Convective	(33.06)(69.2-75) =	-191.74
	Radiant	(50.16)(18.2) =	912.91
Wall:		(28.2)(11.0) =	310.20
		TOTAL	1031.36 Btuh

JUNE: $t_a = 77.9$, $\overline{SHGF} = 21.4$, $\overline{CLTD} = 13.6$

Glass:	Convective	(33.06)(77.9-75) =	95.87
	Radiant	(50.16)(21.4) =	1073.42
Wall:		(28.2)(13.6) =	383.52
		TOTAL	1552.82 Btuh

JULY: $t_a = 85.8$, $\overline{SHGF} = 18.92$, $\overline{CLTD} = 12$

Glass:	Convective	(33.06)(85.8-75) =	357.05
	Radiant	(50.16)(18.92) =	949.03
Wall:		(28.2)(12) =	338.40
		TOTAL	1644.48 Btuh

AUGUST: $t_a = 81.1$, $\overline{SHGF} = 13.96$, $\overline{CLTD} = 8.3$

Glass:	Convective	(33.06)(81.1-75) =	201.67
	Radiant	(50.16)(13.92) =	700.23
Wall:		(28.2)(8.3) =	234.06
		TOTAL	1135.96 Btuh

SEPTEMBER: $t_a = 79.3$, $\overline{SHGF} = 10.38$, $\overline{CLTD} = 4.3$

Glass:	Convective	(33.06)(79.3-75) =	142.16
	Radiant	(50.16)(10.38) =	520.66
Wall:		(28.2)(4.3) =	121.26
		TOTAL	784.08 Btuh

OCTOBER: $t_a = 64.7$, $\overline{SHGF} = 7.96$, $\overline{CLTD} = -6$

Glass:	Convective	(33.06)(64.7-75) =	-340.52
	Radiant	(50.16)(7.96) =	399.27
Wall:		(28.2)(-6) =	-169.20
		TOTAL	-110.44 Btuh

COOLING LOAD CALCULATIONS: SITE B

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

$(2800\ ft^2)(2\ Btuh/ft^2) = 5600\ Btuh$

PEOPLE, 4 occupants

Sleeping: (8 hrs)(4)(350) = 11,200
In House: (6 hrs)(4)(420) = 10,080
Day Activity: (10hrs)(2)(420) = 8400

(29,680)/(24) = 1237 Btuh

UNCONDITIONED SPACES

Garage, 240 ft^2 Wall, U = 0.12

$(U)(A)(t_g - t_i)$

April: -187.2

May: -167.0

June: 83.5

July: 311.0

August: 175.7

September: 123.8

October: -296.64

COOLING LOAD CALCULATIONS: SITE B

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

$S_L = 3684$ sq. ft.

$S_p = 3684/4 = 921$ sq. ft.

$a = \sqrt{3684} = 60.7$

$$N = (1.5)\frac{(60.7)}{(0.75)}\left[\frac{(1.08)(10) + (10)}{(1.08)(10) + (10) + (1.5)(921)}\right] = 1.8$$

$T = \frac{0.6}{3684} = .0002$, $N\sqrt{T} = 0.023$, $\phi = 0.13$

$$n = \frac{(1.5)(921)}{(1.08)(10) + (10) + (1.5)(921)} = 0.9852$$

$$U_o = \frac{1}{\left[(1 - 0.985) + (0.985)(0.13)\right]} = 7.0$$

APRIL: $t_a = 65.5$, $Q_L = 1765.8$

$Q_r = (1765.8) + (300) + (10.8)(65.5 - 70) - (20.8)(7)$

$= 1871.6$ Btuh/person

$Q_d = (1871.6)(4) = 7486.5$ Btuh

MAY: $t_q = 69.2$, $Q_i = 1925.3$

$Q_r = (1925.3) + (300) + (10.8)(69.2 - 70) - (145.6)$
$= 2071.06$ Btuh/person

$Q_d = 8284.24$ Btuh

JUNE: $t_q = 77.9$, $Q_i = 2118.3$

$Q_r = (2118.3) + (300) + (10.8)(77.9 - 70) - (145.6)$
$= 2358.02$ Btuh/person

$Q_d = 9432.08$ Btuh

JULY: $t_q = 85.8$, $Q_i = 2198.12$

$Q_r = (2198.12) + (300) + (10.8)(85.8 - 70) - (145.6)$
$= 2523.16$ Btuh/person

$Q_d = 10{,}092.64$ Btuh

AUGUST: $t_q = 81.1$, $Q_i = 2037.17$

$Q_r = (2037.17) + (300) + (10.8)(81.1 - 70) - (145.6)$
$= 2311.45$ Btuh/person

$Q_d = 9245.8$ Btuh

SEPTEMBER: $t_q = 79.3$, $Q_i = 1936.2$

$Q_r = (1936.2) + (300) + (10.8)(79.3 - 70) - (145.6)$
$= 2191.04$ Btuh/person

$Q_d = 8764.16$ Btuh

OCTOBER: $t_q = 64.7$, $Q_i = 1607.5$

$Q_r = (1607.5) + (300) + (10.8)(64.7 - 70) - (145.6)$
$= 1704.66$ Btuh/person

$Q_d = 6818.64$ Btuh

COOLING ENERGY ESTIMATION: SITE B

(6 hrs/day) × (30 day/month) = 180 hrs/month

APRIL

$$\frac{(180)(7487)}{(6.5\ \text{Btu/watt})(1000)} = \underline{207.3\ \text{KWH}}$$

MAY

$$\frac{(180)(8284)}{(6500)} = \underline{229.4\ \text{KWH}}$$

JUNE

$$\frac{(180)(9432)}{(6500)} = \underline{261.2\ \text{KWH}}$$

JULY

$$\frac{(180)(10{,}097)}{(6500)} = \underline{279.6\ \text{KWH}}$$

AUGUST

$$\frac{(180)(9{,}246)}{(6500)} = \underline{256\ \text{KWH}}$$

SEPTEMBER

$$\frac{(180)(8764)}{(6500)} = \underline{242.7\ \text{KWH}}$$

OCTOBER

$$\frac{(180)(6819)}{(6500)} = \underline{188.8\ \text{KWH}}$$

COOLING LOAD CALCULATIONS: SITE C

Heat Gain through Exposed Walls, Roof, Glass

Areas: Glass - 16 ft^2, South
Walls - North & South - 219 ft^2
East & West - 111 ft^2
Roof - 2700 ft^2

U-factors: Glass = 0.58, SC = 0.88
Walls = 0.07
Roof = 0.07

APRIL: t_a = 64.5, See $\overline{SHGF}$ & $\overline{CLTD}$ Tables

Glass:	(9.28)(-10.5)	= -97.44
	(14.1)(35.3)	= 497.73
Wall:	S (15.33)(29.7)	= 455.30
	N (15.33)(2.5)	= 38.33
	EW (15.54)(31.9)	= 495.7
Roof:	(189)(29.5)	= 5575.5
	TOTAL	6965.12 Btuh

MAY: t_a = 68.1

Glass:	(9.28)(-6.9)	= -64.03
	(14.1)(25.3)	= 356.73
Wall:	S (15.33)(17.5)	= 268.28
	N (15.33)(11.0)	= 168.63
	EW (15.54)(32.5)	= 505.05
Roof:	(189)(29.5)	= 5575.50
	TOTAL	6810.15

JUNE : $t_a = 77.5$

Glass :	(9.28)(2.5)	=	23.2
	(14.1)(22.5)	=	317.3
Wall : S	(15.33)(15.5)	=	237.6
N	(15.33)(13.6)	=	208.5
EW	(15.54)(32.5)	=	505.1
Roof :	(189)(29.5)	=	5575.5
	TOTAL		6362.1 Btuh

JULY : $t_a = 87$

Glass :	(9.28)(12)	=	111.36
	(14.1)(25)	=	352.50
Wall : S	(15.33)(17.2)	=	263.67
N	(15.33)(12)	=	183.96
EW	(15.54)(22.3)	=	346.54
Roof :		=	5575.5
	TOTAL		6833.5 Btuh

AUGUST, $t_a = 82.6$ TOTAL 7091.2 Btuh

SEPTEMBER $t_a = 79.7$ TOTAL 7979.5 Btuh

OCTOBER $t_a = 64.7$ TOTAL 7755.5 Btuh

COOLING LOAD CALCULATIONS: SITE C

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

$(2700\ ft^2)(2\ Btuh/ft^2)$ = 5400 Btuh

PEOPLE: 4 occupants

Sleeping: (8)(4)(350) = 11200
Working: (6)(4)(420) = 10080
In House: (10)(2)(420) = 8400

29,680/24 = 1237 Btuh

UNCONDITIONED SPACES

Not Applicable

COOLING LOAD CALCULATIONS: SITE C

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

$S_L = 4020$ sq. ft.

$S_P = 4020/4 = 1005$ sq. ft.

$a = \sqrt{4020} = 63.4$

$$N = (1.5)\frac{(63.4)}{(0.75)}\left[\frac{(1.08)(10) + (10)}{(1.08)(10) + (10) + (1.5)(1005)}\right] = 1.73$$

$T = \frac{0.6}{4020} = .00015$, $N\sqrt{T} = 0.02$, $\phi = 0.14$

$$n = \frac{(1.5)(1005)}{(1.08)(10) + (10) + (1.5)(1005)} = 0.9864$$

$$U_o = \frac{1}{[(1 - 0.986) + (0.986)(0.14)]} = 6.5$$

APRIL: $t_a = 64.5$, $Q_L = 3400$

$Q_r = (3400) + (300) + (10.8)(64.5 - 70) + (-137.3)$

$= 3503.3$ Btuh/person

$Q_d = 14{,}013.2$ Btuh

MAY: $t_q = 68.1$, $Q_i = 3362$

$Q_r = (3362) + (300) + (10.8)(68.1-70) - (137.3)$
$= 3504.2$ Btuh/person

$Q_d = 14{,}016.72$ Btuh

JUNE: $t_q = 77.5$, $Q_i = 3249.8$

$Q_r = (3249.8) + (300) + (10.8)(77.5-70) - (137.3)$
$= 3493.5$ Btuh/person

$Q_d = 13{,}974$ Btuh

JULY: $t_q = 87$, $Q_i = 3367.7$

$Q_r = (3367.7) + (300) + (10.8)(87-70) - (137.3)$
$= 3714$ Btuh/person

$Q_d = 14{,}856$ Btuh

AUGUST: $t_q = 82.6$, $Q_i = 3432$

$Q_r = (3432) + (300) + (10.8)(12.6) - (137.3)$
$= 3730.8$ Btuh/person

$Q_d = 14{,}923.12$ Btuh

SEPTEMBER: $t_q = 79.7$, $Q_i = 3654.1$

$Q_r = (3654.1) + (300) + (10.8)(9.7) - (137.3)$
$= 3921.6$ Btuh/person

$Q_d = 15{,}686.2$ Btuh

OCTOBER: $t_q = 64.7$, $Q_i = 3598$

$Q_r = (3598) + (300) + (10.8)(-5.3) - (137.3)$
$= 3703.46$ Btuh/person

$Q_d = 14{,}814$ Btuh

COOLING ENERGY ESTIMATION: SITE C

$(6 \text{ hrs/day}) \times (30 \text{ day/month}) = 180 \text{ hrs/month}$

APRIL

$$\frac{(180)(14{,}013)}{(6.5 \text{ Btu/watt})(1000)} = 388 \text{ KWH}$$

MAY

$$\frac{(180)(14{,}017)}{(6500)} = 388.1 \text{ KWH}$$

JUNE

$$\frac{(180)(13{,}974)}{(6500)} = 386.9 \text{ KWH}$$

JULY

$$\frac{(180)(14{,}856)}{(6500)} = 411.4 \text{ KWH}$$

AUGUST

$$\frac{(180)(14{,}923)}{(6500)} = 413.2 \text{ KWH}$$

SEPTEMBER

$$\frac{(180)(15{,}686)}{(6500)} = 434.4 \text{ KWH}$$

OCTOBER

$$\frac{(180)(14{,}814)}{(6500)} = 410.2 \text{ KWH}$$

COOLING LOAD CALCULATIONS: SITE D

Heat Gain Through Exposed Facade: Exposure,

$Q_a + Q_b + Q_c$ Glass Area = 18 sq. ft., U = 0.58
Wall Area = 46 sq. ft., U = 0.37

APRIL: t_a = 64.5, $\overline{SHGF}$ = 13.13, $\overline{CLTD}$ = 2.5

Glass:	Convective	(0.58)(18)(64.5-75) =	-109.62
	Radiant	(18)(0.88)(13.13) =	207.98
Wall:		(46)(0.37)(2.5) =	42.55
		TOTAL	140.91 Btuh

MAY: t_a = 68.1, $\overline{SHGF}$ = 18.2, $\overline{CLTD}$ = 11.0

Glass:	Convective	(10.44)(68.1-75) =	-72.04
	Radiant	(15.84)(18.2) =	288.29
Wall:		(17.02)(11.0) =	187.22
		TOTAL	403.47 Btuh

JUNE: t_a = 77.5, $\overline{SHGF}$ = 21.4, $\overline{CLTD}$ = 13.6

Glass:	Convective	(10.44)(77.5-75) =	26.10
	Radiant	(15.84)(21.4) =	338.98
Wall:		(17.02)(13.6) =	231.47
		TOTAL	596.55 Btuh

JULY: $t_a = 87$, $\overline{SHGF} = 18.92$, $\overline{CLTD} = 12.0$

Glass:	Convective	$(10.44)(87-75) =$	125.28
	Radiant	$(15.84)(18.92) =$	299.69
Wall:		$(17.02)(12.0) =$	204.24
		TOTAL	629.21 Btuh

AUGUST: $t_a = 82.6$, $\overline{SHGF} = 13.96$, $\overline{CLTD} = 8.3$

Glass:	Convective	$(10.44)(82.6-75) =$	79.34
	Radiant	$(15.84)(13.96) =$	221.13
Wall:		$(17.02)(8.3) =$	141.27
		TOTAL	441.74 Btuh

SEPTEMBER: $t_a = 79.7$, $\overline{SHGF} = 10.4$, $\overline{CLTD} = 4.3$

Glass:	Convective	$(10.44)(79.7-75) =$	49.07
	Radiant	$(15.84)(10.4) =$	164.74
Wall:		$(17.02)(4.3) =$	73.19
		TOTAL	286.99 Btuh

OCTOBER: $t_a = 64.7$, $\overline{SHGF} = 7.96$, $\overline{CLTD} = -6$

Glass:	Convective	$(10.44)(64.7-75) =$	−107.53
	Radiant	$(15.84)(7.96) =$	126.09
Wall:		$(17.02)(-6) =$	−102.12
		TOTAL	−83.57 Btuh

COOLING LOAD CALCULATIONS: SITE D

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

$(50\%)(2\ \text{Btuh/ft}^2)(1700\ \text{ft}^2)\ =\ \underline{1700\ \text{Btuh}}$

PEOPLE: 2 occupants, (1 male, 1 female)

Sleeping: (8)(1.85)(320) = 5180
Occupied: (6)(1.85)(420) = 4662

9842 / 24 = 410 Btuh

UNCONDITIONED SPACES:

Garage, Wall area = 250 ft², U = 0.37

$(U)(A)(t_a - t_i)$

April: -971.25

May: -638.25

June: 231.25

July: 1110

August: 703

September: 434.7

October: -952.7

COOLING LOAD CALCULATIONS: SITE D

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

S_L = 2676 sq. ft.

S_P = 2676/2 = 1338 sq. ft.

$a = \sqrt{2676} = 51.7$

$$N = (1.5)\frac{(51.7)}{(0.75)}\left[\frac{(1.08)(10) + (10)}{(1.08)(10) + (10) + (1.5)(1338)}\right] = 1.06$$

$$T = \frac{0.6}{2676} = .0002 \quad , N\sqrt{T} = 0.016 \quad , \phi = 0.1$$

$$n = \frac{(1.5)(1338)}{(1.08)(10) + (10) + (1.5)(1338)} = 0.9897$$

$$U_o = \frac{1}{\left[(1 - 0.989) + (0.989)(0.1)\right]} = 9.15$$

APRIL: $t_q = 64.5$, $Q_L = 639.8$

$Q_r = (639.8) + (300) + (10.8)(64.5 - 70) - (190.32)$

$= 690.1$ Btuh/person

$Q_d = 1380.2$ Btuh

MAY: $t_q = 68.1$, $Q_i = 937.6$

$Q_r = (937.6) + (300) + (10.8)(68.1-70) - (190.32)$
$= 1026.76$ Btuh/person

$Q_d = 2053.52$ Btuh

JUNE: $t_q = 77.5$, $Q_i = 1469$

$Q_r = (1469) + (300) + (10.8)(77.5-70) - (190.32)$
$= 1605.7$ Btuh/person

$Q_d = 3211.36$ Btuh

JULY: $t_q = 87$, $Q_i = 1924.6$

$Q_r = (1924.6) + (300) + (10.8)(17) - (190.32)$
$= 2218$ Btuh/person

$Q_d = 4436$ Btuh

AUGUST: $t_q = 82.6$ $Q_i = 1627.4$

$Q_r = (1627.4) + (300) + (10.8)(82.6-70) - (190.32)$
$= 1873.2$ Btuh/person

$Q_d = 3746.3$ Btuh

SEPTEMBER: $t_q = 79.7$, $Q_i = 1416$

$Q_r = (1416) + (300) + (10.8)(79.7-70) - (190.32)$
$= 1630.4$ Btuh/person

$Q_d = 3260.8$ Btuh

OCTOBER: $t_q = 64.7$, $Q_i = 537.2$

$Q_r = (537.2) + (300) + (10.8)(64.7-70) - (190.32)$
$= 589.64$ Btuh/person

$Q_d = 1179.3$ Btuh

COOLING ENERGY ESTIMATION: SITE D

(6 hrs/day) × (30 day/month) = 180 hrs/month

APRIL

$$\frac{(180)(1380)}{(6.5 \text{ Btu/watt})(1000)} = \underline{38.2 \quad \text{KWH}}$$

MAY

$$\frac{(180)(2054)}{(6500)} = \underline{56.9 \quad \text{KWH}}$$

JUNE

$$\frac{(180)(3211)}{(6500)} = \underline{88.9 \quad \text{KWH}}$$

JULY

$$\frac{(180)(4436)}{(6500)} = \underline{122.9 \quad \text{KWH}}$$

AUGUST

$$\frac{(180)(3746)}{(6500)} = \underline{103.7 \quad \text{KWH}}$$

SEPTEMBER

$$\frac{(180)(3261)}{(6500)} = \underline{90.3 \quad \text{KWH}}$$

OCTOBER

$$\frac{(180)(1179)}{(6500)} = \underline{32.7 \quad \text{KWH}}$$

COOLING LOAD CALCULATIONS: SITE E

Heat Gain Through Exposed Facade: Exposure,

$Q_a + Q_b + Q_c$ Glass Area = 50 sq. ft., U = 0.58
Wall Area = 325 sq. ft., U = 0.07

APRIL: $t_a = 62.9$, $\overline{SHGF} = 13.13$, $\overline{CLTD} = 2.5$

Glass:	Convective	(29)(62.9-75) =	-350.9
	Radiant	(44)(13.13) =	580.8
Wall:		(22.8)(2.5) =	57.0
		TOTAL	286.9 Btuh

MAY: $t_a = 68.5$, $\overline{SHGF} = 18.2$, $\overline{CLTD} = 11.0$

Glass:	Convective	(29)(68.5-75) =	-188.5
	Radiant	(44)(18.2) =	801.2
Wall:		(22.8)(11.0) =	250.8
		TOTAL	863.5 Btuh

JUNE: $t_a = 77.1$, $\overline{SHGF} = 21.42$, $\overline{CLTD} = 13.6$

Glass:	Convective	(29)(77.1-75) =	60.9
	Radiant	(44)(21.42) =	942.5
Wall:		(22.8)(13.6) =	310.1
		TOTAL	1313.5 Btuh

JULY: $t_a = 83.6$, $\overline{SHGF} = 18.92$, $\overline{CLTD} = 12.0$

Glass:	Convective	$(29)(83.6-75) =$	249.4
	Radiant	$(44)(18.92) =$	832.5
Wall:		$(22.8)(12.0) =$	273.6
		TOTAL	1355.5 Btuh

AUGUST: $t_a = 81.7$, $\overline{SHGF} = 13.96$, $\overline{CLTD} = 8.3$

Glass:	Convective	$(29)(81.7-75) =$	194.3
	Radiant	$(44)(13.96) =$	614.2
Wall:		$(22.8)(8.3) =$	189.2
		TOTAL	997.8 Btuh

SEPTEMBER: $t_a = 76.4$, $\overline{SHGF} = 10.38$, $\overline{CLTD} = 4.3$

Glass:	Convective	$(29)(76.4-75) =$	40.6
	Radiant	$(44)(10.38) =$	456.7
Wall:		$(22.8)(4.3) =$	98.0
		TOTAL	595.3 Btuh

OCTOBER: $t_a = 61.8$, $\overline{SHGF} = 8$, $\overline{CLTD} = -6$

Glass:	Convective	$(29)(61.8-75) =$	−382.8
	Radiant	$(44)(8) =$	352.0
Wall:		$(22.8)(-6) =$	−136.0
		TOTAL	−167.6 Btuh

COOLING LOAD CALCULATIONS: SITE E

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

$(2\ \text{Btuh}/\text{ft}^2)(2200\ \text{ft}^2) = \underline{4400\ \text{Btuh}}$

PEOPLE: 4 occupants

Sleeping: (8)(4)(350) = 11200
Working: (6)(4)(420) = 10080
In House: (10)(2)(420) = 8400

(29,680)/(24) = 1237 Btuh

UNCONDITIONED SPACES

Not Applicable

COOLING LOAD CALCULATIONS: SITE E

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

$S_i = 3248$ sq. ft.

$S_p = 3248/4 = 812$ sq. ft.

$a = \sqrt{3248} = 56.9$

$$N = (1.5)\frac{(56.9)}{(0.75)}\left[\frac{(1.08)(10) + (10)}{(1.08)(10) + (10) + (1.5)(812)}\right] = 1.93$$

$$T = \frac{0.6}{3248} = 0.014, \quad N\sqrt{T} = 0.03, \quad \phi = 0.15$$

$$n = \frac{(1.5)(812)}{(1.08)(10) + (10) + (1.5)(812)} = 0.9832$$

$$U_o = \frac{1}{\left[(1 - 0.983) + (0.983)(0.15)\right]} = 6.1$$

APRIL: $t_a = 62.9$, $Q_i = 1481$

$Q_r = (1481) + (300) + (10.8)(62.9 - 70) - (10.8)(6.1)$

$= 1638.5$ Btuh/person

$Q_d = 6554$ Btuh

MAY: $t_q = 68.5$, $Q_i = 1625.2$

$Q_r = (1625.2) + (300) + (10.8)(68.5-70) - (65.8)$

$= 1843.2$ Btuh/person

$Q_d = 7372.8$ Btuh

JUNE: $t_q = 77.1$, $Q_i = 1737.63$

$Q_r = (1737.63) + (300) + (10.8)(77.1-70) - (65.8)$

$= 2048.5$ Btuh/person

$Q_d = 8194$ Btuh

JULY: $t_q = 83.6$, $Q_i = 1749$

$Q_r = (1749) + (300) + (10.8)(83.6-70) - (65.8)$

$= 2130$ Btuh/person

$Q_d = 8520.3$ Btuh

AUGUST: $t_q = 81.7$ $Q_i = 1658.7$

$Q_r = (1659) + (300) + (10.8)(81.7-70) - (65.8)$

$= 2020$ Btuh/person

$Q_d = 8080$ Btuh

SEPTEMBER: $t_q = 76.4$, $Q_i = 1558.1$

$Q_r = (1558) + (300) + (10.8)(6.4) - (65.8)$

$= 1861.3$ Btuh/person

$Q_d = 7445.3$ Btuh

OCTOBER: $t_q = 61.8$, $Q_i = 1367.35$

$Q_r = (1367.35) + (300) + (10.8)(-8.2) - (65.8)$

$= 1513$ Btuh/person

$Q_d = 6052.2$ Btuh

COOLING ENERGY ESTIMATION: SITE E

(6 hrs/day) × (30 day/month) = 180 hrs/month

APRIL

$$\frac{(180)(6554)}{(6.5\ \text{Btu/watt})(1000)} = \underline{181.5 \quad \text{KWH}}$$

MAY

$$\frac{(180)(7373)}{(6500)} = \underline{204.1 \quad \text{KWH}}$$

JUNE

$$\frac{(180)(8194)}{(6500)} = \underline{226.9 \quad \text{KWH}}$$

JULY

$$\frac{(180)(8520)}{(6500)} = \underline{235.9 \quad \text{KWH}}$$

AUGUST

$$\frac{(180)(8080)}{(6500)} = \underline{223.7 \quad \text{KWH}}$$

SEPTEMBER

$$\frac{(180)(7445)}{(6500)} = \underline{206.2 \quad \text{KWH}}$$

OCTOBER

$$\frac{(180)(6052)}{(6500)} = \underline{167.6 \quad \text{KWH}}$$

COOLING LOAD CALCULATIONS: SITE F

Heat Gain Through Exposed Facade: Exposure,

$Q_a + Q_b + Q_c$ Glass Area = 144 sq. ft., U = 0.58
Wall Area = 144 sq. ft., U = 0.07

APRIL: t_a = 65.5, $\overline{SHGF}$ = 13.13, $\overline{CLTD}$ = 2.5

Glass:	Convective	(83.52)(-9.5) =	-793.4
	Radiant	(126.8)(13.13) =	1664.9
Wall:		(10.1)(2.5) =	25.3
		TOTAL	896 Btuh

MAY: t_a = 69.2, $\overline{SHGF}$ = 18.2, $\overline{CLTD}$ = 11.0

Glass:	Convective	(83.52)(-5.8) =	-484.0
	Radiant	(126.8)(18.2) =	2307.8
Wall:		(10.1)(11.0)	111.1
		TOTAL	1934.5 Btuh

JUNE: t_a = 77.9, $\overline{SHGF}$ = 21.5, $\overline{CLTD}$ = 13.6

Glass:	Convective	(83.52)(2.9) =	242.2
	Radiant	(126.8)(21.5) =	2726.2
Wall:		(10.1)(13.6) =	137.4
		TOTAL	3105.8 Btuh

JULY: $t_a = 85.8$, $\overline{SHGF} = 19$, $\overline{CLTD} = 12$

Glass: Convective $(83.52)(10.8) = 902.02$

Radiant $(126.8)(19) = 2394.00$

Wall: $(10.1)(12) = 121.18$

TOTAL 3417.2 Btuh

AUGUST: $t_a = 81.1$, $\overline{SHGF} = 14$, $\overline{CLTD} = 8.3$

Glass: Convective $(83.52)(6.1) = 509.5$

Radiant $(126.8)(14) = 1775.2$

Wall: $(10.1)(8.3) = 83.8$

TOTAL 2368.5 Btuh

SEPTEMBER: $t_a = 79.3$, $\overline{SHGF} = 13.4$, $\overline{CLTD} = 4.3$

Glass: Convective $(83.52)(4.3) = 359.2$

Radiant $(126.8)(13.4) = 1699.1$

Wall: $(10.1)(4.3) = 43.4$

TOTAL 2101.7 Btuh

OCTOBER: $t_a = 64.7$, $\overline{SHGF} = 8$, $\overline{CLTD} = -6$

Glass: Convective $(83.52)(-10.3) = -860.2$

Radiant $(126.8)(8) = 1014.4$

Wall: $(10.1)(-6) = -60.6$

TOTAL 93.6 Btuh

COOLING LOAD CALCULATIONS: SITE F

Heat Gain From Internal Loads

Equipment, Appliances, Lights

People

Unconditioned Spaces

EQUIPMENT, APPLIANCES, LIGHTS

$(2\ Btuh/ft^2)(2000\ ft^2) \quad = \underline{4000\ Btuh}$

PEOPLE: 3 occupants, 2 males

Sleeping: $(8)(2.85)(350) = 7980$
Work: $(6)(2.85)(420) = 7182$

$15162/24 \quad = \underline{632\ Btuh}$

UNCONDITIONED SPACES:

Garage, $U = 0.18$, $A = 240\ ft^2$

April: −410.4 August: 263.5

May: −250.5 September: 185.8

June: 125.3 October: −445

July: 466.6

COOLING LOAD CALCULATIONS: SITE F

$$Q_{i_{month}} = \frac{Q_a + Q_b + Q_c + Q_f + Q_e}{\text{Number of Occupants}}$$

$S_i = 2772$ sq. ft.

$S_p = 2772/3 = 924$ sq. ft.

$a = \sqrt{2772} = 52.6$

$$N = (1.5)\frac{(52.6)}{(0.75)}\left[\frac{(1.08)(10) + (10)}{(1.08)(10) + (10) + (1.5)(924)}\right] = 1.57$$

$T = \dfrac{0.6}{2772} = .0002$, $N\sqrt{T} = 0.022$, $\phi = 0.10$

$$n = \frac{(1.5)(924)}{(1.08)(10) + (10) + (1.5)(924)} = 0.985$$

$$U_o = \frac{1}{\left[(1 - 0.985) + (0.985)(0.1)\right]} = 8.8$$

APRIL: $t_a = 65.5$, $Q_i = 1705.9$

$Q_r = (1705.9) + (300) + (10.8)(-4.5) - (183)$

$= 1774.3$ Btuh/person

$Q_d = 5322.9$ Btuh

MAY: $t_q = 69.2$, $Q_i = 2105.3$

$Q_r = (2105.3) + (300) + (10.8)(-.8) - (183)$

$= 2213.7$ Btuh/person

$Q_d = 6641$ Btuh

JUNE: $t_q = 77.9$, $Q_i = 2621$

$Q_r = (2621) + (300) + (10.8)(7.9) - (183)$

$= (2823.3)$ Btuh/person

$Q_d = 8469.9$ Btuh

JULY: $t_q = 85.8$, $Q_i = 2838.6$

$Q_r = (2838.6) + (300) + (10.8)(15.8) - (183)$

$= 3126.3$ Btuh/person

$Q_d = 9,378.7$ Btuh

AUGUST: $t_q = 81.1$, $Q_i = 2421.3$

$Q_r = (2421.3) + (300) + (10.8)(11.1) - (183)$

$= (2658.2)$ Btuh/person

$Q_d = 7974.6$ Btuh

SEPTEMBER: $t_q = 79.3$, $Q_i = 2306.5$

$Q_r = (2306.5) + (300) + (10.8)(9.3) - (183)$

$= 2524$ Btuh/person

$Q_d = 7572$ Btuh

OCTOBER: $t_q = 64.7$, $Q_i = 1427$

$Q_r = (1427) + (300) + (10.8)(-5.3) - (183)$

$= 1486.8$ Btuh/person

$Q_d = 4460.3$ Btuh

COOLING ENERGY ESTIMATION: SITE F

(6 hrs/day) × (30 day/month) = 180 hrs/month

APRIL

$$\frac{(180)(5323)}{(6.5\ \text{Btu/watt})(1000)} = \underline{147.4 \quad \text{KWH}}$$

MAY

$$\frac{(180)(6641)}{(6500)} = \underline{183.9 \quad \text{KWH}}$$

JUNE

$$\frac{(180)(8470)}{(6500)} = \underline{234.5 \quad \text{KWH}}$$

JULY

$$\frac{(180)(9379)}{(6500)} = \underline{259.7 \quad \text{KWH}}$$

AUGUST

$$\frac{(180)(7975)}{(6500)} = \underline{220.8 \quad \text{KWH}}$$

SEPTEMBER

$$\frac{(180)(7572)}{(6500)} = \underline{209.6 \quad \text{KWH}}$$

OCTOBER

$$\frac{(180)(4460)}{(6500)} = \underline{123.5 \quad \text{KWH}}$$

APPENDIX C

APPLIANCE AND WATER HEATING ENERGY

CONSUMPTION ESTIMATES

APPLIANCE and HOT WATER ENERGY LOAD ESTIMATION

SITE	EST. MONTHLY USAGE (KWH)
A	850
B	1510
C	1580
D	1000
E	1490
F*	1280

* Calculation in Chapter V

Sources:

Davis, A.J. and R.P. Schubert: Alternative Natural Energy Sources in Building Design, Van Nostrand Reinhold Company, New York, 1974.

Energy Conservation in the Home, Department of Energy, EDM-1028, 1977.

SITE A: APPLIANCE LOAD (Plus D.W.H.)

Area: 1370 sq. ft, Water Well
2 Adult occupants
Occupant Evaluation: Average Use (3)
Average No. (3)

Appliance	Est. Monthly Use (KWH)
Water pump	40.0
Coffee Maker	8.8
Dishwasher	30.3
Frying Pan	15.5
Mixer	1.0
Microwave Oven	15.8
Range	100.4
Toaster	3.2
Trash Compactor	4.1
Waste Disposal	2.5
Freezer (15 cu. ft)	146.7
Refrig / Freezer (14 cu. ft)	152.4
Clothes Dryer	82.8
Iron	12.0
Washing Machine	8.6
Water Heater	400.9
Television	36.9
	1061.6 KWH

Since Only 2 people & Avg. Use, Reduce by 20%,

850 KWH/Mo.

SITE B: APPLIANCE LOAD (Plus D.W.H.)

Area: 2800 ft², 4 Occupants; 2 Adults, 2 Adolescents
Occupant Evaluation: More than Avg Use (4)
More than Avg N° (5)

APPLIANCE	EST MONTHLY KWH
Ref: Site A	1061.6
(2) Humidifiers	62.8
Stereo	9.1
(2) Television (Color)	55.0
Lights	70.0
	1258.5 KWH

Increase By 20%, 1510 KWH/Mo

SITE C: APPLIANCE LOAD (Plus D.W.H.)

Area: 2700 ft², 5 Occupants
Occupant Evaluation: Higher than Avg. Use (5)
Avg. N° (3)

APPLIANCE	EST. MONTHLY KWH
Ref: Site A	1061.6
(2) Dehumidifiers	62.8
Stereo	9.1
(2) Television	55.0
Lights	75.0
	1263.5 KWH

Increase By 25% for 5 occupants

1580 KWH/Mo

SITE D: APPLIANCE LOAD (Plus D.W.H.)

Area: 1700 ft², 2 Occupants
Occupant Evaluation: More than Avg. Use (4)
More than Avg. No. (4)

APPLIANCE	EST. MONTHLY KWH
Ref: Site A (adjusted)	850.0
Lighting	40.0
Dehumidifier	31.4
Attic Fan	24.4
Vacuum	4.0
	949.8 KWH

Increase 5% For Evaluation

1000 KWH/Mo

SITE E: APPLIANCE LOAD (Plus D.W.H.)

Area: 2200 ft², 4 Occupants
Occupant Evaluation: Avg Use (3)
Avg. No (3)

APPLIANCE	EST. MONTHLY KWH
Ref: Site A	1061.6
Dehumidifiers	40.0
Stereo	9.1
(2) Television	55.0
Lights	70.0
Power Tools, Misc	60.0
	1295.7 KWH

Increase 15% for 4 occupants,

1490 KWH/Mo

APPENDIX D

BUILDING STANDARDS DESIGN LOAD CALCULATIONS

DESIGN LOADS for MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLINGS

Using Heat Transfer Method Referenced in Chapter 6.

CONSTRUCTION ELEMENT	HEAT TRANSFER FACTORS (HTF) WINTER $\Delta T = 65°$	SUMMER $\Delta T = 25°$
Windows, Single Pane	73.5	26.5
Doors, Hollow Core	73.5	26.5
Infiltration (w/o Storm Dr)	31.6	12.2
Frame Wall; 3½" Insulation (R-11)	5.3	2.1
Pitched Roof; 6" Insulation (R-19) Std. Ventilation	3.4	1.20
Slab on Grade; 1" Insulation (R-3.5)	57.9	0

Latent Gain in Summer = 30% Sensible Gain
5 people Minimum for Heat Gain
Window area divided in half for Solar Gain
Window area = 15% Gross Exposed Area
For Crack Length; All Doors 3×7 (21 ft²)
All Windows 3×4 (12 ft²)

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE A : GENERAL DATA

Window Area: (0.15)(1608) = 241 ft^2

Door Area: 42 ft^2

Net Wall Area: 1325 ft^2

Linear Feet of Crack @ Doors, Windows: 315 ft.

Ceiling Area: 1370 ft^2

Slab Perimeter: 201 ft

HEAT LOSS: ΔT = 65°F

Window: (241)(73.5)	= 17,713.5
Door: (42)(73.5)	= 3087.0
Wall: (1325)(5.3)	= 7022.0
Infiltration: (315)(31.6)	= 9954.0
Ceiling: (1370)(3.4)	= 4658.0
Slab Edge: (201)(57.9)	= 11,637.9
TOTAL	54,072.9 Btuh

HEAT GAIN: ΔT = 25°F

Window: (241)(26.5)	= 6386.5
Door: (42)(26.5)	= 1113.0
Wall: (1325)(2.1)	= 2782.5
Infiltration: (315)(12.2)	= 3843.0
Ceiling: (1370)(1.8)	= 2466.0
Sensible	16,591.0
Latent Gain: (0.3)(16,591)	= 4977.3
Solar Gain: (0.5)(83.5)(241)	= 10,061.8
People (Min 5)(300)(1.8)	= 2700.0
TOTAL	34,330.1 Btuh

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE B : GENERAL DATA

Window Area: (0.15)(1632) = 245 ft^2

Door Area: 63 ft^2

Net Wall Area: 1324 ft^2

Linear Feet of Crack @ Doors, Windows: 337 ft

Ceiling Area: 2800 ft^2

Slab Perimeter: 204 ft.

HEAT LOSS: $\Delta T = 65°F$

Window: (245)(73.5)	= 18,007.5
Door: (63)(73.5)	= 4630.5
Wall: (1324)(5.3)	= 7017.2
Infiltration: (337)(31.6)	= 10649.2
Ceiling: (2800)(3.4)	= 9520.0
Slab Edge: (204)(57.9)	= 11,811.6
TOTAL	61,636 Btuh

HEAT GAIN: $\Delta T = 25°F$

Window: (245)(26.5)	= 6492.5
Door: (63)(26.5)	= 1669.5
Wall: (1324)(2.1)	= 2780.4
Infiltration: (337)(12.2)	= 4111.4
Ceiling: (2800)(1.8)	= 5040.0
Sensible	20,093.8
Latent Gain: (0.3)(20,093.8)	= 6,028.1
Solar Gain: (0.5)(83.5)(245)	= 10,228.8
People (Min 5)(300)(1.8)	= 2700.0
TOTAL	39,050.7 Btuh

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE C : GENERAL DATA

Window Area: (0.15)(1760) = 264 ft^2

Door Area: 84 ft^2

Net Wall Area: 1412 ft^2

Linear Feet of Crack @ Doors, Windows: 376 ft

Ceiling Area: 2700 ft^2

Slab Perimeter: 220 ft.

HEAT LOSS: $\Delta T = 65°F$

Window: (264)(73.5)	= 19,404.0
Door: (84)(73.5)	= 6174.0
Wall: (1412)(5.3)	= 7483.6
Infiltration: (376)(31.6)	= 11881.6
Ceiling: (2700)(3.4)	= 9180.0
Slab Edge: (220)(57.9)	= 12738.0
TOTAL	66,861.2 Btuh

HEAT GAIN: $\Delta T = 25°F$

Window: (264)(26.5)	= 6996.0
Door: (84)(26.5)	= 2226.0
Wall: (1412)(2.1)	= 2965.2
Infiltration: (376)(12.2)	= 4587.2
Ceiling: (2700)(1.8)	= 4860.0
Sensible	21,634.4
Latent Gain: (0.3)(21,634)	= 6490.3
Solar Gain: (0.5)(83.5)(264)	= 11022.0
People (Min 5)(300)(1.8)	= 2700.0
TOTAL	41,846.7 Btuh

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE D : GENERAL DATA

Window Area: (0.15)(1040) = 156 ft^2

Door Area: 42 ft^2

Net Wall Area: 842 ft^2

Linear Feet of Crack @ Doors, Windows: 216 ft

Ceiling Area: 1700 ft^2

Slab Perimeter: 130 ft

HEAT LOSS: $\Delta T = 65°F$

Window:	(156)(73.5)	= 11466.0
Door:	(42)(73.5)	= 3087.0
Wall:	(842)(5.3)	= 4462.0
Infiltration:	(216)(31.6)	= 6825.6
Ceiling:	(1700)(3.4)	= 5780.0
Slab Edge:	(130)(57.9)	= 7527.0
	TOTAL	39,148.2 Btuh

HEAT GAIN: $\Delta T = 25°F$

Window:	(156)(26.5)	= 4134.0
Door:	(42)(26.5)	= 1113.0
Wall:	(842)(2.1)	= 1768.2
Infiltration:	(216)(12.2)	= 2635.2
Ceiling:	(1700)(1.8)	= 3060.0
	Sensible	12,710.4
Latent Gain:	(0.3)(12,710)	= 3813.1
Solar Gain:	(0.5)(83.5)(156)	= 6513.0
People	(Min 5)(300)(1.8)	= 2700.0
	TOTAL	25,736.5 Btuh

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE E : GENERAL DATA

Window Area: (0.15)(1504) = 225 ft^2

Door Area: 63 ft^2

Net Wall Area: 1216 ft^2

Linear Feet of Crack @ Doors, Windows: 314 ft.

Ceiling Area: 2200 ft^2

Slab Perimeter: 190 ft

HEAT LOSS: $\Delta T = 65°F$

Window: (225)(73.5)	= 16537.5
Door: (63)(73.5)	= 4630.5
Wall: (1216)(5.3)	= 6444.8
Infiltration: (314)(31.6)	= 9922.4
Ceiling: (2200)(3.4)	= 7480.0
Slab Edge: (190)(57.9)	= 11,001.0
TOTAL	56,016.2 Btuh

HEAT GAIN: $\Delta T = 25°F$

Window: (225)(26.5)	= 5962.5
Door: (63)(26.5)	= 1669.5
Wall: (1216)(2.1)	= 2553.6
Infiltration: (314)(12.2)	= 3830.8
Ceiling: (2200)(1.8)	= 3960.0
Sensible	17,976.4
Latent Gain: (0.3)(17,976)	= 5,392.9
Solar Gain: (0.5)(83.5)(225)	= 9,393.8
People (Min 5)(300)(1.8)	= 2700.0
TOTAL	35,463.1 Btuh

MINIMUM PROPERTY STANDARDS EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE F : GENERAL DATA

Window Area: (0.15)(1232) = 185 ft^2

Door Area: 63 ft^2

Net Wall Area: 984 ft^2

Linear Feet of Crack @ Doors, Windows: 267 ft.

Ceiling Area: 2000 ft^2

Slab Perimeter: 160 ft.

HEAT LOSS: $\Delta T = 65°F$

Window:	(185)(73.5)	= 13,597.5
Door:	(63)(73.5)	= 4630.5
Wall:	(984)(5.3)	= 5215.2
Infiltration:	(267)(31.6)	= 8437.2
Ceiling:	(2000)(3.4)	= 6800.0
Slab Edge:	(160)(57.9)	= 9264.0
	TOTAL	47,944.4 Btuh

HEAT GAIN: $\Delta T = 25°F$

Window:	(185)(26.5)	= 4902.5
Door:	(63)(26.5)	= 1669.5
Wall:	(984)(2.1)	= 2066.4
Infiltration:	(267)(12.2)	= 3257.4
Ceiling:	(2000)(1.8)	= 3600.0
	Sensible	15,495.8
Latent Gain:	(0.3)(15,496)	= 4648.7
Solar Gain:	(0.5)(83.5)(185)	= 7723.8
People	(Min 5)(300)(1.8)	= 2700.0
	TOTAL	30,568.3 Btuh

DESIGN LOADS for ASHRAE 90-75 EQUIVALENT DWELLINGS

WINTER: Type "A" Building, Inside Design Temp = 72°
Using OKC Degree Day Total (3725) & Figures noted below, U-factors are determined.

Figure 1: $U_{req'd}$ Wall = 0.252

Figure 2: $R_{req'd}$ Slab = 3.33, F = 31*

Sec. 4.3.2.2.: $U_{req'd}$ Roof = 0.05

Exhaust Fan req'ments @ 60 CFM ea. Used for Infiltration loss; All houses are total electric.

SUMMER: Outside Design Temp. = 100° F

Typical Above-grade Construction assumed with Required U-factors.

	HEAT TRANSFER MULTIPLIER*
Wall - frame w/ veneer (U=0.19)	5.4
Roof - light, pitched, (U=0.06) natural ventilation	2.5
Windows: (no awning)	
Single glass North	35.0
South	52.0
East/West.	93.0

Window area assumed as 10% Gross exposed wall area. Placement typical

* SOURCE: M.J. McGuinnes and B. Stein, Mechanical and Electrical Equipment for Buildings, John Wiley and Sons, Inc. New York, 1971.

DESIGN LOADS for 90-75 Equivalent Dwellings

WINTER HEAT LOSS $\Delta T = 59°$

SITE A : (1370 ft²)

Wall : (1608 ft²)(0.252)(59) = 29,907.7
Roof : (1370 ft²)(0.05)(59) = 4,041.5
Slab : (201 ft)(31) = 6231.0
Infil : (3 fans)(60)(1.08)(59) = 11,469.6

TOTAL 45,649.8 Btuh

SITE B : (2800 ft²)

Wall : (1632 ft²)(0.252)(59) = 24,264.5
Roof : (2800 ft²)(0.05)(59) = 8,260.0
Slab : (204 ft)(31) = 6324.0
Infil : (60)(1.08)(59) = 3823.2

TOTAL 42,671.7 Btuh

SITE C : (2700 ft²)

Wall : (1760 ft²)(0.252)(59) = 26,167.7
Roof : (2700)(0.05)(59) = 7,965.0
Slab : (220 ft)(31) = 6820.0
Infil : (2)(60)(1.08)(59) = 7646.4

TOTAL 48,599.1 Btuh

DESIGN LOADS for 90-75 Equivalent Dwellings

WINTER HEAT LOSS: $\Delta T = 59°$

SITE D: (1700 ft²)

Wall: (1040)(0.252)(59) = 15,462.7
Roof: (1700)(0.05)(59) = 5,015.0
Slab: (130 ft)(31) = 4030.0
Infil: (3)(60)(1.08)(59) = 11,469.6

TOTAL 35,977.3 Btuh

SITE E: (2200 ft²)

Wall: (1504)(0.252)(59) = 22,361.5
Roof: (2200)(0.05)(59) = 6,490.0
Slab: (188 ft)(31) = 5828.0
Infil: (2)(60)(1.08)(59) = 7646.4

TOTAL 42,325.9 Btuh

SITE F: (2000 ft²)

Wall: (1232)(0.252)(59) = 18,317.4
Roof: (2000)(0.05)(59) = 5900.0
Slab: (154)(31) = 4774.0
Infil: (3)(60)(1.08)(59) = 11,469.6

TOTAL 40,461 Btuh

DESIGN LOADS for 90-75 Equivalent Dwellings

SUMMER HEAT GAIN, Internal = people + equipment

SITE A : 2 People

Wall:	(1447 ft²)(5.4)	=	7814.9
Window:	N) (80.4)(35)	=	2814.0
	S) (80.4)(52)	=	4180.8
Roof:	(1370 ft²)(2.5)	=	3425.0
Infil:	(180)(1.08)(20)	=	3888.0
Internal:	840 + 2052	=	2892.0
	TOTAL		25,014.7 Btuh

SITE B : 4 People, Garage ~95°

Wall:	G (220 ft²)(0.176)(20)	=	774.4
	(1469 ft²)(5.4)	=	7932.6
Window:	N) (33 ft²)(35)	=	1155.0
	S) (33 ft²)(52)	=	1716.0
	EW) (99 ft²)(93)	=	6237.0
Roof:	(2800)(2.5)	=	7000.0
Infil:	(60)(1.08)(20)	=	1296.0
Internal:	1680 + 5600	=	7280.0
	TOTAL		30,223.0 Btuh

SITE C : 4 People

Wall:	(1584 ft²)(5.4)	=	8553.6
Window:	N) (68 ft²)(35)	=	2380.0
	S) (68 ft²)(52)	=	3536.0
	EW) (40 ft²)(93)	=	3720.0
Roof:	(2700 ft²)(2.5)	=	6750.0
Infil:	(120)(1.08)(20)	=	2592.0
Internal:	(1680)+(5400)	=	7080.0
	TOTAL		34,612 Btuh

DESIGN LOADS for 90-75 Equivalent Dwellings

SUMMER HEAT GAIN: Internal = People + Equip

SITE D: 2 People

Wall:	(936 ft²)(5.4)	=	5054
Window:	N) (32)(35)	=	1120
	S) (32)(52)	=	1664
	EW) (40)(93)	=	3720
Roof:	(1700)(2.5)	=	4250
Infil:	(180)(1.08)(20)	=	3888
Internal:	(840 + 3400)	=	4240
	TOTAL		23,936 Btuh

SITE E: 4 People

Wall:	(1354)(5.4)	=	7311.6
Window:	N) (37 ft²)(35)	=	1820.0
	S) (37 ft²)(52)	=	1924.0
	EW) (74 ft²)(93)	=	6882.0
Roof:	(2200 ft²)(2.5)	=	5500.0
Infil:	(120)(1.08)(20)	=	2592.0
Internal:	1680 + 4400	=	6080.0
	TOTAL		32,110 Btuh

SITE F: 3 PEOPLE

Wall:	(1109)(5.4)	=	5988.6
Window:	N) (24.6)(35)	=	861.0
	S) (24.6)(52)	=	1279.2
	EW) (73.8)(93)	=	6863.4
Roof:	(2000 ft²)(2.5)	=	5000.0
Infil:	(180)(1.08)(20)	=	3888.0
Internal:	(960)+(4000)	=	4960.0
	TOTAL		28,840.2 Btuh

DESIGN LOADS for "ARKANSAS" HOUSE EQUIVALENT DWELLINGS

Using Heat Transfer Method Referenced in Chapter 6.

CONSTRUCTION ELEMENT	HEAT TRANSFER FACTORS (HTF) WINTER $\Delta T = 65°$	SUMMER $\Delta T = 25°$
Windows, Insulating Gl.	41.2	15.80
Doors, S.C. & Storm	20.2	7.80
Infitration (w/ storm)	20.5	12.2
Frame Wall, 6" Insulation (R-19)	3.4	1.3
ROOF, 12" Insulation (R-38) Controlled Ventilation	1.6	0.7
Slab on Grade; 1½" Urethane	22.0	0

Latent Gain in Summer = 30% Sensible Gain
5 People Minimum for Heat Gain
Window Area × (0.5) for Solar Gain
For Crack Length; All Doors 3×7 (21 ft²)
All Windows 3×4 (12 ft²)

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE A : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(1370) = 110 ft

Door Area: 42 ft^2

Net Wall Area: (1456.4 ft^2

Linear Feet of Crack @ Doors, Windows: 160 ft.

Ceiling Area: 1370 ft^2

Slab Perimeter: 201 ft.

HEAT LOSS, $\Delta T = 65°F$

Window:	(109.6)(41.2)	= 4515.5
Door:	(42)(20.2)	= 848.4
Wall:	(1456.4)(3.4)	= 4951.8
Infiltration:	(160)(20.5)	= 3280.0
Ceiling:	(1370)(1.6)	= 2192.0
Slab Edge	(201)(22)	= 4422.0
	TOTAL	20,209.7 Btuh

HEAT GAIN, $\Delta T = 25°F$

Window:	(109.6)(15.8)	= 1732.0
Door:	(42)(7.8)	= 327.0
Wall:	(1456.4)(1.3)	= 1893.3
Infiltration:	(160)(12.2)	= 1952.0
Ceiling:	(1370)(0.7)	= 959.0
	Sensible	6863
Latent Gain -	(0.3)(6863)	= 2063
Solar Gain	(0.5)(83.5)(109.6)	= 4576
People: Min	(5)(300)(1.80)	= 2700
	TOTAL	16,199 Btuh

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE B : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(2800) = 224

Door Area: 63 ft^2

Net Wall Area: 1345 ft^2

Linear Feet of Crack @ Doors, Windows: 312 ft.

Ceiling Area: 2800 ft^2

Slab Perimeter: 204 ft.

HEAT LOSS, $\Delta T = 65°F$

Window: (224)(41.2)	= 9228.8
Door: (63)(20.2)	= 1272.6
Wall: (1345)(3.4)	= 4707.5
Infiltration: (312)(20.5)	= 6396.0
Ceiling: (2800)(1.6)	= 4480.0
Slab Edge (204)(22)	= 4488.0
TOTAL	30,572.9 Btuh

HEAT GAIN, $\Delta T = 25°F$

Window: (224)(15.8)	= 3539.2
Door: (63)(7.8)	= 491.4
Wall: (1345)(1.3)	= 1748.5
Infiltration: (312)(12.2)	= 3806.4
Ceiling: (2800)(0.7)	= 1960.0
Sensible	11,545.5
Latent Gain - (0.3)(11,545)	= 3463.7
Solar Gain (0.5)(83.5)(224)	= 9352.0
People: Min (5)(300)(1.80)	= 2700.0
TOTAL	27,061.2 Btuh

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE C : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(2700) = 216

Door Area: 84

Net Wall Area: 1460

Linear Feet of Crack @ Doors, Windows: 320

Ceiling Area: 2700

Slab Perimeter: 220

HEAT LOSS, $\Delta T = 65°F$

Window: (216)(41.2)	= 8899.2
Door: (84)(20.2)	= 1696.8
Wall: (1460)(3.4)	= 4964.0
Infiltration: (320)(20.5)	= 6560.0
Ceiling: (2700)(1.6)	= 4320.0
Slab Edge (220)(22)	= 4840.0
TOTAL	31,280.0 Btuh

HEAT GAIN, $\Delta T = 25°F$

Window: (216)(15.8)	= 3412.8
Door: (84)(7.8)	= 655.2
Wall: (1460)(1.3)	= 1898.0
Infiltration: (320)(12.2)	= 3904.0
Ceiling: (2700)(0.7)	= 1890.0
Sensible	11760.0
Latent Gain - (0.3)(11760)	= 3528
Solar Gain (0.5)(83.5)(216)	= 9018
People: Min (5)(300)(1.80)	= 2700
TOTAL	27,006.0 Btuh

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE D : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(1700) = 136

Door Area: 42

Net Wall Area: 862

Linear Feet of Crack @ Doors, Windows: 193

Ceiling Area: 1700

Slab Perimeter: 130

HEAT LOSS, $\Delta T = 65°F$

Window: (136)(41.2)	= 5603.2
Door: (42)(20.2)	= 848.4
Wall: (862)(3.4)	= 2930.8
Infiltration: (193)(20.5)	= 3956.5
Ceiling: (1700)(1.6)	= 2720.0
Slab Edge (130)(22)	= 2860.0
TOTAL	18,918.9 Btuh

HEAT GAIN, $\Delta T = 25°F$

Window: (136)(15.8)	= 2148.8
Door: (42)(7.8)	= 327.6
Wall: (862)(1.3)	= 1120.6
Infiltration: (193)(12.2)	= 2354.6
Ceiling: (1700)(0.7)	= 1190.0
Sensible	7141.6
Latent Gain - (0.3)(7,142)	= 2142.5
Solar Gain (0.5)(83.5)(136)	= 5678.0
People: Min (5)(300)(1.80)	= 2700.0
TOTAL	17,662.1 Btuh

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE E : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(2200) = 176

Door Area: 63

Net Wall Area: 1265

Linear Feet of Crack @ Doors, Windows: 257

Ceiling Area: 2200

Slab Perimeter: 190

HEAT LOSS, ΔT = 65°F

Window: (176)(41.2)	= 7251.2
Door: (63)(20.2)	= 1272.6
Wall: (1265)(3.4)	= 4301.0
Infiltration: (257)(20.5)	= 5268.5
Ceiling: (2200)(1.6)	= 3520.0
Slab Edge (190)(22)	= 4180.0
TOTAL	22,273.3 Btuh

HEAT GAIN, ΔT = 25°F

Window: (176)(15.8)	= 2780.8
Door: (63)(7.8)	= 491.4
Wall: (1265)(1.3)	= 1644.5
Infiltration: (257)(12.2)	= 3135.4
Ceiling: (2200)(0.7)	= 1540.0
Sensible	9592.1
Latent Gain - (0.3)(9592)	= 2877.7
Solar Gain (0.5)(83.5)(176)	= 7348.0
People: Min (5)(300)(1.80)	= 2700.0
TOTAL	22,517.80 Btuh

"ARKANSAS" HOME EQUIVALENT DWELLING DESIGN LOAD CALCULATIONS

SITE F : GENERAL DATA

Window Area: 8% Gross Living Area = (0.08)(2000) = 160

Door Area: 63

Net Wall Area: 1009

Linear Feet of Crack @ Doors, Windows: 238

Ceiling Area: 2000

Slab Perimeter: 160

HEAT LOSS, $\Delta T = 65°F$

Window: (160)(41.2)	= 6592.0
Door: (63)(20.2)	= 1272.0
Wall: (1009)(3.4)	= 3430.6
Infiltration: (238)(20.5)	= 4879.0
Ceiling: (2000)(1.6)	= 3200.0
Slab Edge (160)(22)	= 3520.0
TOTAL	22,894.2 Btuh

HEAT GAIN, $\Delta T = 25°F$

Window: (160)(15.8)	= 2528.0
Door: (63)(7.8)	= 491.4
Wall: (1009)(1.3)	= 1311.7
Infiltration: (238)(12.2)	= 2903.6
Ceiling: (2000)(0.7)	= 1400.0
Sensible	8634.7
Latent Gain - (0.3)(8635)	= 2590.4
Solar Gain (0.5)(83.5)(160)	= 6680.0
People: Min (5)(300)(1.80)	= 2700.0
TOTAL	20,605.1 Btuh

VITA

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Candidate for the Degree of

Master of Architectural Engineering

Thesis: ENERGY ANALYSIS OF EARTH SHELTERED DWELLINGS

Major Field: Architectural Engineering

Biographical:

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Education: Graduated from Sooner High School, Bartlesville, Oklahoma, in May, 1973; attended Brigham Young University in 1973-75; received the Bachelor of Architectural Studies degree from Oklahoma State University in May, 1978; completed requirements for the degree of Master of Architectural Engineering at Oklahoma State University in July, 1980.

Professional Experience: Graduate Teaching Assistant, Oklahoma State University School of Architecture, 1978-80; Draftsman for Glen A. Summers, AIA, Stillwater, Oklahoma, May, 1978, to August, 1978; Architectural designer and draftsman for Phil D. Fitzgerald, AIA, Ponca City, Oklahoma, August, 1978, to January, 1980.

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