Dr. 1533

Energy-Conserving Site Design

Greenbrier Case Study Chesapeake, Virginia

Final Report

MASTER

April 1980

Prepared For:

U.S. Department of Energy

Assistant Secretary for Conservation and Solar Energy

Office of Buildings and Community Systems

Under Contract No. AC01-78CS24216

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price:	Printed Copy:	\$7.00
	Microfiche:	\$4.00

Energy Conserving Site Design:

Greenbrier Case Study,

Chesapeake, Virginia

Final Report

April 1980

Prepared By: 951 1514
Greenbrier Associates
Chesapeake, Virginia 23320
Under Contract No. AC01-78CS24216

Prepared For:
U.S. Department of Energy
Assistant Secretary for Conservation and Solar Energy
Office of Buildings and Community Systems
Washington, D.C. 20585

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Introduction	1
1:0 The Research Response	5
1.1 Team Organization	5
1.2 Process.	5
1.3 Energy Consumption Estimation.	11
1.4 The Site	16
1.5 The Conventional Plan/Base Case.	24
2:0 Conservation Options.	29
2:1 Land Planning Applications	31
2:1.1 Reduction in Street Widths.	31
2:1.2 Improved Efficiency in Lotting.	32
2:1.3 Reduction of Curbs, Gutters, and Sidewalks.	33
2:1.4 Lot Orientation	33
2:1.5 Transportation.	34
2:1.6 Vegetative Cooling.	35
2:2 Architectural Applications	37
2:2.1 Reconfiguration of Internal Living Space.	37
2:2.2 Solar Screening, Window Location, House Orientation	38
2:2.3 "Arkansas" Construction	39
2:2.4 Double Glazing.	41
2:2.5 Slab and Crawl Space.	42
2:2.6 Roof Overhang	43
2:2.7 Greenhouse.	43
2:2.8 Trombe Wall	44

<u>Section</u>	<u>Page</u>
2:3 Mechanical Systems	46
2:3.1 Groundwater Heat Pump	46
2:3.2 Domestic Hot Water - Heat Reclaimer	48
2:3.3 Active Solar Domestic Hot Water	49
2:3.4 Active Solar Residential Heating Systems.	50
2:4 Community Systems.	51
2:4.1 Wind Energy Systems	51
2:4.2 Solar Total Energy System	51
2:4.3 Central Thermal Plants.	52
3:0 Conservation Plan	54
3.1 Lot Orientation.	60
3.2 Vegetative Cooling	60
3.3 Arkansas Construction.	61
3.4 Insulated Slab on Grade Foundation	61
3.5 Groundwater Source Heat Pump	61
3.6 Domestic Hot Water-Heat Reclaimer.	62
3.7 Greenhouse	62
3.8 Comparison of Conventional and Conservation Plans.	62
3.9 Summary.	64

INTRODUCTION

The research summarized in this report was funded for the one year period ending April, 1979 by the Community Systems Division of the United States Department of Energy. The objective was to produce a specific case study of project planning for energy conservation for a major planned unit development at the 3,000 acre Greenbrier development site in Chesapeake, Virginia. The Developer, Greenbrier Associates, was integrally involved in the management of the research to ensure that the outcome was both realistic and implementable.

Our research suggests that very considerable reductions in energy conservation can be achieved within the confines of private sector land development and residential construction with increased incremental costs of \$200.00 to \$3150.00 per dwelling unit. Through computer simulation and analysis we have hypothesized that energy consumption at Greenbrier can be reduced by one-half with an average annual savings of 21,275 KWH per residential unit, using state of the art technology with careful planning and control. This represents an annual savings of \$750.00 per unit at the current utility rate of 3.5¢ per KWH. These savings can be achieved through reduction in heating and cooling loads and application of more efficient heating and cooling of the remaining loads. The reduction in loads are achieved by redesign of the land plan to include a higher percentage of south facing lots, use of vegetation to modify microclimate, decreases in air infiltration, the use of 2 x 6 framing, better insulation, and the use of an insulated slab on grade foundation. Further energy savings can be expected by increased efficiencies in mechanical systems used for space heating and cooling and domestic hot water. When applied to the single family portion of Greenbrier containing 541 dwelling units, these options reduce the total end-use energy consumption 54.7%. This reduction represents an annual savings of \$432,800.00 for an initial capital investment of \$1.7 million.

While the research indicates that energy conservation is achievable, there are several obstacles which must be overcome. The residential construction industry is by nature, highly fragmented and competitive. The majority of all new single family housing in this country is constructed by individual builders who produce less than ten houses per year. These builders take considerable personal financial risks in a speculative market and are not in a position to increase those risks by implementing construction practices and energy conserving features that are currently "unproven." Until there is demonstrable proof, or until the consuming public demands widespread energy conservation practices, it appears unlikely that the small builder will implement most of the conservation options advocated in this report. It would appear from our findings, that currently only those conservation options such as storm windows, air to air heat pumps, and insulation, which are "visible" to the consumer are immediately achievable within the larger market. Conservation options yielding significant energy savings, such as 2 x 6 construction, domestic hot water heat reclaimers, and orientation, are poorly understood by consumers and are subsequently not promoted by most builders at this point in time.

The land developer's role in relation to the residential market is, in many important aspects, similar to the builder's. The builder is the consumer of the product or improved lots, offered by the land developer. In this regard, the developer's success or failure depends on his or her ability to offer individual builders a product that their previous experience indicates will sell to the potential homebuyer, at a price which is competitive in relation to other lots within the market. If, and when, consumer demand places a premium on south facing lots for example, then builders will respond accordingly in their purchases, and land developers will make every effort to provide as many lots with southern orientations as the market can reasonably absorb. Similarly, energy conservation practices at a community scale which require the developer to make a significant role change are likely to be met with considerable resistance.¹

¹Appendix C "Impediments to Implementation".

The study area, Bayberry, is a 415 acre initial phase of a larger planned unit development at Greenbrier in Chesapeake, Virginia of approximately 3,000 acres, this development includes industrial, office, commercial and institutional land uses, including a Volvo assembly plant and an 800,000 square foot retail shopping mall. Residential development ranges from high density apartments to single family detached dwelling units. At completion, the 415 acre study area will contain 2,758 residential units, representing a total end value of approximately \$180,000,000. To service this development program, Greenbrier Associates will build over 30 miles of streets, 46 miles of sidewalks, and 64 miles of sewer and water lines. Energy for the development will be provided by Virginia Electric Power Company, VEPCO. Natural gas is not available at the site. 250 million gallons of impounded fresh water on the site, offers significant opportunities for thermal extraction.

The Standard Metropolitan Statistical Area (SMSA) of Norfolk-Portsmouth-Chesapeake-Virginia Beach is often referred to as Tidewater, Virginia. The population within the S.M.S.A. is approximately 800,000. Demographic trends show that this S.M.S.A. has had moderate but consistent growth over the past decade although there have been substantial demographic shifts within the S.M.S.A. in terms of residential construction and other economic activity. The U.S. Government, principally the Navy, is the largest single employer in the S.M.S.A.

The entire Greenbrier program is exceptionally important to the overall Tidewater development plan, and therefore, has the support of Chesapeake, Norfolk, and other local and state political units. A large portion of the site's infrastructure (Bayberry) is in place since construction began in the fall of 1977.

The method employed by the research team can be divided into two major parts. The first part established the total energy consumed in the production and operation of the development. The second part was a systematic evaluation of proposed changes in the development that would make it more energy efficient. These changes, or

conservation options ranged from on-site energy generation to a series of changes within the residential building envelope. Each conservation option was evaluated for its performance in conserving energy, its capital requirement, commercial applicability, its legality, and finally, and perhaps most importantly, its market acceptance. The result of this systematic evaluation is a set of conservation options which together form the basis of a conservation plan. While this plan does require alteration of certain procedures normally followed in the process of development and construction, it requires minimal increases in capital expenditures averaging approximately \$3,000.00 per residence.

1. THE RESEARCH RESPONSE

1.1 Team Organization

In response to the overall objective of this research effort, Greenbrier Associates, a subsidiary of Realty Capital Incorporated of Chesapeake, Virginia, organized an interdisciplinary team of architects, engineers, landscape architects, and planners, to develop an effective and implementable energy conserving plan. Greenbrier Associates is the primary contractor. The College of Architecture and the Engineering Experiment Station of the Georgia Institute of Technology served as coordinators of the technical team. Thompson, Ventulett, Stainback and Associates served as research architects; Lewis Clark and Associates as research landscape architects, and Brady, Anglin and Associates as consulting mechanical engineers. The research effort was headed by Greenbrier Associates.

The research team consisted of a group of small, specialized enterprises, each having a unique expertise essential to the effort. The disciplines represented include land planning, advanced energy technology, architecture, engineering, landscape architecture, development economics, finance, marketing and management. Greenbrier Associates, the prime contractor, has complete responsibility for the Greenbrier project and retained its parent company, Realty Capital, Inc. to supervise the planning, finance and marketing. The firm of Lewis Clarke Associates, is well recognized in the Southeast, and provided critical land planning and landscape input in addition to preparing the alternative plan. An established working relationship existed between Realty Capital and Lewis Clarke. Both Thompson, Ventulett, and Stainback Architects and Brady, Anglin Engineers have been active in developing energy conservation design methods and solar energy systems.

1.2 Process

Initially, the research effort was divided into two major tasks. The first task was to document the Greenbrier development program as it would have proceeded under a

GENERAL ORGANIZATION OF PROJECT RESEARCH TEAM

Figure 1

conventional development program, and to project from this conventional plan the total energy consumed in construction and operation of the development. Operating energy consumption was projected over a thirty year period, the normal mortgage period for conventionally financed housing. This task is called the "Base Case" energy model and is presented in detail in Appendix A.

The second major task was to propose and evaluate energy conservation options that could conceivably contribute to a conservation development plan. Initially, the research team developed a set of four conservation categories. These were:

Land Planning Applications

Architectural Applications

Mechanical Applications

Community Systems

The conservation options that were identified within these categories were then independently appraised according to a common set of evaluation criteria.

For example, site orientation was listed as conservation option within both the architectural and land planning categories. Once such an option was proposed, it was assigned to the appropriate members of the technical research team for documentation of design, materials and costs. Any option proposed by any team member would be fully reviewed by both the technical and management teams at regularly scheduled monthly review sessions. This two-stage process allowed for review of all options without initial bias as to the "appropriateness" of any option. Figure 2 diagrams the conservation option review process.

At the technical and management review sessions, an initial evaluation of each of the options was conducted to determine if the proposed option conformed to our pre-determined evaluation criteria. These criteria included whether the option was:

- . Within the scope of the developer's role
- . Technically feasible; and
- . Legally implementable.

Figure 2 Conservation Option Evaluation Process

Critical here, is an understanding of the limitations of the developer's role and the incremental nature of the development process. As the developer, Greenbrier Associates can determine the overall land-use development and design strategies within the confines of the marketplace and within the confines of the developer's own financial and managerial resources.

While there may be a commitment to larger societal purposes, these are usually not primary motives for development. The developer must ascertain his ability to assume risk as measured by his cash outlays and expected returns over time. The developer, at Greenbrier and elsewhere, is dependent on the builders and the consumer to determine the actual end products. While building and land use design principles can be significantly influenced, their ultimate manifestation is a product of market demand and usually becomes a function of negotiation between what the developer would like to achieve and what the builder can actually sell. Such negotiations must also function within a larger governmental framework. These limitations are basic to an understanding of what energy conservation options are practical and desirable. Once an option was considered to have been within the scope of the developer's role, to be technically and legally feasible, the option was then advanced to a second stage of evaluation.

Through computer simulation and standard manual analytic techniques, the technical and management review teams were able to assess the relative quantifiable costs and benefits at each option within each category. In this way, the most efficient options were developed for each construction problem. Over and above the quantifiable dollar costs and benefits of each conservation option, every option was then evaluated according to its marketability. While extensive market surveys were well beyond the scope of this research effort, Realty Capital, Inc.'s extensive experience in real estate development, management and marketing served as the final sieve through which an option must pass before incorporation into an energy conserving plan.

Figure 3 summarizes several options and the evaluation criteria.

Figure 3

	<u>SCOPE</u>	<u>TECHNOLOGY</u>	<u>OPERATING</u>	<u>EFFICIENCY</u> <u>CAPITAL</u>	<u>LEGAL</u>	<u>MARKET</u>
<u>Energy Options</u>	(1)	(2)	(3)	(4)	(5)	(6)
Orientation	+	+	+	+	0	+
Site Planning	+	+	-	-	-	0
Colors	-	X	X	X	X	X
Slab on grade						
crawl space	+	+	+	+	0	-
Greenhouse	+	+	+	0	0	+
Int. living space	+	+	*	+	0	+
Arkansas construction	+	+	+	+	0	+
Heat Pump	+	+	+	+	0	+
Heat Reclaim	+	+	+	+	0	+
Active Solar	+	+	+	-	X	X
Central Plant	+	+	+	-	-	-
Wind	+	-	X	X	X	X
Waste Recycle	-	X	X	X	X	X
Energy Monitoring	+	+	+	+	0	+
Glazing	+	+	+	+	0	*
Screening	+	+	0	0	0	*
Roof Overhangs	+	+	+	+	0	*
Shading	+	+	+	+	0	+
Energy Delivery Systems	-	X	X	X	X	X

LEGEND

- + Positive Impact
- Negative Impact
- 0 Insufficient Impact to Measure
- X N/A
- * Insufficient Data to Fully Assess

1.3 Energy Consumption Estimation and Simulation Models

It became evident early in the Greenbrier program that a computerized building load simulation program would be required to evaluate the large number of structure oriented conservation options being considered. Initial loads for the five base case buildings were determined using the National Environmental Systems Contractors Association's "Manual J" residential load calculation procedure.² This is a standardized industry procedure for determining the summer and winter design loads for residences, but does not easily allow accurate estimates of the annual heating and cooling load. The design heating and cooling loads determined by "Manual J" calculations were used with the "Airforce Manual 88-8" "Bin" method to develop an estimated annual heating and cooling load.³

Since the "Manual J" and "AFM 88-8" methods do not lend themselves well to the determination of the effect of relatively minor structural changes, a survey of existing computer load simulation programs was made to determine which ones would provide the data needed or could be easily modified to provide these data. A second consideration due to the tight time frame of the program was easy implementation on the Georgia Tech Computer. It was quickly determined that most load simulation programs were developed for simulation of large buildings and do not lend themselves well to the simulation of residences.

Of the many computer building load simulation models considered, four appeared to both have the capabilities required and to be capable of being implemented on the Georgia Tech computer in the time frame required by the Greenbrier program. A brief description of the four programs is given below.

²"Manual J", "Load Calculation for Residential Winter and Summer Air Conditioning", National Environmental Systems Contractors Association, Washington, D.C. 1975.

³"Engineering Weather Data", AFM 88-8 Chapter 6, Departments of the Airforce, the Army, and the Navy, U.S. Government Printing Office, Washington, D.C. 1967.

A program developed by the National Bureau of Standards called NBSLD can simulate residences and was already available at Georgia Tech.⁴ This program looked attractive but requires extensive input data files and is relatively difficult to quickly change for evaluation of different options.

A NASA developed simulation program called NECAP can simulate residences and has been used to evaluate load profiles of various buildings on the Georgia Tech campus for several years.⁵ This program eliminates many of the problems found with NBSLD, but still requires a very detailed building description.

A relatively new program called BLAST developed by the U.S. Army Construction Engineering Research Laboratory promised to eliminate many of the time consuming steps required by NBSLD and NECAP.⁶ A copy of this program was purchased but could not be implemented on the Georgia Tech computer in time to be of assistance to this program.

A program called TRNSYS developed by the Engineering Experiment Station at the University of Wisconsin has been used for active solar collector system simulation for several years by Georgia Tech Personnel.⁷ The latest version (9.2) includes the ASHRAE transfer function method of calculating transient energy gain and loss from buildings.⁸ TRNSYS was selected as being best suited to the needs of the Greenbrier program.

Although TRNSYS is not nearly as sophisticated as NBSLD, NECAP, or BLAST, it lends itself well to very easy use, easy modification and expanded capabilities. Initial

⁴Kusuda, T. and F.J. Powell, "Use of Modern Computer Programs to Evaluate Dynamic Heat Transfer and Energy Processes in Buildings", NBS Publication 361, Vol. 1 National Bureau of Standards, 1972.

⁵"NASA's Energy-Cost Analysis Program", NASA Report CR-2590, National Aeronautics and Space Administration, Washington, D.C., 1975.

⁶"The Building Loads Analysis and System Thermodynamics Program", CERL-TR-E-119, U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois, 1977.

⁷"A Transient Simulation Program", Solar Energy Laboratory, Engineering Experiment Station Report 38, University of Wisconsin at Madison, Madison, Wisconsin, 1978.

⁸"Handbook of Fundamentals", Chapter 25, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., New York, New York, 1977.

simulations using TRNSYS revealed several areas which were seriously deficient. A series of modifications were made to the initial 9.2 version, resulting in a program with greatly expanded capabilities which would permit the determination of the effect of the various conservation options required by the project personnel.

A fifth program called Z-TRAN developed by Canadian National Research Council was implemented to permit determinations of transfer functions for wall sections not in the ASHRAE Handbook of Fundamentals.⁹ This was necessary because few of the published transfer functions are applicable to wall sections typical of residences.

In addition to the simulation models, it was necessary to develop "typical year" weather data for the Greenbrier site. Since the National Oceanic and Atmospheric Administration (NOAA) does not have a weather computer tape available for the Norfolk area, a tape was created using degree days as the basis for the "typical year" rather than the normal ASHRAE technique. The modified method of developing a "typical year" was chosen because the ASHRAE technique can result in a typical year with significantly different heating and cooling degree days than the average for a particular location.

The average (10-20 year) heating and cooling degree days for each month for the Norfolk area was determined from published NOAA data.¹⁰ The monthly data for the past twenty years were then searched until a month was found that had a heating and/or cooling degree day equal to the 10 or 20 year average for that month. A computer tape was then made which included pertinent data for each hour of the composite year.

⁹Mitalas, G.P. and J.G. Areseneault, "A Fortran IV Program to Calculate Z-Transfer Functions for the Calculation of Transient Heat Transfer through Walls and Roofs", DBR Computer Program No. 33, National Research Council of Canada, 1972.

¹⁰"Local Climatological Data, Monthly and Annual Summary", Norfolk, Virginia, 1933-1977, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina

Since there are no long term solar insolation data available for the Norfolk or Greenbrier area, it was necessary to develop an insolation profile based on insolation maps of the United States published in the Climatic Atlas of the United States.¹¹ Maps for each month were used to estimate the average daily insolation on a horizontal surface for the Greenbrier area. This average daily horizontal insolation was converted to average hourly radiation on a horizontal surface using a computer program based on procedures developed by Liu, Jordan¹² and modified by Kusuda.¹³ The average hourly radiation on a horizontal surface developed by this program for each month was added to the composite year weather tape. The TRNSYS Program has a built-in radiation data processor to develop data for surfaces other than horizontal.

The modified TRNSYS program was run for each conservation option using the composite year weather data. Once the effect of each conservation option was determined, simulations were run with combinations of options.

¹¹"Climatic Atlas of the United States", National Oceanic and Atmospheric Administration U.S. Department of Commerce, 1977.

¹²Liu, B.Y.H. and Jordan, R.C., "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation, Solar Energy Vol. 4, No. 3, pp. 1-19, 1960.

¹³Kusuda, T. and K. Ishii, "Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada", NBS Building Science Series 96, National Bureau of Standards, U.S. Department of Commerce, 1977.

-15

NORTH

REGIONAL LOCATION MAP

FIGURE 4

1.4 The Site

City of Chesapeake: Incorporated in 1967, the city of Chesapeake absorbed all land masses in Washington County not contained within the surrounding communities of Norfolk, Portsmouth, or Virginia Beach, as shown in Figure 4. As a relatively young political subdivision, those departments of City Government which most directly impact the development process within the subject property were created under progressive enabling legislation and are staffed by professionals who have had the opportunity to create an environment "from the ground up" within the city's limits. The City Government is vitally interested in the project's development and has interacted with the evolution of the general plan from its inception.

Greenbrier: The 3000 acre Greenbrier Planned Unit Development is expected to have a development cycle of 15 to 20 years. Acquired in 1969 by a subsidiary of American Cyanamid, the Ervin Company, the total project received intensive planning and analysis in accordance with the appropriate disciplines during the early 1970's. Since acquisition, approximately 800 acres have been sold together for a variety of uses including residential, commercial and both light and heavy industry.

Greenbrier's strategic location near the center of the S.M.S.A. has excellent access to all major employment, recreational and shopping facilities in the S.M.S.A. Vehicular access is via an interchange on I-64 in the center of the project. Rail access is provided by Southern Railway's main North/South line on the western boundary of the project.

The property is located in the geographic center of Chesapeake, as bordered on the West by the Southern Railroad, on the North by US-13 (Military Highway, the main commercial strip in the Norfolk/Virginia Beach area) and it is intersected East to West by I-64 with an interchange in the dead center of the property. To the East are residential areas containing densities of no less than three homes per acre and with a generally low aesthetic quality. The Norfolk housing market has been consistent even during 1974-75, with lot prices averaging \$10,000 to \$15,000 for 9,000 square feet in the less desirable portion of nearby Virginia Beach. There are no golf course communities

or water front communities, other than the beach front itself, at Virginia Beach which has become highly commercial. The median price for new housing in the Norfolk region is slightly below the national average.

Physiography: The topography is essentially flat with only a three foot natural elevation change throughout the site. Geological characteristics can generally be described as a two foot cover of high quality top soil overburdening a sand base for a depth of 15 to 50 feet. Occasional layers of deposits of silty clay/clay sand with high moisture, low bearing characteristics occur throughout the site. Hydrologically, land is dedicated for impoundment areas to handle rain runoff and drainage. These impoundments are incorporated into the conventional plan as a series of lakes useable for recreational purposes. The land has been used alternatively for farming, and as a commercial nursery, for more than 150 years.

Climate: The Greenbrier climate is characterized as hot-humid, typical of the southeastern United States coastal areas. Greenbrier has 3488 heating degree days and 1441 cooling degree days. The area has an average yearly temperature of 60.6° F, an average winter temperature of 47.3° F, and an average summer temperature of 78.3° F. Winter 2.5% design temperature is 22° F. Summer 2.5% design temperatures are 91° F dry bulb and 78° F wet bulb.

The Greenbrier area has relatively low wind velocities both summer and winter. Average summer wind velocity is 9.5 m.p.h., while average winter wind velocity is 11.2 m.p.h. Average rainfall for the Greenbrier area is 43.1 inches per year.

The Greenbrier area receives a yearly average of 1399 Btu's of solar radiation per sq. ft. per day, or roughly 54.7% of possible radiation. The area receives an annual average of 2803 hours of sunshine, or 62% of possible. While receiving a good quantity of solar radiation, a relatively high percentage of this radiation is diffuse, being scattered or reflected by clouds or other atmospheric constituents.

Figure 5

BAYBERRY DEVELOPMENT PROGRAM

<u>MAP KEY</u>	<u>DENSITY</u>	<u>NO. OF ACRES</u>	<u>NO. OF UNITS</u>	<u>SIZE</u>
--Housing Units--				
Low (L)				
Single family detached (SF)	2.0 units/acre	292.5		
1 story			436	2,100 sq. ft.
2 story			149	2,400 sq. ft.
Low Cluster (LC) (zero lot line)	6.5 units/acre	114.2	742	1,800 sq. ft.
Low Medium (LM) (SF detached)	4 units/acre	88	352	1,600 sq. ft.
Medium (M) (townhouse)	11.5 units/acre	74.4	856	1,450 sq. ft.
High (H) (apartments)	11.5 units/acre	19.4	223	1,100 sq. ft.
--Commercial Buildings--				
Commercial (C)				350,000 sq. ft.
Business (B)***		25.6		400,000 sq. ft.
Religious Center (RC)			1 church	
School (E)			1 public elementary school 1 private secondary school	
Fire Station (F)				
Golf Course		165	clubhouse parking-	10,000 sq. ft.

***Office park for the Business (B) with five story masonry and steel building at an average of \$26/sq. ft. with adjacent asphalt surface parking.

Figure 6 LAND USE PLAN

Figure 7: Example of Quantity Schedule in the Residential Sector for Roads and Storm Sewers

ROADS (sq.ft.)			R.C.P. STORM SEWERS (linear ft.)										
	A 4"	B 2"	A 12"	B 15"	C 18"	D 21"	E 24"	F 27"	G 30"	H 36"	I 42"	J 48"	
Low		1008.00 (sq.ft. per unit)		9' unit	9.66'	3.99'	9.13'		1.83'	5.3'	4.12'	2.9'	
Total		439,488		5265'	5651'	2334'	5341'		1071'	3101'	2410'	1697'	
Low Medium		969.71 (sq.ft. per unit)		4.68' unit		2.61'		6.7'			8.44'	5.77'	
Total		341,338'		1647'		919'		2358'			2971'	2031'	
Low Cluster		784.0 (sq.ft. per unit)	1.42' unit	7.53'	3.33'	1.85'	2.77'	1.79'	2.19'	8.08'			
Total		581,728	1054'	5587'	2471'	1373'	2055'	1328'	1625'	5995'			
Medium		630.52 (sq. ft. per unit)		4.0'		4.0'	4.36'		8.0'				
Total		539,725		3424		3424'	3732'		6848'				
High		630.52 (sq.ft. per unit)		4.0		4.0	4.36		8.0				
Total		140,606		892'		892'	972'		1734'				

Figure 8: Example of Embodied Energy Conversion for Asphalt Road Infrastructure

ROAD TYPES (1)	MATERIAL (2)	GAL./SQ. FT. (3)	Btu/SQ. FT. (4)	ITEM QUANTITY SQ. FT.	TOTAL Btu
Road A	Asphalt	.1386	26,643.77	599,200	1.5964×10^{10}
Road B	Asphalt	.069	13,264.22	3,776,885	5.0097×10^{10}
					6.6061×10^{10}

1. Road Type (Road profiles are described in Section 1.3):

Type A: Arterial = 4" Asphalt

Type B: Residential = 2" Asphalt

2.

<u>MATERIAL</u>	<u>UNIT</u>	<u>BTU CONTENT*</u>
AC-20	Gallon	192,235
Petroleum		
Asphalt Product		

3. AC-20 Petroleum Asphalt per square foot of road (See Appendix A

Type A: .1386 gallons/sq. ft.

Type B: .069 gallons/sq. ft.

*Center for Advanced Computation, and R.G. Stein and Associates, Energy in Building Construction, ERDA Contract #E (11-1)-2791

Figure 9: Embodied Energy Conversion for an above ground 2,100 square foot home by item

<u>ITEM</u>	<u>UNIT</u>	<u>Btu/UNIT*</u>	<u>MILLIONS OF Btu</u>
Foor	3263 ft. ²	61,844/sq. ft.	201.8
Floor	2100 ft. ²	29,818/sq. ft.	62.6
Ext. Walls	1868 ft. ²	32,286/sq. ft.	60.3
Int. Walls	2408 ft. ²	17,326/sq. ft.	41.7
Sliding Doors	203 ft. ²	72,570/sq. ft.	14.7
Windows	4 (68 ft. ²)	66,308/sq. ft.	4.5
Exterior Doors	10.4 (208 ft. ²)	43,644/sq. ft.	9.15
Footing/Foundation	295 lin. ft.	456,434/lin. ft.	134.6
Deck	600 ft. ²	20,791/sq. ft.	12.5
Deck Foundation	80 lin. ft.	513,799/lin. ft.	45.2
Fireplace/Chimney			
Bricks	3000	14,283/brick	42.8
Concrete	32 ft. ²	96,087/cu. ft.	3.1
Rebars	4 @ 7'0"	10,145 Btu/lin. ft.	.3
Porch	81 ft. ²	39,151/sq. ft.	3.2
Garage			
Floor	480 ft. ²	39,151/sq. ft.	18.8
Walls	470 ft. ²	25,426/sq. ft.	12.0
Pier Footings (4)	4	237,984 footing	.95
Total per unit			668.15

*Center for Advanced Computation, and R.G. Stein and Assoc., Energy in Building Construction, ERDA Contract #E (11-1)-2791

FIGURE 10: SUMMARY OF EMBODIED ENERGY IN GREENBRIER INFRASTRUCTURE
(All Figures are in 0.00×10^{10})

	<u>ROADS</u>	<u>STORM SEWERS</u>	<u>SEWERS</u>	<u>CURBS</u>	<u>WALKS</u>	<u>WATER LINES</u>
RESIDENTIAL						
L 2400	1.5656	1.5661	.9932	1.6159	1.6456	.6896
L 2100						
LM-1600	.4527	.9312	.2872	.4533	.3354	.0601
LC-1800	1.1486	1.1326	.7796	1.2116	1.3281	.05778
M-1450	.7159	.8838	.5811	.6757	.6759	.2579
H-1150	.1865	.2301	.1514	.1760	.1761	.0671
SUBTOTAL	<u>4.0694</u>	<u>4.7437</u>	<u>2.7925</u>	<u>4.1325</u>	<u>4.1611</u>	<u>1.1325</u>
BUSINESS	.9616	.0598	.0324	.0668	.7949	.0168
COMMERCIAL	1.3384	.1375	.0525	.1557	.4508	.0283
MAJOR ARTERIES	<u>1.5964</u>	<u>.1444</u>	<u>1.0061</u>	<u>1.0682</u>	<u>1.3763</u>	<u>.6328</u>
SUBTOTAL	<u>7.9659</u>	<u>.3417</u>	<u>1.091</u>	<u>1.2907</u>	<u>2.622</u>	<u>.06779</u>
TOTAL	<u>12.0353</u>	<u>5.0854</u>	<u>3.8835</u>	<u>5.4232</u>	<u>6.7831</u>	<u>.7457</u>

1.5 The Conventional Plan/Base Case

In order to evaluate the performance of the proposed conservation options, it was first necessary to establish a base case energy consumption pattern for the proposed development if carried out in a conventional manner. Figure 5 describes the ultimate planned volume at Bayberry. For example, 742 low cluster housing units are planned to average 1800 square feet each with 6.5 units per acre. Figure 6 is the land use plan, dated January 1978, which was used as the conventional plan/base case.

Detailed material quantity schedules were prepared for both site infrastructure and above ground construction. From these material quantity schedules, it was possible to project the energy consumed in the construction of the development program. Each unit of material was examined to determine the embodied energy contained within the material, in place, at Bayberry.

Figure 7 describes the type and quantity of storm sewers and roads expected at the site in the Greenbrier residential sectors. Figure 8 is an example of the translation of these quantities into energy as measured by British thermal units (Btu's). For example, arterial type A, 4" asphalt roads at Bayberry have an embodied energy content of 1.5964×10^{10} Btu's.¹⁴

Figure 9 examines the amount of embodied energy for a 2100 square foot house by item. For example, the bricks in a fireplace and chimney have 42.8 million Btu's. From Figure 5 we can see that Greenbrier has 149 2100 square foot units, indicating that the total embodied energy for all units of this type at Greenbrier is 667.3 million Btu's x 149 units or 10×10^{10} Btu's. Figure 10 summarizes all of the expected embodied energy for the Greenbrier infrastructure on the roads, sewers, curbs, walks and waterlines.

¹⁴ Center for Advanced Computation, and R. G. Stein and Associates, Energy in Building Construction, EDRA Contract No. E(11-1)-2791.

Figure 11: Summary of Expected Residential Energy Consumption at Bayberry

<u>Type of Housing</u>	<u>Sq. Ft.</u>	<u>Annual Heat</u>	<u>Annual Cool</u>	<u>Total Load H & C</u>	<u>Miscellaneous Load Plus Hot Water</u>	<u>Total Load Per Unit</u>	<u>Number of Units</u>	<u>Total overall Consumption in KWH</u>
Single Family detached 2-story	2400	14,357	7,912	22,269	18,754	41,023	436	17,886,028
1-Story	2100	14,357	7,200	21,557	17,880	39,437	149	5,876,113
Single Family detached	1600	10,939	4,876	15,815	14,460	30,275	742	22,464,050
Cluster Home	1800	11,075	6,566	17,641	16,200	33,841	352	11,912,032
Town House**	1450	7,038	4,261	11,299	12,540	23,839	856	20,406,184
Apartments	1100	<u>4,512</u>	<u>3,663</u>	<u>8,157</u>	<u>10,290</u>	<u>18,465</u>	223	<u>4,117,695</u>
TOTALS		62,278	34,478	96,738	90,124	186,880		82,662,102

Btu/Sq. Ft./Year

<u>Type of Housing</u>	<u>Sq. Ft.</u>	<u>Heating</u>	<u>Cooling</u>	<u>Total H & C</u>	<u>Misc. Load Plus Hot Water</u>	<u>Total Load/Unit</u>
Single Family detached 2 story	2400	20,417	11,252	31,669	26,670	58,338
1-Story	2100	23,334	11,702	35,035	29,059	64,095
Single Family detached	1600	23,334	10,401	33,735	30,845	64,580
Cluster Home	1800	20,999	12,450	33,450	30,717	64,166
Town House	1450	16,566	9,924	26,559	29,517	56,112
Apartments	1100	13,999	11,365	25,309	31,927	57,292

*Loads in KWH

**Average of center and end units in 4 unit block.

Figure 12: Summary of Expected Annual Operating Energy Consumption for Commercial, Office and Institutional Users*

Type	Number of Units	Annual Heating	Annual Cooling	Fans	Lights	Water Heat	Misc.	Number of Units	Gross Consumption in KWH
Shopping Center fully a/c 89,548 sq. ft.	4	KWH 14,128	KWH 622,323	KWH 382,346	KWH 1,203,403	KWH —	KWH 876,000	4	3,098,200 x 4 = 12,392,800
Office Bldgs. each 5 stories fully a/c total 100,000 sq. ft., each	4	35,160	369,177	193,378	773,513	—	386,756	4	1,757,984 x 4 = 7,031,936
Secondary School 36 classrooms 1080 students air conditioned	1	555,376	238,826	679,488	392,617	—	-0-	1	1,866,267
Elementary School 20 classrooms 600 students not a/c classrooms	1	262,840	43,400	169,864	197,100	146,250	-0-	1	819,454
Church 4860 sq. ft. limited use	1	40,833	10,850	51,683	14,688	1,350	—	1	119,404
Fire Station 1 bay, 2 engines limited a/c 1850 sq. ft.	1	14,033	9,757	-0-	5,000	1,000	—	1	29,790
Clubhouse 9100 sq. ft. fully air conditioned	1	245,130	126,000		97,200		—	1	468,330

*Explanation of estimation procedures is contained in Appendix A, Base Case Energy Model, p. 76. Btu per square foot per building type is contained in Appendix A, p. 76.

Figure 13: Summary of all Expected Consumption at Greenbrier

<u>Base Case/Conventional Plan</u> <u>Aggregate Energy Consumption (Btu)</u>			
	<u>Embodied Energy</u>		<u>Operating Consumption</u>
	<u>Site Infrastructure</u>	<u>Above Ground</u>	<u>End Use in Btu/yr</u>
Business & Commercial	9.9197 x 10 ¹⁰ *	21.854 x 10 ¹⁰	7.7916 x 10 ¹⁰
Residential	21.0317 x 10 ¹⁰	124.432 x 10 ¹⁰	28.213 x 10 ¹⁰
Sub Total	<u>30.9514 x 10¹⁰</u>	<u>146.286 x 10¹⁰</u>	<u>36.0046 x 10¹⁰</u>
Total		177.374 x 10 ¹⁰	36.0046 x 10 ¹⁰

In 4.92 years, the end use operating consumption equals the total embodied energy. If we assume that line losses in transmission from production to end use is a ratio of approximately 3:1, then the total Btu production requirement for operating the conventional plan for one year and seven months equals the embodied energy.

Over a thirty year period, end use consumption is 6.09 times greater than embodied energy. Including transmission losses, operating consumption is 18.28 times greater than embodied energy over the same thirty year period.

	<u>Emobdied Energy (Btu)</u>	<u>End Use Consumption</u>	<u>Consumption W/Losses</u>
First Year	177.3740 x 10 ¹⁰	36.0046 x 10 ¹⁰	108.0138 x 10 ¹⁰
Fifth Year	177.3740 x 10 ¹⁰	180.023 x 10 ¹⁰	540.069 x 10 ¹⁰
Thirty Years	177.3740 x 10 ¹⁰	1080.138 x 10 ¹⁰	3240.414 x 10 ¹⁰

*All amounts are in British thermal units (Btu's).

The second category of energy in the Base Case is the energy consumed during the ongoing operation of the development. Load calculations were estimated for each dwelling type, office, and retail facility. For accuracy, the data was compared to actual observed energy consumption in similar facilities in Virginia. A full description of these estimating procedures may be found in Appendix A.¹⁵ Projections of operating, or end-use consumption, were made for space heating and cooling, water heating, and miscellaneous loads, which included typical lighting and appliances. Figure 11 summarizes the end use consumption of the residential units at Bayberry.

For example, the 2100 square foot, one story homes examined earlier for their embodied energy will also consume 5.9 million kilowatt hours on an ongoing operating basis each year. Figure 11 similarly examines overall expected energy consumption for Greenbrier's commercial office and institutional users.

The research team found that end-use consumption, when projected over the normal 30 year mortgage period was considerably higher than embodied energy. Figure 13 is a comparison of embodied energy and end-use consumption.

The management and technical teams concluded, that while the embodied energy at a site as large as Greenbrier was not insignificant, that the major emphasis of an energy conservation plan should be directed at the expected ongoing operating consumption. Since over 30 years, operating consumption would be six times greater than the original embodied energy used to construct the community, the scope of our research was narrowed to those energy options which would most affect operational consumption.

¹⁵ Appendix A, "Base Case Energy Model", Section A.4

2. CONSERVATION OPTIONS

For the purposes of presentation and analysis, the proposed conservation options are separated into four categories:

Land Planning Applications

Architectural Applications

Mechanical Applications

Community Systems

Each represents a different level of control on the part of the developer.

Land planning applications include those conservation options which are controlled most directly by the developer and his agents. These options may be employed at any point in the development process, from raw land conversion, through site infrastructure development and lotting, to the point where the land is sold to a builder or commercial developer. Architectural applications include those options which are not in the direct control of the developer or his agents, but rather controlled by individual builders and/or individual commercial developers. Greenbrier Associates, for example, does exercise limited, indirect control over much of the architectural development, mostly in the form of published guidelines and review.

The third category, mechanical applications is normally within the direct control of the builder in residential development, and the mechanical engineer or commercial developer in the non-residential sectors. Heating, ventilating, and air conditioning equipment is selected by the builder or the HVAC sub-contractor. Equipment is usually selected on the basis of initial purchase price alone; although consumer demand for air to air heat pumps have created recent shifts in equipment purchases at Greenbrier.

Community Systems are those which involve the community itself as the primary agent of energy conservation, either through on-site alternate energy production, or through such practices as organized car pools. Options falling within the first sub-category may, in fact, require control by the developer, and have considerable impact on the manner in which the land plan is evolved. Normally, the primary developer does

not control any form of energy production, but rather ties in to the existing grid of the local utility company. Options which were considered in this category involved either on-site energy production or co-generation with VEPCO, the local utility company. These options would substantially change the role of the developer in that the developer would have to accept more risk and expend a greater amount of his financial resources early in the development process.¹⁶

Together, these categories helped synthesize the options examined in a specific energy conservation plan. Each category represented a different tier of control from which the developer could have an input into the decision making process. The site orientation option was clearly within the scope of the developers control; while the individual consumer adjusting his thermostat downward was clearly beyond the developer's sphere. The following explains each of the options in each category in greater depth.

¹⁶ Appendix C, "Impediments to Implementation"

2:1 Land Planning Applications

2:1.1 Reduction in Street Widths: This action is directly controlled by the developer, subject to the subdivision regulations established by the City of Chesapeake. Current subdivision regulations require that streets be 28 feet in width curb to curb. Residential streets are two inch asphalt slab over 4 inches of crushed gravel. Arterial roads vary in width, depending upon the requirements of the City of Chesapeake. Arterial roads are 4 inches of asphalt over 4 inches of crushed gravel and 4 inches of tamped soil. In place, residential streets consume 13,264 Btu's per square foot.¹⁷ Embodied energy could be saved by reducing either the thickness of the slab or the width of the pavement.

The largest lots at Greenbrier are 12,000 square feet. Since the ratio of road to lot is greatest in this category, larger savings could be achieved here than in any other residential category. Reducing the thickness of the slab would require either a change in the minimum construction specifications by the City of Chesapeake or permanent maintenance by Greenbrier Associates. Preliminary discussions with the city indicated that they would not be willing to modify their construction specifications in any area which would increase maintenance costs in the long run. Greenbrier Associates is not in a position to maintain site infrastructure once the development is sold out. To do so would not only require the addition of a permanent maintenance crew, but also a change in the property tax laws of the City of Chesapeake and the State of Virginia. As a result of this preliminary evaluation, reduction in slab thickness was excluded from further consideration.

Reduction in street widths, however, did not encounter the same obstacles. Although current subdivision regulations require widths of 28 feet, reductions to 24 feet might be negotiable with the city. The average square footage of street in the low density residential sectors is 1008 per lot. By reducing the width of the street four

¹⁷ Appendix A, Base Case Energy Model, Section 2.

feet, the total square footage per lot is reduced by 144 square feet. From the Base Case we estimated that the savings achieved by reducing the street widths would be 3.8 million Btu's. Converting this to the dollar value of the embodied energy in the asphalt, the gross savings per lot would be \$19.48.¹⁸

2:1.2 Improved Efficiency in Lotting: As with streets, the layout of the lots is directly controlled by Greenbrier Associates. While street frontage and setback requirements are regulated by the City of Chesapeake, the configurations of lots and streets are developed by a land planner. The land plan is then engineered and the requirements for subsurface infrastructure are determined. If optimum efficiency in subsurface infrastructure was a criteria in the land planning stage, then embodied energy could conceivably be reduced by decreasing sewer and water pipe lengths, and utility runs.

Several configurations of street and lot layouts were considered.¹⁹ These are described in detail in Appendix B:1.2. Since the selling price of lots must include the costs of subsurface infrastructure, it is in the best interest of Greenbrier to reduce this portion of the capital investment as much as possible, as long as the marketability of the lots are not adversely affected.

An evaluation of several different lotting strategies showed that the most efficient layout is a single street, double loaded. This efficiency decreases considerably when connections to other streets are made, due to corner lots.²⁰ This configuration also produces a visual appearance that tends toward monotony. This is particularly true at Greenbrier where the topography is virtually flat. Such a configuration also makes orientation to site amenities difficult to achieve, since the efficiency is obtained by the repetition of the double loaded street. Considering maximum orientation to site

¹⁸For comparison purposes only, embodied Btu's were converted to KWH by dividing the Btu's by 3413 and then converted to dollars by multiplying the KWH by .035, the current average residential rate at Greenbrier.

¹⁹The low density residential sections of Bayberry place have an average street frontage of 72 ft. and an average lot depth of 140 ft. Since the greatest savings per lot could be expected here, the low density areas were used in the calculations.

²⁰Appendix B:1.2

amenities and minimum infrastructure simultaneously, the most efficient lotting strategy is a combination of linear streets and cul-de-sac streets.²¹ An examination of the conventional plan shows that this design is already in use. While careful attention to lot infrastructure efficiency could produce adjustments to the conventional plan, these changes had a negligible effect on embodied energy. This option was not considered further.

2:1.3 Reduction in Embodied Energy in Curbs and Sidewalks: Current subdivision regulations require poured in place concrete curb and gutter on all residential streets, and four foot wide reinforced concrete sidewalks four inches thick on each side of the street. Details of these appear in Appendix A. While reduction in street widths and changes in lot to infrastructure relationships would not affect these items to a significant degree, the research team did expect that savings could be obtained by either changing material or changing the quantity of material per linear foot.

Studies in the Base Case showed that the embodied energy contained in asphalt is 55% less than in poured in place concrete. By changing the concrete sidewalks from four inch concrete slab to two inch asphalt slab, 4.0×10^{10} Btu's could be saved.

This represents a dollar value of \$410,196.29 if converted to a KWH.equivalent.²² (On a per unit basis, the average saved in all residential types is \$88.00.) Changing the curb and gutter from concrete to asphalt represents an energy savings of 2.9×10^{10} Btu's.

While these changes would require modifications of existing subdivision regulations, the predicted savings may be sufficient to warrant such a change, particularly in the case of the sidewalks.

2:1.4 Lot orientation: A subset of land planning, the orientation of lots was considered in relation to maximum solar insulation. Preliminary analysis indicated that substantial

²¹ Appendix B:1.2

²² For comparison purposes only, embodied Btu's were converted to KWH by dividing the Btu's by 3413 and then converted to dollars by multiplying the KWH by .035, the current residential rate at Greenbrier.

reductions in heating loads on individual houses could be achieved by orienting the longitudinal axis of the structure east/west, so that the house would face south. A TRNSYS simulation of a Base Case, 2100 sq. ft., conventional residence indicated a 4.4% annual reduction over the same house facing west.²³

Orientation of all houses for maximum solar efficiency, however, is difficult to achieve without single loading all streets which would double the price of each lot.²⁴ Nevertheless, by including proper solar orientation as a parameter in the land planning phase considerable savings can be expected. A portion of the study area was redesigned incorporating this option. The result was an increase in north/south facing lots of 12.2% over the conventional plan, and a decrease of east/west facing lots by 4.8%. In addition to the improved orientation, the efficiency of lot to infrastructure was improved adding 25 lots for the same infrastructure investment.²⁵

2:1.5 Transportation: Energy consumed in transportation was considered briefly, but was eliminated from consideration due to the limited impact of Greenbrier Associates on trip generation. Journey to work trips as well as trips with destinations beyond the Greenbrier site could easily account for over 70% of the total trip origins at Greenbrier. The remaining trips could conceivably be altered by careful location of commercial and institutional facilities. A cursory investigation found, however, that the central location of these facilities in the conventional plan produced the most efficient distribution of internal trips, and could not be substantially improved upon without a change in transportation modes. In order to achieve a substitution between modes, retail and institutional facilities would have to be located within one mile of all trip

²³ Appendix B, Section 1.4

²⁴ Optimum orientation could be achieved on double loaded streets by rotating the houses on the lot. This option was discarded due to expected difficulties in marketing houses without street front orientations.

²⁵ Appendix B, Section 1.4

origins. To support such a dispersment of retail facilities within the site, the overall density of the residential sector at Greenbrier would have to be increased five times. Since the current densities reflect market demand (to the best estimate possible), increasing the density substantially was not feasible. As a result, transportation related energy consumption was dropped from further consideration.

2:1.6 Vegetative Cooling: Shading of residential structures can have a significant effect on reduction of cooling loads. Although much has been written concerning microclimatic control from trees, there is little empirical analysis evident in the literature which actually translates this concept into hard data.²⁶ Cooling from vegetation occurs primarily in two ways. First, by blocking direct heat and light energy from the sun, internal temperatures may be reduced. In addition to the reduction in direct gain, the evapotranspiration of water from the ground and through the leaves uses energy and subsequently reduces the ambient external air temperatures. A study by Deering at the University of California at Davis, showed a reduction of 20° F in mobile home when placed in the shade of a large Eucalyptus grove.²⁷

In order to calculate the reduction in cooling loads, the shading coefficients of various trees must be known. Again, a thorough search of the literature produced only sparse, and widely varying data. Victor Olgyay, in Design With Climate gives .20 to .25 shading coefficients for "mixed deciduous" shade.²⁸ Geiger, gives a range of .02 to .40 for Deech.²⁹ Other studies show similar disparities.

Nevertheless, manual calculations were performed for reduction in direct gain through glass surfaces on a typical 2100 ft.² Greenbrier residence. Using a shading

²⁶Center for Landscape Architecture Research, Landscape Planning for Energy Conservation

²⁷Deering, Robert B., "Effective Use of Living Shade", in California Agriculture, Vol. 9, 1955

²⁸Olgyay, Victor, Design With Climate, Princeton University Press, Princeton, N.J., page 71

²⁹Geiger, Rudolph, The Climate Near the Ground, 2nd Edition, Harvard University Press, 1950 (Table 49)

coefficient of .10, deciduous shade on the East and West facades can reduce the cooling load by 85,500 Btu's per day. This is the equivalent of 25.06 KWH or \$0.87 per day. Over the cooling period, this results in a gross savings of \$78.30.³⁰

There are two ways to achieve shading. One is to carefully site each structure so that shade is provided from existing trees on the site. This would require additional effort from the builder.

Normally, an effort to control the cutting of trees is made by the developer and land planner through the layout of streets and lots, and by the use of restrictive covenants attached to the lot at time of sale to the builder. Those trees saved by the builder, however, are normally done so for their aesthetic appeal to the potential consumer. While the developer could restrict the cutting of trees on east and west facades, enforcement may be difficult due to the staging requirements of the builder and his or her subcontractors during the construction period. Individual siting of structures normally is done by the builder. To insure the preservation of trees in the correct location, the developer or his agent may have to control the siting of each structure.

The second way of achieving these results is to plant trees, after construction, in the desired location. This does not have the advantage of immediate results, and requires additional capital expenditures on the part of the builder. In order to qualify for FHA financing, the builder must have landscaping equivalent to 1½% of the selling price. At Greenbrier, this averages \$984.00 per residence. Again, the developer can influence the location and type of plantings through restrictive covenants, but only to the extent that the builder feels the marketability of his or her product will not be diminished.

³⁰ Appendix B, Section 1.6

2.2 Architectural Applications

2:2.1 Re-configuration of Internal Living Space: Comfort in internal living spaces can be maintained passively depending upon their location in relation to direct solar gain. Areas, such as living rooms, family rooms, eating, and working areas should be located on the southeast, south and southwest. Sleeping areas should be on northern exposures. During the heating period this would allow for maximum passive direct gain in those areas of the house used during the periods of the day when solar gain is maximized.³¹ Additionally, the floor plan could achieve greater efficiencies from the residence's mechanical systems by reducing the heating load. This reduction in load can reduce the capital investment as well, by requiring smaller equipment.

While the idea behind this option seems to be correct, demonstrating its performance proved to be a difficult task. None of the available load simulation programs could handle this task without considerable difficulty. Nevertheless, the technical team felt that this concept had considerable merit, and should become part of the conservation plan to every extent possible.

Several obstacles, however, must be overcome to achieve this. Foremost is the resistance of the builder to alter his floor plans. Typically, a builder will purchase a set of plans from a plan service. Minor modifications might be made by the builder during construction, but to re-configure each floor plan to suit the specifics of lot orientation, tree location, and amenity location would require the services of an architect. Since the specific points listed above vary with each lot, this would mean that each residence would have to be designed individually. This is far beyond the means of the speculative builders operating at Greenbrier or in over 90% of the new home markets nationally.

³¹Wright, Henry Niccols, Solar Radiation as Related to Summer Cooling and Winter Radiation in Residences, New York, 1936.

2:2.2 Solar Screening, Window Location, House Orientation: This option is integrally related to the reconfiguration of internal living space. The placement of windows in a structure is primarily a function of the location of the rooms, and the function of those rooms. Living areas, with either street orientations or amenity orientations will have significantly more glass than bedrooms. Ideally, the south facing facade should contain as much glass as possible, and the north facade should contain none. East and west facades should contain glass, but must be shaded by trees, calculated roof overhang, louvered screens, or some other device to reduce summer cooling loads.

A preliminary TRNSYS load simulation of a 2100 sq. ft. Greenbrier house for the month of January indicated a reduction in load of 24% when all the windows are moved to the south facade.³² Further simulations show the effects of reducing glass on the north and moving it to the south. Moving only the north windows (72 sq. ft.) to the south facade, reduced the heating load 21%. In all, 15 combinations of window locations were simulated. The results appear in Appendix B:2.1.

Although the best performance was obtained from the simulation having no windows on the north, east, or west, implementation of such a structural configuration is virtually impossible in speculative housing markets, but could conceivably be achieved through regulatory enforcement via building codes. The review team did feel that maximizing south facing glass was a desirable goal, and in situations where either the orientation of the lot or the floor plan configuration prevents placing the maximum glazing surface to the south, solar loads could be effectively reduced by deciduous shade, or other screening devices.

Preliminary analysis was completed for several screening devices. Koolshade solar screens, manufactured by Kaiser Aluminum corporation can reduce solar gain through windows 80% with the sun at a 40° profile angle.³³ These shades would be most

³² Appendix B:2.2. Base unit is 65.5 feet long and 32.5 feet wide. The long sides have 104 sq. ft. of glass on the rear or amenity side and 72 sq. ft. of glass on the front or street side. The side facades have 21 sq. ft. of glass each.

³³ Kaiser Aluminum Corporation "Koolshade Performance Data". See Appendix B.

effective on southern exposures of two-story structures where the roof overhang would not be an effective screening device. They have the advantage of removal during the heating period to allow for maximum solar gain. Venetian blinds, draperies, and shutters were also considered. While preliminary analysis indicates that such devices can reduce heat gain during the cooling period, the implementation of them can be achieved as an add-on feature by the builder, but their effect depends solely on the consumer after purchase of the house from the builder.

In summary, thermal loads can be reduced 21% by moving the glass (72 sq. ft.) from the north facade to the south. A marginal decrease of 4% can be expected if the east and west windows (42 sq. ft. total) are relocated to the south. There are serious design and marketing constraints related to this option, as tested, but the option should be considered as a goal in the conservation plan. In situations where glass cannot be reduced, solar gain can be reduced during the cooling months by both landscaping and the use of solar screening devices.

2:2.3 "Arkansas" Construction: This option incorporates two major energy conserving features: reduction in air infiltration and increased wall cavity for added insulation. The name is derived from an experimental residential structure built by Arkansas Light and Power Company. The major feature is the use of 2 x 6 stud wall construction set 24 inches on center rather than the normal 2 x 4 stud wall set on 16 inch centers. The increased thickness of the wall cavity allows a 6" fiberglass friction-fit batt to be used, increasing the insulation value of the wall from R-19 (Base Case) to R-23. By reducing the number of studs per linear foot of wall, conduction through the wall is reduced. The second major feature of Arkansas construction is the sealing of the toe plate where the wall rests on the foundation, and caulking all corner joints and other breaks in the exterior facade, such as dormer windows. Construction details of these features appear in Appendix B:2.3.

TRYNSYS load simulations were performed on a Base Case house (2100 sq. ft.) incorporating the "Arkansas" construction features. Reduced infiltration proved to be

the most effective single means of reducing the heating and cooling load as compared to the 2100 ft.² Base Case unit. This has been common knowledge in the engineering community for many years, but is apparently ignored in the construction industry. For engineering analysis in the simulation, air infiltration was reduced from one (1.0) air change per hour to a .3 air change per hour.³⁴ This reduction in infiltration reduced the annual energy consumption for heating and cooling 39%.

A separate analysis was performed for 2 x 6 construction. Taken separately this portion of the "Arkansas" option reduced energy consumption only 8%. Although air infiltration is also reduced by the use of 2 x 6 stud walls, this was not included in the analysis.

The results of the analysis indicate that a few changes in conventional construction methods can produce fairly remarkable energy conservation. Cost analysis of 2 x 6 and 2 x 4 walls revealed that the 2 x 6 is, or should be, less expensive per linear foot of wall. While the cost of 2 x 6 lumber is slightly more per board foot than the cost of 2 x 4 lumber, the added strength of the 2 x 6 studs allows for a 24 inch spacing rather than the conventional 16 inch spacing. The total effect is less lumber used to build the same house, resulting in an actual savings in capital investment.

Reduction in infiltration is a slightly different problem. Normally, the framing subcontractor secures the stud to a toe plate which is attached directly to the foundation. The greatest air leakage occurs at this point. If the foundation is a slab-on-grade, the toe plate is affixed directly to the slab, usually by a 22 caliber nail gun. Since the slab cannot be poured absolutely flat, gaps occur between the slab and the toe plate. Sealing this with gasket or roofing felt or weather stripping, and caulking the exterior perimeter should reduce air infiltration at the foundation and toe plate by 95%. Field investigations of several houses currently under construction at Greenbrier, using

³⁴ One air change per hour is the assumed air change for residential structures in, National Solar Heating and Cooling Information Center, "Passive Design Ideas for the Energy Conscious Architect". In theory, this could be reduced below .1 air changes per hour. Air changes below .15 to .2 air changes per hour could endanger the health and safety of the occupant. An assumed reduction in air infiltration to .3 air changes per hour was simulated using TRNSYS. The effect of this reduction was a corresponding reduction in load of 39%.

an AGA 750 Thermo-Vision infra-red scanner indicated that this initial hypothesis is correct. Several houses constructed on slab foundations had only the carpet and carpet pad blocking air infiltration at the slab and toe plate connection. In addition to sealing the toe plate, all corners and other joints must also be sealed. An expandable caulking compound, carefully applied at the completion of framing could virtually eliminate this problem.

The results of the simulations of this option were so promising that Greenbrier Associates contacted the two largest builders currently operating at the site. The result of this meeting was disappointing. The position of these builders is implementation of these options will cost more, and that increased construction cost would reduce their marketing advantage by increasing the selling price. Although the research indicated that 2 x 6 construction could actually reduce costs and that caulking joints was a relatively minor expense, the builders were not willing to take that risk, until the consumer demanded it.³⁵ Since the consumer, in general, is relatively uninformed on the value of reduced infiltration, demand is not likely to produce the desired action on the part of the builder. As a result, it became evident that until a small group of houses incorporating these features were actually constructed and tested, builders are not going to be convinced of the value of this option.

2:2.4 Double Glazing: This option is currently in use by builders at Greenbrier. It is included here because of its incorporation in the "Arkansas" construction option. Double glazed windows reduce air infiltration as well as increase the insulation value of the window.

The 39% reduction in thermal loads from air infiltration in Arkansas construction included double glazed windows. A separate analysis of the performance of double glazing in relation to heat transfer through the glass showed a 9% decrease in energy consumption for heating and cooling. Further analysis indicated that there are substantial differences in performance in relation to the width of the air space between

³⁵ Appendix C "Impediments to Implementation".

the glazing surfaces. Windows with 5/8 inch to 3/4 inch air spaces perform approximately 4% better than windows with 1/8 to 1/4 inch air spaces.³⁶ While double glazed windows are roughly 50% more expensive than single glazed windows, builders are more than willing to incorporate them into the house. This is due to their "visibility" in the marketplace. Consumers are aware of their benefit and are willing to pay. This is in marked contrast to the "invisible" aspect of 2 x 6 construction, toe plate sealing, and caulking of joints.

2:2.5 Slab and Crawl Space: The results of the analysis of the "Arkansas construction option raised the question of the relative benefits of slab foundations and crawl space foundations. For reasons unknown to the research team, the Norfolk-Chesapeake market associates crawl-space foundations with higher quality construction and is apparently reluctant to purchase "premium" housing with slab-on-grade foundations. While the Base Case houses which have slab foundations at Greenbrier have serious problems with air infiltration, such foundations should offer advantages to both builder and consumer due to their low cost and the insulating property of the earth.

A TRNSYS simulation was made for a 2100 sq. ft. Base Case house with slab foundation and compared to a simulation of the same unit with an uninsulated crawl space. The floor of the house over the crawl space was insulated with 6 inch fiberglass (R-19). One important difference between the slab foundation on houses currently under construction at Greenbrier and the slab of the Base Case house in the simulation was the inclusion of two inches of urethane foam (R-16) for a distance of 24 inches in the slab itself. The presence of this insulation in the slab prevents heat transfer through the slab to the outside air and allows the slab to use the earth as insulation.

The insulated slab foundation reduced energy consumption for heating and cooling 2.8% over the same house with crawl space. When applied to the package of options

³⁶ Comparisons of double glazing and storm windows were also performed. Results of this analysis are in Appendix B, Section 2.4.

included in the "Arkansas" house, a further reduction of 1.8% was achieved.³⁷ Another analysis of the effect of insulating the crawl space showed equivalent reductions to the insulated slab foundation.

The cost of insulating the slab is minimal. The major difference is in the added labor required in pouring a two stage foundation at the two foot perimeter. When compared to the cost of pouring the continuous footings and block piers required for crawl space, the insulated slab is cheaper. The question of market acceptance in the Norfolk area remains unanswered.

2:2.6 Roof Overhang: Houses currently under construction at Greenbrier have minimal roof overhangs of six to eight inches. Increasing the overhang to one meter could be an effective control in reducing thermal loading in the cooling period. A TRNSYS analysis of this option proved to be difficult because it affects the transitional months when neither heating nor cooling is likely to be used. Increasing the roof overhang to one meter from the external facade reduced the cooling load of the Base Case (2100 sq. ft.) Greenbrier house only 2.3%. A separate analysis of a one meter overhang coupled with the "Arkansas" option package reduced the cooling load 5%.

While the material cost of increasing the overhang is minimal, there are substantial problems associated with builder implementation of this option. Builders at Greenbrier, as well as most independent builders nationally purchase plans from a plan service catalogue. The vast majority of these plans do not feature one meter overhangs. To incorporate such an overhang into the roof structure, the roof plan would require alteration by redesign and is viewed as having substantial associated costs by builders at Greenbrier.

2:2.7 Greenhouse: This option was well received by both Greenbrier Associates and the builders, primarily because it was seen as a marketing device, adding increased value to

³⁷ Appendix B, Section 2.6.

the housing product. The greenhouse, as a potential add-on feature, does not have the inherent marketability risks associated with other options.

The Greenhouse, in order to provide heat to the house, would have to have a heat storage capability. For purposes of analysis it was assumed that the most cost effective means of producing this heat storage was with 55 gallon barrels of water. TRNSYS simulations were made for four possible greenhouse configurations. A 128 sq. ft., 970 cubic ft. attached greenhouse was modeled with single glazing, double glazing, three barrel storage, and five barrel storage. It was assumed that an ambient temperature of 40° F was maintained in the greenhouse at the lowest point. At temperatures above 70° F it was assumed that the greenhouse supplied heat to the house. All configurations provided an overall positive energy flow to the house. The total annual value of the energy collected varied from \$98.00 to \$148.00. This is relatively low when compared to the cost of the greenhouse.³⁸ Due to the capability of this option to serve as an "add-on" feature, and because of the positive marketability, the greenhouse appears to be a viable option.

2:2.8 Trombe Wall: Named for a French engineer, the Trombe Wall stores heat from direct solar gain in the mass of the wall itself, heating the structure at night by re-radiating the stored energy gained during the day. If perfected, this device could conceivably replace fossil based heating without the expense or maintenance problems associated with active solar equipment.

Preliminary performance data on this option was promising. A survey of several houses across the country incorporating Trombe Walls in their design indicate that in relatively mild climates (less than 3500 heating degree days) a Trombe Wall could provide 80 to 95% of the total heating needs.³⁹ The total capital cost of a Trombe Wall installed in a house in Davis, California was \$2500.00.⁴⁰ This compares favorably to conventional HVAC systems currently in use at Greenbrier.

³⁸ Appendix B, Section 2.7

³⁹ Appendix B, Section 2.8

⁴⁰ Appendix B, Section 2.8

The efficacy of this option in a speculative housing market ultimately depends upon consumer acceptance. Builders operating in this market are not willing to assume the risk associated with Trombe Walls.

2:3 Mechanical Systems

2:3.1 Groundwater Heat Pumps: One of the largest development problems at Greenbrier is the presence of an extremely high water table, and extremely flat topography. In order to insure proper drainage as well as stable soil conditions for roads and building sites, extensive modifications must be made. The primary result of these modifications is the creation of a large network of lakes and drainage canals. Early in the study, the technical team discussed the potential heat storage capacity of such a large volume of water. Extensive regulation of surface water bodies in Virginia renders these lakes unusable for such purposes.⁴¹ However, the large amount of available groundwater at Greenbrier did open the possibility of exploitation of this resource for energy production. The groundwater is available in enormous quantities from a large unconsolidated aquifer extending throughout the Virginia Tidewater region. At a depth of 70 feet, the water has a constant, year-round temperature of 62° F, a balanced Ph, and is relatively low in iron, calcium carbonate, and other minerals.⁴² While groundwater resources are regulated by the Virginia Water Quality Control Board in Richmond, residential use is exempt from regulation under the current act.⁴³

The constant temperature of 62° F makes this water ideal for both heating and cooling when used in conjunction with a water source, or water to air heat pump. Air to air heat pumps are currently in widespread use at Greenbrier.⁴⁴ While these units are considerably more efficient than conventional electric resistance heating, their efficiencies decrease considerably when the ambient air temperature falls below 38° F. In addition to efficiency decreases from drops in ambient air temperatures, air to air heat pumps have a tendency to form ice in the condenser unit and must be defrosted

⁴¹ Appendix C, Virginia Water Quality Control Act

⁴² Conversation with Mr. Thomas Gildersleeve, Well Driller, Virginia Beach, VA, July 1978

⁴³ Appendix D, Virginia Groundwater Act of 1973, Chapter 3.4, Title 62.1

⁴⁴ Appendix A, Base Case Energy Model, Section 1.7

automatically approximately every half hour using electric resistance heating coils. This defrost cycle creates further decreases in operating efficiencies.

Heat pumps, which use constant temperature water as a heat or cooling source, do not experience losses in efficiency due to the constant temperature source and the elimination of the need for a defrost cycle.

Initial estimates of performance indicated that the groundwater heat pump could achieve a coefficient of performance of approximately 3.5 to 1.⁴⁵ TRNSYS load simulations of a 2100 sq. ft. Base Case house with a groundwater source heat pump yielded a reduction in space heating and cooling of 52% as compared to the same house with an air to air heat pump. Discussions with several heat pump manufacturers, and one sales distributor in the Norfolk area, indicated that the installed cost, excluding the well, could range from \$500.00 less than conventional HVAC equipment to \$500.00 more. Estimates of well costs were obtained from two well drillers in the Chesapeake area and ranged from \$150.00 to \$300.00 for a 70 foot extraction well and a 25 foot injection well.⁴⁶ The high performance and low capital cost of this option appears to offset any perceived marketing disadvantages. There are, however, several constraints peculiar to this option. Disposal of the exhaust water cannot occur in surface water bodies under present law. This means that the water must be either sprayed onto large open areas, such as golf courses, or injected back into the aquifer. The spraying alternative is not desirable due to the large capital investment required for storage and piping. The injection well appears to be the most practical method of water disposal, having the additional advantage of returning to the aquifer the same volume of water that is extracted. The effect of returning heated water (70-75° F) to the aquifer on a large scale basis is unknown. A study completed by Battelle indicates that severe problems occurred in the solidification of existing calcium carbonate in the aquifer at

⁴⁵ Appendix B, Section 3.1

⁴⁶ Conversation with Mr. Thomas Gildersleeve, Well Driller, Virginia Geach, VA, July 1978

temperatures of 95-105° F.⁴⁷ Conversations with the State Hydrologist and the National Water Well Association in Canton, Ohio indicate that little is known about potential environmental impacts from injection wells, since they are currently not in widespread use.⁴⁸

2:3.2 Domestic Hot Water - Heat Reclaimer: The ability of heat pumps and air conditioners to take energy from one place and deliver it to another efficiently has been well recognized. Only recently, as a result of the energy shortage, have researchers and manufacturers realized that this efficiency could be used to heat domestic hot water considerably more efficiently than with electric resistance heating.

In the cooling mode the energy being removed from a building is discharged (thrown away) to either the outside air or to water in the case of ground water heat pumps. If this energy is used to preheat domestic hot water rather than being thrown away, the energy becomes essentially free, and the overall efficiency of the heat pump will double.

In the heating mode the energy is not free because it was being used to heat the structure, but it is available much more efficiently than with electric resistance heat. Air source heat pumps (annual C.O.P. of 2.0) can preheat domestic hot water approximately twice as efficiently as electric resistance water heaters, while water source heat pumps can be three to three and one half times as efficient as electric resistance water heaters (annual C.O.P. of 3.0).

The research team analyzed the domestic hot water preheater for use with water source heat pumps quite extensively and concluded that there were no technical or institutional impediments to its application. No significant modification is required to the heat pump, and the energy reclaim unit, presently priced at \$500, is simple and

⁴⁷ Battelle Laboratories, "Heat Pump Analysis, Appendix D", obtained from State Water Quality Control Board, Albert H. Giles, Geologist.

⁴⁸ Albert H. Giles, Geologist, VA Water Quality Control Board.

available from several manufacturers.⁴⁹

The analysis showed the heat pump energy reclaim unit to be easily implemented during new construction or new installation and to pay for itself in approximately three years depending upon the quantity of hot water used and the amount of time the heat pump was running.

2:3.3 Active Solar Domestic Water Heating Systems: Numerous studies have shown that active solar domestic hot water systems are the most economically practical of all active solar energy systems. These systems were investigated extensively for use at the Greenbrier site.

A number of flat plate domestic hot water systems were simulated on a computer to determine probable system performance and relative economic feasibility. The simulations quickly revealed that system performance is highly dependent upon the particular collector used in the system. One of the better systems available appears capable of collecting approximately \$145 worth of energy per year if one assumes it replaces an electric resistance heater. This system costs approximately \$1200 to the contractor. If an excessive markup is not made on this system for installation and fuel costs continue to increase at the rate that appears likely, this system will pay for itself in less than ten years this then would be an attractive investment for most families if other more attractive alternatives are not available. An average collector available in the Greenbrier area will collect \$100 dollars worth of energy per year and would cost approximately the same as the more efficient collector. Although possibly economically viable, this system is not nearly as attractive as the more efficient collector.

Mention was made above to more attractive alternatives. Heat reclaimers on water source heat pumps appear to be very attractive as domestic water heaters for the Greenbrier site. These heat reclaimers cost only \$500 and will collect more energy than the most efficient collector evaluated.

⁴⁹ Manufacturers list price varies from \$175 to \$225. Current prices which are substantially higher than this possibly due to their newness in the market.

The research team concluded that for the Greenbrier site, heat pump heat reclaimers appear to be a more attractive alternative. For sites which do not lend themselves to water source heat pumps and where the performance of air source heat pumps is marginal, the high efficiency solar domestic water heater can be an attractive alternative to electric resistance water heaters.

2:3.4 Active Solar Residential Heating Systems: Active solar home heating systems were studied through computer models to determine the performance and economic feasibility of such systems. As with previous studies of such systems, this modeling showed that due to the relatively low yearly heating load at Greenbrier, active solar heating systems could not be justified economically.

If a system were sized to supply 60 percent of the annual heating requirements of a home, it would represent a capital expenditure of approximately \$12,000. The system would collect excess energy for roughly eight months of the year due to the low heating requirement during these months. Part of this excess energy can be used to heat domestic hot water, but the majority would have to be vented (wasted).

The solar home heating system would require a full auxiliary backup and would contribute nothing to the summer cooling load. Solar powered cooling systems were not considered due to the prohibitively high cost and low efficiencies of systems presently available.

As with the solar domestic hot water system, the building heating system is sensitive to the collector used in the system. Eight hundred sq. ft. of an average collector available in the Norfolk area will usefully collect 63×10^6 Btu per year while 400 sq. ft. of a high efficiency system costing roughly the same as the average collector will usefully collect 60×10^6 Btu per year.

The solar home heating system was considered by the research team to be economically impractical at the present time. It would not come close to being competitive with the water source heat pump.

2:4 COMMUNITY SYSTEMS

2:4.1 Wind Energy Systems: Wind energy systems show promise for many parts of the world. The wind energy is available in many locations and, when the proper hardware becomes available, may become an attractive energy source for many locations. It was felt by the research teams that hardware suitable for residential wind energy systems is not presently available and will not be developed within the next five years. The team did look at the feasibility of wind energy systems at the Greenbrier site should the hardware become available.

Although not an ideal site for a wind energy system, the Greenbrier/Norfolk area is a relatively good site for wind energy systems. Wind speeds are not great but are relatively steady throughout the year. It appears that the D.O.E. 100 Kw Mod I wind turbine would average an output of about 40 Kw throughout the year at the Greenbrier site. This is a relatively small turbine and is less efficient than larger turbines in the design stages.

The research team felt that wind energy systems were not presently available that were of sufficient size and efficiency and at a competitive cost to be considered as a viable alternative for the Greenbrier site. As larger, more efficient and less expensive systems become available; wind energy systems may be an attractive alternative. It was felt that the system probably should be owned by an existing or new utility rather than a residential community.

2:4.2 Solar Total Energy Systems: In theory, solar total energy systems promise greater system efficiencies and lower operating costs than other types of solar energy systems. The sun's energy is concentrated with reflective heliostats or parabolic devices so that high grade energy, i.e., energy at high temperatures, is available. This high grade energy is used to vaporize a high pressure liquid which is then expanded through a turbine to develop electric energy. The electric energy is used by the community, and the exhaust from the turbine, a low grade energy, is used to chill absorption chillers or to heat water for community heating and cooling.

In practice the promised high efficiencies and low system costs have proved difficult to obtain. A thorough review of these solar total energy systems designed with D.O.E. funding was made to determine the feasibility as an energy system for a residential community. The Fort Hood system seemed to be representative of the three systems and since project personnel had ready access to data from this study, it was used as the basis for evaluation.

The Fort Hood system has an estimated cost of approximately \$112 per sq. ft. of collector and an estimated energy delivery of 98,000 Btu/sq. ft./year. This compares with 150,000-200,000 Btu/sq. ft./year for flat plate residential heating systems which cost less than \$35/sq. ft. From this analysis alone, one can determine that the solar total energy system cannot compare with a solar flat plate heating system.

At \$.04/Kw hr., the solar total energy system collects only \$1.14/sq. ft. each year. With a capital cost of \$112/sq. ft., it is relatively easy to determine that the system has an excess payout period even if the cost of money, interest, was zero.

The Solar Total Energy System becomes even less attractive for communities where all of the land is useable and very valuable such as at the Greenbrier site. The cost of the land required to locate the Solar Total Energy System increases the system cost to well above the \$114/sq. ft. used in the analysis briefly described above. It was decided by the research team that solar total energy systems are not economically viable for the Greenbrier site.

2:4.3 Central Thermal Plants: Central thermal energy plants are widely used in large apartment buildings, apartment complexes and many office buildings. They have an advantage to the building or apartment complex operator in that only a few large units have to be maintained rather than many smaller units. The large centrifugal chillers also operate more efficiently than the smaller air conditioners.

The research team undertook to determine whether all or some of these advantages could be realized in a detached single family residential community such as Greenbrier. A system sized for a 100 home complex was chosen for the analysis

because it permitted the use of the smallest high efficiency centrifugal chiller. An oil fired hot water boiler was chosen as the source for the thermal energy during the heating mode.

A four pipe thermal distribution system was considered a necessity because differences in building design, orientation and operation would certainly require some homes to be cooled while others were being heated.

The analysis revealed that while the central plant was considerably more efficient during the cooling mode, due to the high efficiency of the water cooled centrifugal chiller, the central plant was less efficient during the heating mode because the oil fired boiler at an assumed efficiency of 80% was less efficient than a high efficiency water source heat pump. The analysis revealed that the annual operating costs per residence for the central thermal plant was almost identical to that of a water source heat pump.

An economic analysis was then made to determine how the central thermal plant compared with more conventional HVAC installations. This analysis revealed that for single family detached residences, the central thermal plant was approximately twice as expensive to install per residence as the water source heat pump.⁵⁰ It also did not permit the additional saving possible with domestic hot water preheaters on the heat pumps.

The central plant had additional difficulties regarding breakdowns affecting a large number of homes at once. There was also a belief among the research team that the public was distrustful of utilities and that a thermal utility would be viewed by the public as another source of future utility problems, thereby affecting home sales.

Considering the comparable operating costs and the much higher capital costs, the thermal utility was not considered a competitive conservation option for the Greenbrier single family detached community.

⁵⁰ Appendix B, Section 4.3

3. CONSERVATION PLAN

The Conservation Plan consists of those options deemed feasible and appropriate for implementation by the Review Team. A comparison between the conventional plan and the conservation plan was made to determine the relative costs and benefits. The conventional plan used in the comparison is a section of Greenbrier containing 719 acres of residential development, including an eighteen hole golf course.⁵¹ Options included in the conservation plan include:

- . Maximum south facing lots (orientation)
- . Vegetative cooling
- . "Arkansas" Construction
- . Insulated Slab on Grade Foundation
- . Groundwater Source Heat Pump
- . Domestic Hot Water - Heat Reclaimer
- . Greenhouse

Several options which proved to be promising were not included in the conservation plan due to either their questionable legal status (reduction in sidewalks, curbs, and gutters, and reduction in street widths) or because the option was considered to be an add-on feature by the builder (Greenhouse).

In the conservation plan, energy consumption is reduced two ways. First, by reducing the heating and/or cooling load, less energy is required to maintain internal comfort within the dwelling unit. The second is by heating or cooling the remaining loads more efficiently. Because the total effect of each option is not necessarily cumulative, all options were added prior to simulation of the performance of the conservation plan.

⁵¹The Bayberry site was not used for comparison purposes. Due to the advanced stage of infrastructure development, proposed options could not be implemented at Bayberry. Since there is virtually no difference in the development program of the 719 acre site and Bayberry, the research team developed the conservation plan for possible implementation on the 719 acre site, Bayberry II.

Figure 14A

CONVENTIONAL PLAN

Figure 14B

CONVENTIONAL PLAN

Figure 15B CONSERVATION PLAN

SECTION A - FRONT NINE

GOLF and WATER	93
GOLF	80
WATER or GOLF ACCESS	31
NO AMENITIES	86
	subtotal	290
	total	566

Figure 16

SUMMARY OF LOT ORIENTATION: CONVENTIONAL
PLAN AND CONSERVATIONAL PLAN

Front Nine (224 Acres)

<u>Facing</u>	<u>Conventional Plan</u>		<u>Conservation Plan</u>		<u>Differences</u>	
	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>
N	50	17.2	72	24.5	21	42.0
S	67	23.1	82	28.3	15	22.4
E	82	28.3	68	23.5	(14)	(17.1)
W	91	31.4	69	23.7	(22)	(24.2)
TOTAL	<u>290</u>	<u>100.0</u>	<u>290</u>	<u>100.0</u>	<u>-0-</u>	<u>---</u>

Back Nine (205 Acres)

<u>Facing</u>	<u>Conventional Plan</u>		<u>Conservation Plan</u>		<u>Differences</u>	
	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>
N	35	13.9	43	15.6	8	22.9
S	35	13.9	55	19.9	20	57.1
E	80	31.9	102	37.0	22	27.5
W	101	40.3	76	27.5	(25)	(24.8)
TOTAL	<u>251</u>	<u>100.0</u>	<u>276</u>	<u>100.0</u>	<u>25</u>	<u>10.0</u>

Total 18 Holes (429 Acres)

<u>Facing</u>	<u>Conventional Plan</u>		<u>Conservation Plan</u>		<u>Differences</u>	
	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>
N	85	15.7	114	20.2	29	34.1
S	102	18.9	137	24.2	35	34.1
E	162	30.0	170	30.0	8	4.9
W	192	35.4	145	25.6	(47)	(24.5)
TOTAL	<u>541</u>	<u>100.0</u>	<u>566</u>	<u>100.0</u>	<u>25</u>	<u>4.6</u>

3.1 Lot Orientation

The first task in preparing the conservation plan was a revision of the existing Land Plan for the 719 acre Bayberry II site, to obtain maximum southern orientation in lotting. Figure 14 shows the conventional plan. This plan is divided into two sections. Section A is the plan for lots surrounding the "front" nine holes of the golf course, and Section B is the "back" nine.

The Conservation Plan is shown in Figure 15. This plan reduced east-west facing lots from 65.4% of the total lots to 55.6% of the total. North-South facing lots were increased from 34.6% to 44.4% of the total lots. In addition to the increase in optimum orientation, the conservation plan yielded 25 more lots than conventional plan, which increased the lot to infrastructure efficiency. A summary comparison of the two plans is shown in Figure 16.

3.2 Vegetative Cooling

This option can have its greatest impact on the remaining East-West facing lots. Assuming the worst case, a totally unshaded conventional residence with the longitudinal axis of the house oriented north-south, the retention of vegetation or the planting of new vegetation can reduce the direct gain to the structure by 85,000 Btu per day. At 3.5¢ per KWH, this represents a savings of \$0.87 per day. The addition of roof overhang and re-configuration of glass on the exterior facades will change these savings. Additional changes to the window surface, such as venetian blinds, shades, draperies, and shutters will affect the estimated benefits as well. These modifications are controlled exclusively by the consumer. Since there is no reasonable method of modeling consumer behavior, this option has not been included in the estimate of savings in the conservation plan. The research team believes that vegetation can have a very significant impact on energy conservation, and has prepared, as part of the Conservation Plan, a consumer oriented brochure on the potential benefits of careful use of vegetative screening.

3.3 Arkansas Construction

This option includes reduced air infiltration from one air change per hour to .3 air changes per hour. This is achieved primarily by sealing and caulking all joints, the foundation and toe plate connection, and weatherstripping all doors, windows, and other openings. Arkansas construction also includes 2 x 6 (R-23) studwalls, and double glazed windows. This package of options has the greatest cost impact of any option included in the conservation plan. Experience with 2 x 6 framing indicates that once the framing subcontractors are familiar with it, the expense is less than conventional 2 x 4 framing. This is due primarily to the decrease in board feet of lumber, resulting from 24" center spacing in the studwalls. The increased size of the wall cavity does increase insulation costs approximately \$100 to \$200.00. Increased costs can also be expected from caulking and sealing all joints. This is not normally done in conventional construction. Added cost from sealing is approximately \$450 to \$500.00. Double glazed windows would add an additional \$500 to \$1000.00 over conventional single glazing. As a package, Arkansas construction can be expected to increase construction costs from \$1050.00 to \$1750.00.

3.4 Insulated Slab on Grade Foundation

This option allows the house to use the earth as insulation. By insulating the outer 24 inches of the slab perimeter, heat is not transferred through the slab to the exterior of the structure. If compared to continuous footing and pier foundations commonly in use at Greenbrier, the slab foundation is \$1500.00 less expensive. When compared to conventional slab on grade foundations, however, the insulation would increase the cost approximately \$600.00. This cost is incurred because the perimeter of the slab must be poured in two stages.

3.5 Groundwater Source Heat Pump

This option yielded the highest performance in energy conservation with virtually no known impediments to implementation. The high efficiencies of the heat pump (C.O.P. 3.5) were not matched by any other heating and cooling option, except for a 100

unit central thermal plant. Data obtained from two manufacturers show that the groundwater source heat pump costs the same as an equivalent air source heat pump. Two wells, at a total cost of \$300.00 would be required for operation.

3.6 Domestic Hot Water-Heat Reclaimer

The Base Case revealed that the heating of domestic hot water is the largest consumer of energy in the dwelling other than space heating and cooling. The heat reclaimer captures "waste" heat from the heat pump and uses it to heat domestic hot water. It provides approximately half of the total hot water needs of the average Greenbrier house at an initial cost of \$500.00. Widespread use of this device should reduce the price considerably.

3.7 Greenhouse

Several configurations of greenhouses were tested for their energy production capabilities. While those tested all yielded positive energy flow to the primary structure, the relatively high costs in relation to energy production capabilities make the greenhouse option difficult to justify on energy costs alone. Because of the "add-on" capability of this option, however, there is reason to believe that the greenhouse is a viable option. Since the decision to "add-on" a greenhouse is primarily the choice of the consumer, this option has not been included in the estimated energy savings of the conservation plan. A consumer oriented brochure, outlining the costs and energy benefits of this option has been prepared.

3.8 Comparison of Conventional and Conservation Plans

A comparison of the Conventional Plan and Conservation Plan was made for both costs and performance. The initial capital investment for the Conservation Plan is between \$200.00 and \$3150.00 more than the Conventional Plan, per unit. The Conservation Plan, however, decreases energy consumption by 54.7% per unit, an equivalent of \$744.63 per year at current prices. A summary is given in Figure 17.

Costs: The total increase in capital investment required to implement the Conservation Plan is \$3150.00 per unit. This estimate may be high.

SUMMARY COMPARISON
CONVENTIONAL PLAN AND CONSERVATION PLAN

For 2100 sq. ft. Greenbrier Base Case House

CONVENTIONAL PLAN (541 dwelling units)

<u>DIRECTION</u>	<u>NO. OF UNITS</u>	<u>HEATING & COOLING</u>	<u>DHW</u>	<u>MISC</u>	<u>TOTAL/UNIT</u>	<u>TOTAL</u>
N	85	20048	9000	8880	38008	3.230x10 ⁶ KWH
S	102	19401	9000	8880	37361	3.812x10 ⁶ KWH
E	162	21557	9000	8880	39517	6.402x10 ⁶ KWH
W	192	21557	9000	8880	39517	7.587x10 ⁶ KWH
TOTAL						21.03 x10 ⁶ KWH

Average per unit = $21.03 \times 10^6 \div 541 = 38872$ KWH/yr.

@ 3.5¢ per KWH = \$1360.52 per unit/yr. ($\$1360.52 \times 541 = \$736,041.32$)

CONSERVATION PLAN (566 dwelling units)

<u>DIRECTION</u>	<u>NO OF UNITS</u>	<u>HEATING & COOLING</u>	<u>DHW</u>	<u>MISC</u>	<u>TOTAL/UNIT</u>	<u>TOTAL</u>
N	114	5383	3150	8880	17413	1.985x10 ⁶ KWH
S	137	5209	3150	8880	17239	2.362x10 ⁶ KWH
E	170	5788	3150	8880	17818	3.029x10 ⁶ KWH
W	145	5788	3150	8880	17818	2.584x10 ⁶ KWH
TOTAL						9.960x10 ⁶ KWH

Average per unit = $9.960 \times 10^6 \div 566 = 17,597$ KWH/yr.

@ 3.5¢ per KWH = \$615.90 per unit/yr. ($\$615.90 \times 541 = \$33,320.19$)

ENERGY SAVED*

	<u>KWH/YR</u>	<u>DOLLARS</u>	<u>CAPITAL COST</u>
Per Unit	21,275 KWH	\$ 744.63	\$ 200.00- \$ 3,150.00
Total	11,509,775 KWH	\$402,842.12	\$108,200.00- \$1,704,150.00

*For 541 units.

Summary of Costs

<u>Option</u>	<u>Cost Above Conventional Plan</u>
1. South facing lots	-0-
2. Arkansas construction	\$1050.00 to \$1750.00
3. Insulated slab foundation	-\$1500.00 to \$ 600.00
4. Groundwater source heat pump	\$ 150.00 to \$ 300.00
5. Heat Reclaimer*	\$ 500.00
TOTAL	\$ 200.00 to \$3150.00

Percent of average selling price 4.8%

3.9 Summary

The objective of this research was to produce a "case study" of energy conservation at a major private sector planned unit development, which could hopefully serve as a model for similar developments to follow. The research was divided into three major parts. Part one is the development of a Base Case Energy Model which would establish the total energy consumption for the community if developed in a conventional manner. Part two is the systematic evaluation of a series of conservation options. These options were evaluated for their cost, performance, legality, marketability, and their impact on the developer's role as community builder. Part three develops a conservation plan which is compared to the Conventional Plan for its relative costs and energy saving benefits.

The research indicates that for relatively small increases in capital expenditure, developers, and especially residential builders, can substantially decrease end-use energy consumption. For a capital investment of \$200.00 to \$3150.00, operating energy consumption can be reduced by 54.7% in residential development. This represents an energy savings to the consumer of 21,275 KWH per year. Over a thirty year

*Includes high efficiency shower and faucet heads.

conventional mortgage period, this represents a savings of \$22,338.00 per house at current energy costs of 3.5¢ per KWH.

Although the expected energy savings is achievable within the confines of current "state of the art", commercially available mechanical equipment and careful land planning and construction techniques, several obstacles remain in the way of implementation. Foremost among these obstacles are the highly competitive and inflationary nature of the residential construction industry, and an overwhelming lack of knowledge among the residential consumer as to what constitutes energy conservation in residential structures. Until there is demonstrable evidence that either these expected savings can be achieved at no increase in cost, or until the consuming public demands more energy efficient structures from the residential construction industry, it appears unlikely that the energy conserving options advocated in this research will be implemented in the speculative building market.