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Energy Conserving Site Design

Case Study—Shenandoah, Georgia

Final Report

January 1980

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Prepared For:
U.S. Department of Energy
Assistant Secretary for Conservation and Solar Energy
Office of Buildings and Community Systems
Under Contract No. AC01-78CS20349

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Available from:

National Technical Information Service (NTIS)
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5285 Port Royal Road
Springfield, Virginia 22161

Price:	Printed Copy:	\$20.00
	Microfiche:	\$4.00

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Prepared For:
U.S. Department of Energy
Assistant Secretary for Conservation and Solar Energy
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CHAPTER 1

EXECUTIVE SUMMARY

1.1 -- Introduction

The Shenandoah case study for community planning and passive site design is one of five case studies funded through the Buildings & Division of Buildings and Community Systems as part of the Site and Neighborhood Design program. The primary objective of the case study is to examine the means by which energy conservation can be achieved at an aggregate community level by using proper planning and analytical techniques. The case study format permits the study team to analyze a particular site and measure construction costs, energy consumption, and the life cycle costs of the entire community for the appropriate development time horizon under a normal development program. Given this base plan the study team examines the land use options, siting characteristics of each building type, alternate infrastructure plans, possible decentralized energy options, and central utility schemes to determine how community energy conservation can be achieved by use of pre-construction planning. The output of this procedure is a potentially implementable energy conservation community plan.

The general program plan involved Shenandoah Development Corporation (SDC) as the prime contractor and five sub-contractors: Georgia Institute of Technology Engineering Experiment Station (GT), Finch, Alexander, Barnes, Rothschild, and Pascal (FABRAP), Newcomb & Boyd (NB), Williams-Russell and Associates (WR), and Laubmann-Reed and Associates (LR). These six team members provided expertise in land development practices, energy engineering, central utility system, landscape planning, mechanical engineering, architecture, civil engineering, and program management.

SHENANDOAH

REGIONAL
LOCATION

MAP 1.2

The results of the study are the product of a one year effort by the research team. Since the results will be available before the first ground is broken on the site, there is no way of knowing the extent to which the assumptions which were made in each plan, including the conventional plan, will be accurate. For this reason the assumptions for each plan must be thoroughly understood and reasonable, given the data which we currently have.

In order to fulfill the two goals of being understood and being reasonable, the research team has worked closely among its members in addition to working with the developer and the Advisory Committees which are comprised of builders, bankers, and marketing people. In addition, the research team has worked very closely with the utility companies and government agencies. Because of these efforts it is felt that although the results of the study are forthcoming prior to actual build-out, they will reflect the reality of that build-out as best can be anticipated.

1.2 -- Location and Climate

The new town of Shenandoah, Georgia, is situated on 7,400 acres surrounding the Newnan exit of Interstate 85, twenty-five miles southwest of Atlanta's Hartsfield International Airport. Shenandoah is a balanced community planned for homes, business, and industry. The town is in the early stages of a twenty-five year development program toward becoming a community of 42,000 people. Map 1.1 shows Shenandoah's location within the Atlanta Metropolitan Area.

The Shenandoah study site is contained in Village One as shown on Map 1.2. The study area contains approximately 235 acres. It will ultimately include residential areas, high school, church, fire station, commercial, and recreational facilities. Almost half of the area (approximately 85 acres) is scheduled for development in 1981; the remainder in 1982-83. The area is bounded on the north by Georgia 34; on the east by Tracts B and C and by Proposed Road C; on the south by Neighborhood Two; and on the west by White Oak Creek.

About 20 percent of the site is cleared land: abandoned pastures, fields, and farm land. In the past, it has been maintained in stands of Fescue and Bahia grasses. The rest of the proposed site is covered with varying densities of second-growth mixed pine-hardwood canopy, with pines predominating. Scattered individual trees represent ages beyond 30 years.

The eastern boundary of the site is intended as a boulevard and is already cleared and grubbed. Some vegetation was replanted and other land cover has developed in the right of way.

The climate of the west central section of Georgia is classified as subtropical humid. This area is influenced by its location near the foothills of the southern Appalachian Mountains to the north and the Gulf of Mexico to the south, with the total effect being slight modification of both winter and summer temperatures and ample precipitation.

Mean daily solar radiation measurements have been recorded at the Griffin, Georgia experimental weather station. The measurements taken include both direct and diffused sky radiation received on a horizontal flat plate surface. The mean daily radiation received ranges from 601 Langleys in May to 226 Langleys in December. This data was recorded from 1950 through March 1966.

1.3 -- Project Overview

Execution of the project, or program plan, revolved around development of three plans in conjunction with a base, or conventional, plan and development of the necessary inputs to permit evaluation of each plan level. The end result was to be the choice of the best conservation plan from the alternatives; the best plan being the plan with the lowest life-cycle cost. Initial research began with the selection of a study site within Shenandoah. Site selection was based upon Shenandoah's land development schedule, in that the site selected was an area of approximately 235 acres intended for development over the next five years. Once selected, the site was analyzed for topography, vegetation, physiography, zoning and existing land use and climate. Following the

analysis maps were developed showing results of each phase of the analysis. At this same time a conventional plan was developed to provide base values for construction costs and energy consumption levels. These values would serve as comparison values for the later plans to determine the changes in costs and energy consumption.

Along with development of the three plans other research was undertaken which would be needed later. This research involved determining the institutional barriers to utilizing solar energy and development of solar rights solutions. Other research undertaken at this time included developing a life-cycle cost model, determining the central utility system alternatives and energy supply alternatives available and their costs, and developing a central utility design.

The first alternative plan to the conventional plan to be developed was the Level 1, or passive, plan. As its name implies, the major emphasis of the plan was on energy conservation through passive site design. In the passive plan, streets are generally oriented along an east-west axis and the structures are oriented to the south to achieve maximum solar heat gain. In addition to the southern exposure, the majority of the window area is moved to the southern wall and the window glass is double-glazed to reduce heat loss in the winter and heat gain in the summer. The residential structures are also designed with increased insulation in the roof and walls and Arkansas construction, which is a tighter construction. The Passive Site Plan also features higher density and some smaller lot sizes. The analysis which follows takes these additional features, measures changes in energy consumption and costs, and compares the plan with the conventional plan.

The Level 2 Plan is designed to take the process one step beyond the Level 1 Plan. This plan is referred to as the passive site plan with decentralized systems, both active and passive, added to the residential structures. Again, both conventional and improved construction techniques are analyzed with the decentralized systems.

The Level 3 Plan, or Central Utility Plan, examines the possibility of using some form of cogeneration plant to generate electricity for the study area and for sale back to the grid; hot and chilled water would then be distributed throughout the study site to provide the needed thermal loads. A number of central plant systems were studied, including solar, coal, and wood systems. Another possibility is to distribute the thermal energy to only multi-family and commercial dwellings.

Given all of these plans, the economic analysis was made to determine the life-cycle costs of each entire plan. The final output of this analysis is a determination of the total costs of the 235-acre development over 25 years including site development costs, lot development costs, construction costs, and energy costs. By comparing the present value of additional investments in each alternative level to the present value of savings (primarily from reduced energy consumption), a final savings-investment ratio is calculated for each comparison with the conventional plan.

1.4 -- Economic Model

L3MODEL is a community level life cycle cost model for project analysis and evaluation. The analytical technique employed is a computer coded application of the familiar total net present value of costs method. Automated data processing and formatted input/output techniques are used to produce a variety of reports.

The model employs a mix of interactive and batch processing for maximum efficiency and flexibility. The user interactively establishes the values of the constraining variables and selects one or more of the processing options. The descriptive data base is prepared as a file organized by building type and cost category.

Using this basic set of data containing project parameters, construction and development costs and energy consumption, the model calculates project costs on an annual basis over the expected life of the development. Several processing options are available for utilizing these basic results to produce a variety of analytical reports for evaluation.

1.5 -- Energy Simulation Model

Traditionally, predictions of building energy consumption have been based on empirical "rule-of-thumb" numbers, such as degree-day calculations. These methods are not accurate or sensitive enough to adequately evaluate the kinds of changes involved in community planning. An example of this problem is a typical passive solar building. On a sunny day, the total daily solar heat gain through the windows can be more than the daily heat loss from the building. The problem is that the solar heat gain does not occur at night, when it is needed most. As a result, only an hour by hour analysis of the interaction of the building, solar transmission, and internal loads with the space conditioning system can provide a reliable estimate of a building's designed energy consumption. Due to the number of calculations required to analyze a building for 8760 hours of the year, a computer simulation is a necessity.

For this project, the ESP-1 program developed by APEC (Automated Procedures for Engineering Consultants) was used to predict energy consumption. This program uses hourly weather data and information about a building's architecture, occupancy, and internal loads such as lights to calculate the thermal building loads for each hour. The program then simulates the action of a space conditioning system in response to each hour's loads.

1.6 -- Conservation Options

1.6.1 -- Level 1 Plan

The types of architectural passive systems geared for a particular building type often create a framework from which the site design may begin. For example, the types of solar collection systems will often dictate the size and length of adequate solar access corridors in the site plan. The text summarizes passive options that were considered applicable for the Shenandoah Site Plan. They include: Solar Access, Building Orientation, Cluster Layout response to Sun and Wind, Microclimate Evaluation, Shading, Berming, and Reorientation of Planning Policies.

TABLE 1.1

Dispersed Energy Alternatives

A. Passive Solar Devices

Shutters
Direct Gain System
Solar Window Unit
Convective Loop Collector
Attached Solar Greenhouse
Trombe Wall
Solar Chimney

B. Active Solar Devices

Heating and Hot Water - water medium
Heating - air medium
Space Cooling
Solar Supplemented Heat Pump

C. Photovoltaics

D. Solar Heat Engines

E. Wood

Direct Combustion in Residence

Fireplace
Furnace
Stove

The evaluation methodology for the development of mixed land uses at Shenandoah involved a complete and thorough site resource inventory and analysis of existing site conditions and the development of building criteria and site design guidelines. Through the study process, two main objectives became clear:

1. To provide long range passive energy conservation design measures and guidelines which (a) must be compatible with normal construction costs on the base plan, and (b) could be used for immediate implementation.
2. The implementation of these long range energy measures.

In order to determine the specific site areas within the development plan for Shenandoah that are the most attractive for site construction and energy conservation, a detailed inventory and analysis of existing environmental factors was prepared. Natural site characteristics such as wind effects, seasonal solar angles, slope, slope aspect, soils, physiography, hydrology and vegetation were mapped and analyzed. The analysis delineates specific areas of similarity that pose potentials for or constraints to the construction and energy efficiency.

1.6.2 -- Level 2 Plan

We initially considered an assortment of dispersed energy options for the Level 2 Passive Site Plan. Dispersed energy options are devices that can be incorporated into individual buildings. Thus, options such as district heating were not considered in this phase of the study. Table 1.1 lists the options examined. A preliminary screening used the following criteria to select specific alternatives for further analysis:

Technical feasibility

Cost Effectiveness

Marketability

In the screening process for the Level 2 Plan, we considered installation of the dispersed options mainly in single family units. The options selected for inclusion in Level 2 were evaluated in other land use settings to determine their total potential for implementation.

TABLE 1.2
Summary of Evaluation of Dispersed Energy Options

	Criteria			
	Technical	Economic	Marketing	Potential Fuel Savings(if selecte
PASSIVE SOLAR SYSTEMS: Shutters	No Problems	Potentially economic in houses built with standard construction	Require resident to put into place	Up to 25% space heating needs (1)
Direct Gain System	May increase cooling load	Economical only with increased southern window exposure	Aesthetically pleasing but glare and fading problems may occur	About 25% of space heating needs (2)
Convective Window Loop	Few proven units are in existence	Economically feasible	Unconventional appearance, not yet proven commercially in the marketplace	Not selected
Attached Solar Greenhouse	Possible problems of humidity and overheating in the summer	Look very feasible especially with added benefits of food production	Aesthetically pleasing. Requires some effort on the part of the resident	Varies, a greenhouse along the southern exposure of a house will provide up to 30 of the home's heating needs. (3)
Trombe Wall	Possible problem of overheating in the summer	Negative net present value, but estimates had high uncertainty	Peculiar appearance cited; requires effort by resident	Not selected
Solar Chimney	Appears feasible, but little data on performance	Too little data to evaluate	Is not compatible with central air conditioning	Not selected

TABLE 1.2 (Cont'd)

	Criteria			
	Technical	Economic	Marketing	Potential Fuel Savings
ACTIVE SOLAR DEVICES: Solar Space Heating, Water Fluid Enclosed in Pipes	Potential leak and freezing problems are not very likely with proper design	Negative net present value	--	Not selected
Solar Space Heating, Trickle Collectors	Recently studied, no major technical problems	Net present value was negative	Questionable aesthetics. Recent development of North Atlanta "Solar Suburb" will help. Liked by marketing committee	Not selected
Solar Water Heating, Water Medium	Leak, freezing and contamination problems are now minor	Positive net present value with low interest loan	Questionable aesthetics. Most popular active solar approach	60% of hot water fuel needs (4)
Solar Supplemented Heat Pump	Potential leak and freezing problems are not very likely with proper design	Negative net present value	Still early in commercialization	Not selected
PHOTOVOLTAICS	Possible cooling problems if concentrated. Mass production techniques need development; storage systems need research	Not yet cost competitive	--	Not selected
SOLAR HEAT ENGINES	Still need research	--	--	Not selected
WOOD	Problems of fire & creosote build-up if not properly operated & maintained	Competitive only if wood is scavenged or supplied through community wood supplier	Pollution, deforestation and safety problems	Not selected

Table 1.2 summarizes the evaluation of dispersed energy options. Those systems that were selected have the potential energy savings indicated in the right-hand column. In Chapter 4, we will analyze application of selected systems throughout the community.

1.6.3 -- Level 3 Plan

In the case of the Shenandoah development it was felt that a central plant could conserve energy through the more efficient use of primary fuels, stabilize energy costs and accrue savings to the residents of the community in the areas of capital outlay cost, maintenance and operating costs. To do this, the plan had to be feasible within the constraints of financing, current technology, phased construction and marketability to the end-user.

Two levels of central utility plant schemes were considered. The first level considered the total 7400 acre Shenandoah development as being the ultimate build out and service area of the central utility plant. It was anticipated that a central power plant in the capacity range of 30 to 60 megawatts could be constructed on a site adjacent to the Shenandoah Industrial park. The design of the plant would include provision for district heating, cooling and process steam for industrial customers. Electricity from the plant would be cogenerated with the steam and thermal energy uses and tied into the Georgia Power Company electrical distribution grid in a TIES mode of operation. This option was eventually abandoned due to site specific technical considerations and the long build out period of the Shenandoah Development.

A second plan was to consider a small central utility plant located within our 235 acre site which was phased to serve our site and possible adjacent sites. The small site central utility plant would be designed to provide thermal energy for heating and cooling and electric energy which could be sold into the electric utility company's power grid.

The six alternatives are as follows:

1. Fuel cell ICES-TIES mode

2. Internal combustion engine with heat recovery ICES-TIES mode;
3. Wood fired thermal/electric ICES - TIES mode;
4. Photovoltaic ICES - TIES mode;
5. Solar thermal central plant;
6. Solar thermal/electric ICES - TIES mode.

It appears that the wood fired cogeneration system is the most suitable of the central plant schemes. The first costs and operating costs are relatively low when compared to other central plant options of this size.

One important favorable point of the wood fired cogeneration plan is the use of a non-depletable fuel. Present research and development work and funding is wary of systems based on scarce fuels, while much effort is being placed into alternate fuel utilization.

1.7 -- Impediments and Solutions

The criteria for evaluating different energy-conserving options were technical feasibility, economic feasibility, and marketability. Although an option may meet the criteria, other factors could constrain its development. Impediments could include regulations and opposition from decision-making institutions (utilities, bankers, zoning boards, builders, developers, etc.). This chapter discusses the most pertinent impediments to the development of energy-conserving communities.

The impediments are quite different for the Level 2 plan, which uses dispersed energy devices, than for the Level 3 plan, which uses a central utility with thermal energy distribution. Impediments for the Level 1 passive plan would be similar to those for Level 2. The following categories of impediments may constrain implementation of energy-conserving designs in the community:

- Utility attitudes,
- Regulatory constraints,
- Environmental impacts,
- Incidence of costs and benefits,
- Marketing,

SHENANDOAH
COMET COUNTY, GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. DE-78-0-01-4216
TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY - ENGINEERING EXPERIMENT STATION
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NEWCOMB AND BOYD - MECHANICAL ENGINEERS
WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

SHEET **1** OF

CONVENTIONAL
PLAN

Developer's attitudes, and
Builder's attitudes.

We recommend the following actions for encouraging development of the Level 1 and Level 2 plans:

1. Investigate the use of energy-conserving and solar utilization zoning categories in the community.
2. Urge the state to rigorously enforce the Georgia State Energy Code for Buildings in the community.
3. Developer may prescribe Btu performance standards.
4. Establish solar access covenants which restrict the obstruction of insolation on buildings in Shenandoah.
5. Publicize the incentives passed in the National Energy Act and in response to President Carter's proposed Import Reduction Program.
6. Work to educate local builders, bankers, and appraisers about the economic savings of the energy-conserving plans.
7. Perform market research studies to estimate the demand (and acceptable cost) for energy-conserving structures.
8. Help market homes, apartments and townhouses in the community.
9. Consult with builders about the acceptability of different covenants and contractual agreements. Work out compromises that preserve the energy-conserving nature of the community.

Specific recommendations for overcoming impediments to the Central Utility Plan are as follows:

1. Investigate in a detailed feasibility study, the specific institutional arrangements for the plan.
2. Provide loans for cogenerating facilities through federal, state, or private agencies.
3. Make provisions for incorporating cogenerating systems with thermal distribution lines into the rate base.
4. Provide tax credits for helping building owners purchase systems that use thermal energy from cogenerating power plants; low interest loans; grants.

1.8 -- The Conventional Plan

The conventional site plan for the 235-acre study area is shown in Map 1.3. The conventional site plan has been designed from standard development practices and the buildings have been sized and oriented in accordance with standard practices.

The cost per square foot for each building type is presented below. The costs include the energy end-use systems and represent the costs associated with the standard construction. Standard construction implies: (a) single-glazing in residential units, double-glazing in non-residential units (b) R-11 insulation in walls, R-19 insulation in ceilings (c) standard 2x4 frame construction in residential units, golf club, and convenience store (d) brick veneer with interior concrete block in the school and fire/police station.

Building	Units	\$/sf	\$/unit	Total \$
SFD-1600	73	23	36,800	2,686,400
SFD-2200	26	24	52,800	1,372,800
TH-1200	20	23	27,600	552,000
TH-1500	30	24	36,000	1,080,000
APT-950	80	20	19,000	1,520,000
APT-1300	120	20	26,000	3,120,000
SCHOOL	1	32	5,120,000	5,120,000
F/P	1	40	96,000	96,000
GOLF	1	48	705,600	705,600
COMMERCIAL	1	24	96,000	96,000
Total				\$16,348,800

In addition to the above construction costs, the site and lot development costs are allocated to each building type as follows:

Building	Lot Development	Site Development
SFD-1600	\$113,600	\$383,202
SFD-2200	39,910	186,806
TH-1200	20,039	79,446
TH-1500	37,711	148,157
APT-950	51,673	243,075
APT-1300	105,867	511,034
SCHOOL	152,588	521,770
FIRE-POLICE	34,367	8,589
GOLF CLUB	44,770	47,238
COMMERCIAL	40,980	12,883
TOTALS	\$641,505	\$2,141,200

The total annual electrical energy consumption for the conventional plan is 8932.5 MWH. The electrical energy consumption in MWH per unit as well as the cost in \$/MWH is shown below in Table 1.3.

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MWH)
1	SFD(16JU)	42.400	17.61	0.00	0.00	0.00	1285.64
2	SFD(22JU)	42.400	24.35	0.00	0.00	0.00	633.22
3	TH(12LU)	45.000	15.12	0.00	0.00	0.00	302.47
4	TH(15JU)	45.000	20.47	0.00	0.00	0.00	614.11
5	APT(95J)	49.000	10.00	0.00	0.00	0.00	1446.36
6	APT(13JU)	49.000	22.38	0.00	0.00	0.00	2686.10
7	MS	43.400	1532.70	0.00	0.00	0.00	1532.70
8	F/P	54.900	66.70	0.00	0.00	0.00	66.70
9	GOLF	54.900	287.10	0.00	0.00	0.00	287.10
10	COMM	54.900	78.10	0.00	0.00	0.00	78.10
							8,932.50

Table 1.3.

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MMBtu)
1	SFD(1600)	2.796	113.07	0.00	0.00	0.00	8,253.86
2	SFD(2200)	2.796	156.36	0.00	0.00	0.00	4,065.34
3	TH(1200)	2.796	67.63	0.00	0.00	0.00	1,352.54
4	TH(1500)	2.796	91.53	0.00	0.00	0.00	2,746.06
5	APT(950)	2.796	56.54	0.00	0.00	0.00	4,522.84
6	APT(1300)	2.796	70.00	0.00	0.00	0.00	8,399.56
7	MS	2.912	220.30	0.00	0.00	0.00	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10
9	GOLF	2.912	156.10	0.00	0.00	0.00	156.10
10	COMM	2.912	42.50	0.00	0.00	0.00	42.50
							<hr/> 29,790.20

Table 1.4

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290822.	0.	585715.	0.	1879685.	0.	5756224.
SINGLE FAMILY (2200)	1616006.	0.	288488.	0.	925741.	0.	2830235.
TOWNHOUSE (1200)	691152.	0.	120855.	0.	396577.	0.	1208583.
TOWNHOUSE (1500)	1283566.	0.	224407.	0.	805276.	0.	2313251.
APARTMENT (950)	1852752.	0.	366388.	0.	1909334.	0.	4128474.
APARTMENT (1300)	3761696.	0.	744005.	0.	3545280.	0.	8050981.
SENIOR HIGH SCHOOL	6195200.	0.	815973.	0.	1395291.	0.	8406464.
FIRE-POLICE STATION	116160.	0.	51977.	0.	79793.	0.	247930.
GOLF CLUBHOUSE	853776.	0.	111330.	0.	336161.	0.	1301267.
COMMERCIAL SPACE	116160.	0.	65174.	0.	88953.	0.	270287.

Table 1.5

ANALYSIS INFORMATION	
SITE PLANNING OPTION	L.S.
CONVENTIONAL	STANDARD
ANALYSIS PERIOD	22 YEARS
CONSTRUCTION PERIOD	3 YEARS
CONSERVATION LEVEL	5-10 ELEMENTS

ANNUAL INTEREST RATES	
CONST FINANCING	5.00%
DISCOUNT RATE	10.00%
R O I CAPITAL	20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00% (5)
THERMAL 5.00%

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4906828.	0.	874284.	0.	2805426.	0.
CLUSTER DWELLING UNITS	7589168.	0.	1455854.	0.	6656467.	0.
INSTITUTIONAL FACILITIES	6311360.	0.	867950.	0.	1475044.	0.
COMMUNITY FACILITIES	989936.	0.	176504.	0.	425114.	0.
TOTAL	19777293.	0.	3374312.	0.	11362091.	0.
INTEREST	988865.	0.	0.	0.	0.	0.

TOTAL NET PRESENT VALUE - \$ 35502501.

Table 1.6

SITE PLAN

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6094799.	0.	1143913.	0.	229761.	0.	7465473.
1982 - 2	12004532.	0.	2027618.	0.	583715.	0.	14815865.
1983 - 3	3230831.	0.	472033.	0.	676638.	0.	4279503.
1984 - 4	0.	0.	0.	0.	730437.	0.	730437.
1985 - 5	0.	0.	0.	0.	788576.	0.	788576.
1986 - 6	0.	0.	0.	0.	851410.	0.	851410.
1987 - 7	0.	0.	0.	0.	919327.	0.	919327.
1988 - 8	0.	0.	0.	0.	992743.	0.	992743.
1989 - 9	0.	0.	0.	0.	1072112.	0.	1072112.
1990 - 10	0.	0.	0.	0.	1157925.	0.	1157925.
1991 - 11	0.	0.	0.	0.	1256714.	0.	1256714.
1992 - 12	0.	0.	0.	0.	1351057.	0.	1351057.
1993 - 13	0.	0.	0.	0.	1459580.	0.	1459580.
1994 - 14	0.	0.	0.	0.	1576961.	0.	1576961.
1995 - 15	0.	0.	0.	0.	1703938.	0.	1703938.
1996 - 16	0.	0.	0.	0.	1841308.	0.	1841308.
1997 - 17	0.	0.	0.	0.	1989938.	0.	1989938.
1998 - 18	0.	0.	0.	0.	2150768.	0.	2150768.
1999 - 19	0.	0.	0.	0.	2324820.	0.	2324820.
2000 - 20	0.	0.	0.	0.	2513199.	0.	2513199.
2001 - 21	0.	0.	0.	0.	2717109.	0.	2717109.
2002 - 22	0.	0.	0.	0.	2937854.	0.	2937854.
2003 - 23	0.	0.	0.	0.	3176852.	0.	3176852.
2004 - 24	0.	0.	0.	0.	3435639.	0.	3435639.
2005 - 25	0.	0.	0.	0.	3715889.	0.	3715889.

Table 1.7

PASSIVE SITE PLAN

LEGEND

- 6 GARDEN APARTMENTS
- 2 TOWNHOUSE UNITS
- TYP. SINGLE FAMILY DWELLING
- BICYCLE PEDESTRIAN PATH
- TOT LOT or PLAY AREA

SHENANDOAH

COMETA COUNTY,

GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. 88-79-G-01-4218

TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY - ENGINEERING EXPERIMENT STATION

SHENANDOAH DEVELOPMENT, INC.

LAUBMANN REED AND ASSOCIATES - LANDSCAPE ARCHITECTS AND ENVIRONMENTAL PLANNERS

FRICH, ALEXANDER, BARNES, ROTHSCHILD, AND PASCHAL, INC. - ARCHITECTS

NEWCOMB AND BOYD - MECHANICAL ENGINEERS

WILLIAMS-BUSSELL AND ASSOCIATES - CIVIL ENGINEERS

**PASSIVE
SITE PLAN**

The total annual natural gas consumption for the conventional plan is 29,790.2 MMBtu. The per unit consumption (MMBtu) and costs (\$/MMBtu) are shown in Table 1.4.

The total construction, development, and energy costs are summarized by each of the 10 elements, or building types, in Table 1.5.

Table 1.6 shows the present value of all costs by cost centers, including construction, development, energy, and interest on construction. The total present value of all costs of the LOS plan is \$35,502,561. The meaning of this figure is the construction of all buildings on the site and the consumption of energy in the buildings over the next 25 years would cost, in 1981 present value dollars, approximately \$35.5 million. The annual costs of construction and energy consumption are summarized in Table 1.7.

1.9 -- The Level 1 Plan

The concept for the development of mixed land uses at Shenandoah as a passively sited, energy conserving community is based on a plan that uses the natural site characteristics, maximizes on passive energy siting requirements, and allows flexibility for the changing needs of the Shenandoah Development Corporation.

1.10 -- The Level 2 Plan

The Level 2 plan is identical with the Level 1 site plan plus a series of decentralized systems have been added to the residential units: the single-family detached, the apartments, and the townhouses.

As discussed in Chapter 4, four options were considered economically feasible, technically feasible, and marketable. The four options include solar water heating, direct gain systems, attached greenhouse, and Trombe walls. Since it is unlikely that both a direct gain system and a Trombe wall would be used in conjunction with one another, we have decided to use only the direct gain system in the Level 2 analysis.

CENTRAL UTILITY SITE PLAN

LEGEND

- 6 GARDEN APARTMENTS
- 2 TOWNHOUSE UNITS
- TYP. SINGLE FAMILY DWELLING
- BICYCLE & PEDESTRIAN PATH
- TOT LOT or PLAY AREA

HIGH SCHOOL
with Track, Football, Baseball Fields &
480 Capacity Parking Lot - 36 Ac.

32 SINGLE FAMILY
7 Large Lots, 25 Regular Lots
Large Lot - 0.9 Ac.
Regular Lot - 0.25 Ac.

11 SINGLE FAMILY
25 Ac. Lots

GOLF CLUBHOUSE &
MAINTENANCE BUILDING
0.9 Acres

115 KVA POWERLINE (GEORGIA
POWER COMPANY) 1,000
IN FT. FROM E. BOUNDARY
POWERLINE R.O.W. (200 FT.)
ROAD PARALLEL TO ROAD 'C'

CHURCH & DAY CARE CENTER
9.7 Acres

PROPOSED COMMERCIAL
1.9 Acres

CONVENIENCE SHOP & GAS
4.5 Acres 4,000 sq. ft.

FIRE & POLICE STATION
3.7 Acres 3,400 sq. ft.

100 GARDEN APARTMENTS & CLUBHOUSE
11.0 Ac. ; 10.0 DU per Acre

GOLF COURSE

50 TOWNHOUSES
10.2 Ac. ; 5.7 DU per Acre

70 SINGLE FAMILY DWELLINGS
18 Large Lots ; 52 Regular Lots
Large Lot - 0.8 Ac. ; Regular Lot - 0.25 Ac.

SCALE: 1"=200'
0 100 200 400 600 800 1000

SHENANDOAH

COWETA COUNTY

GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

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NEWCOMB AND BOYD - MECHANICAL ENGINEERS
WILLIAMS RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

**CENTRAL UTILITY
SITE PLAN**

1.11 -- The Level 3 Plan

The central utility plan (L3) is shown in Map 1.5. The location of the central plant is on the eastern side of the site in a central location to the study site. The basic site plan is similar to the Level 1 plan except that higher density dwellings have been moved to areas adjacent to central site. This will reduce the distribution costs of these more dense, more energy intensive land uses. Other than these changes, the same principles which were discussed in the Level 1 plan hold and were used for development of the Level 3 plan.

The actual plant which is recommended for the site is the wood-fired cogeneration plant and is discussed in Chapter 4.

1.12 -- Energy Savings

The total energy savings for each conservation plan relative to the conventional plan are shown in the following table:

Plan	ENERGY SAVINGS		
	Natural Gas (MMBtu)	Electricity (MWH)	Thermal (MMBtu)
Level 1	8,907.88	496.25	0
Level 2	19,555.88	335.43	0
Level 3	29,790.20	2,995.65	(33,779.52) (1)

(1) Additional usage of thermal energy in Level 3 plan.

1.13 -- Economic Analysis

The total present values of the three conservation plans and the savings/investment ratios for each plan are shown below. The S/I ratio is calculated by dividing the savings in present value of the energy costs by the change in investment (over the LOS plan) necessary to bring about the energy savings. The energy savings are in present value 1981 dollars. To calculate the change in investment, we add the incremental interest charges, incremental construction, and incremental development costs.

PRESENT VALUE AND S/I

Plan	Present Value	S/I
Conventional	\$35,502,561	-
Level 1	35,202,443	1.3
Level 2	35,344,603	1.1
Level 3	36,422,816	negative

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CHAPTER 2

INTRODUCTION

2.1--Objectives

The Shenandoah case study for community planning and passive site design is one of five case studies funded through the Buildings Division of Buildings and Community Systems as part of the Site and Neighborhood Design program. The primary objective of the case study is to examine the means by which energy conservation can be achieved at an aggregate community level by using proper planning and analytical techniques. The case study format permits the study team to analyze a particular site and measure construction costs, energy consumption, and the life cycle costs of the entire community for the appropriate development time horizon under a normal development program. Given this base plan the study team examines the land use options, siting characteristics of each building type, alternate infrastructure plans, possible decentralized energy options, and central utility schemes to determine how community energy conservation can be achieved by use of pre-construction planning. The output of this procedure is a potentially implementable energy conservation community plan.

In the Shenandoah case study, three such energy conservation plans are devised. the first level plan employs passive siting techniques to place the appropriate building types on the 235 acre site to maximize winter solar gain, to provide shading in summer, to utilize natural drainage systems, to take advantage of natural wind screens, and to utilize any other beneficial characteristics of the site.

The second level energy conservation plan begins with the Level 1 plan and examines the potential use of decentralized systems within the site. A range of possible systems was examined and the team finally decided to examine solar water heating, solar-assisted heat pumps and solar heating as the primary candidates.

The third level energy conservation plan examines the various central utility options which are feasible within the site. Again, several options were examined with emphasis placed on central solar and cogeneration facilities, specifically in the latter case a wood-fired cogeneration plant. The prime movers in the Level 3 plan are the type of plant decided upon and the optimal location of the plant in terms of minimizing distribution costs and maximizing phasing potentials. After these two decisions are made, the optimal siting of building and land use is determined so that the highest density land uses are sited closest to the facility. Given these locations the site characteristics are again evaluated and buildings are placed to optimize the energy conservation potentials of the site terrain.

At this point, the study team has a conventional or base plan and three levels of energy conservation plans. The construction costs of each of the four plans are calculated as well as the energy consumption levels of each building type. With these data as well as infrastructure plans and costs, construction phasing, and energy costs, the life cycle cost of each plan is calculated. The savings/investment ratio is calculated to compare the benefits, reduced energy consumption, to the costs, any additional construction or other initial investments, for each plan.

Finally, the study team analyzes the potential barriers to the implementation of the plans with regard to solar access, institutional and legal, developer, builder, consumer, and financing impediments, and suggests possible solutions.

2.2--General Program Plan for the Case Study

The general program plan involved Shenandoah Development Corporation (SDC) as the prime contractor and five sub-contractors: Georgia Institute of Technology Engineering Experiment Station (GT), Finch, Alexander, Barnes, Rothschild, and Pascal (FABRAP), Newcomb & Boyd (NB), Williams-Russell and Associates (WR), and Laubmann-Reed and Associates (LR). These six team members provided expertise in land development practices, energy engineering, central utility system, landscape planning, mechanical engineering, architecture, civil engineering, and program management. The specific roles of each are described in Chapter 3.

2.3--Limits of Research

The Shenandoah 235-acre site which is the object of this study is essentially raw land with no clearing, grading, or construction underway except for the initial rough clearing of Road "C" on the eastern boundary. The majority of the building on the site is to be residential with some commercial and institutional construction. The energy, construction, and economic evaluations of the site development are derived from simulations and projected costs and time horizons. Consequently, there are factors which limit the perspective of the study.

2.3.1.--Immediacy of results and impacts

The results of the study are the product of a one year effort by the research team; the results will be available before the first ground is broken on the site. There is no way of knowing, therefore, the extent to which the assumptions which were made in each plan, including the conventional plan, will be accurate. For this reason the assumptions for each plan must be thoroughly understood and reasonable, given the data which we currently have.

In order to fulfill the two goals of being understood and being reasonable, the research team has worked closely among its members in addition to working with the developer and the Advisory Committees which are comprised of builders, bankers, and marketing people. In addition, the research team has worked very closely with the utility companies and government agencies. Because of these efforts it is felt that although the

results of the study are forthcoming prior to actual build-out, they will reflect the reality of that build-out as best can be anticipated.

Although the results of the study are based upon the assumptions referred to above and serve as "a priori" estimates of the costs and benefits of various scenarios of build-out options, these results can prove to be valuable assets to energy conservation through site planning. The developer and builders can maximize the impacts of these results because they are before the fact; i.e., although it is probable that the absolute values of energy consumption, energy costs, and construction costs will vary within limits around the calculated data, the relative costs and benefits should move together. If it is decided actually to develop the site along the guidelines of one of the energy conservation plans, the potential benefits can serve as an incentive to the developer, builder, utility company, government agency and ultimately the consumer to participate in the plan.

Therefore, even if the immediacy of the results limits the research team, the ultimate goal of energy conservation through site planning is well served by the potential maximization of the impacts of research results on the site.

2.3.2--Size and Scale

Examining the limits of the research related to size and scale requires looking at the size and scale in two directions: what limits exist because we are studying a large site in aggregate and what limits exist because we are not studying building envelopes and interiors, macro-limits and micro-limits, respectively.

The macro-limits were in most cases not binding constraints. The techniques involved in determining energy consumption and costs, construction costs, passive site planning, infrastructure systems, and decentralized energy systems can be applied over a 235-acre site, a 50-acre site, or a 500-acre site. The 235-acre site was chosen not because of size but because of development phasing; this site is the next large parcel of

land to be developed in the near term. Time, not size, was the limiting factor.

One major limit was a combination of macro and micro elements. Although the techniques of passive site planning are well developed at the logical and qualitative level, there is little quantitative data available which combines passive site planning and energy conservation in a rigorous manner. For example, while it is logical that trees serve as a buffer to reduce wind infiltration into buildings and deciduous trees provide shade in the summer and allow solar insolation in the winter, rigorous details are lacking, particularly where applied to a larger scale site. Consequently, this case study, rather than serving as an application of a general theory of site planning and energy conservation, employs a potpourri of theories, some specific and some qualitative to examine the effects of site planning and design on energy conservation.

The macro-limits were important in the central utility conservation plan. Because of the large capital expenditures necessary for the development of any type of energy generation plant, it is desirable to serve as large an area as is technically possible to disperse the capital costs. However, the research team did not take this as a binding constraint and examined other locations outside of the 235-acre site in order to size the plant and to choose the type of plant necessary to meet the load requirements, utility interface, water requirements, distribution costs, and phasing. An on-site location was decided upon.

The micro-limits proved to be more bothersome. For example, a general principle in passive siting is to place a structure to maximize the solar heat gain in the winter. However, to achieve the maximum heat gain requires designing a house, for example, with large window areas on the southern exposure; since glazing has a higher U-value than a wall the larger window area increases the potential heat loss through conduction in the winter and heat gain during the summer. Also, although there is benefit from the solar heat gain in the winter, it is not fully utilized unless there is some storage system within or built in the structure. The research team viewed the "optimal" design of passive structures as falling

SHENANDOAH

REGIONAL
LOCATION

outside the scope of this study. Consequently, glass areas were, in general, held constant from one plan to the next and relatively simple techniques were used, such as moving most of the existing glass area to the southern wall, using insulated shutters in the winter, and providing overhangs to limit direct solar gain in the summer. Although these techniques are limited and could definitely be improved upon, the research team felt these to be the limits within which we could operate. The problem with this system is that the effects of passive siting and design are sub-optimal unless the building structures are adapted to the principles of passive site planning and design.

2.3.3--Community Focus

The community focus was not found to be a constraint or limit to the research in this study. The community in the Shenandoah study includes a number of land use options, mostly residential. As mentioned above, the analysis techniques, given certain assumptions, are adequate to calculate potential costs and benefits associated with each of the energy conservation plans. As discussed in the previous section on macro-limits, the research team stepped beyond the boundaries of the study site and examined possible locations of a central utility system based in other areas of the Shenandoah community, including the industrial park, with thermal and/or electrical distribution within the study site.

Any other limitations to perspective because of a community focus parallel those limitations discussed in the previous section.

2.4-- Overview of the Case Study.

2.4.1--Location.

The new town of Shenandoah, Georgia, is situated on 7,400 acres surrounding the Newnan exit of Interstate 85, twenty-five miles southwest of Atlanta's Hartsfield International Airport. Shenandoah is a balanced community planned for homes, business, and industry. The town is in the early stages of a twenty-five year development program toward becoming a community of 42,000 people. Map 2.1 shows Shenandoah's location within the Atlanta Metropolitan Area.

- RESIDENTIAL
- COMMERCIAL
- INDUSTRIAL
- OPEN SPACE

- VILLAGE CENTER
- ELEM. SCHOOL
- JR./SR. HIGH SCHOOL
-

MAP 2.2

TOWN PLAN

The intersection of I-85 and Georgia Route 34 is the main intersection of Coweta County. The town of Newnan, the county seat, touches the west boundary of Shenandoah, and the two communities are connected by Route 34, a four-lane, median-divided highway. Newnan provides a wide range of shopping, banking, industrial, medical, and recreational facilities for the residents of Shenandoah, and Newnan- Coweta Airport is only five minutes south of Shenandoah. Map 2.2 shows the total Shenandoah area proposed for development.

2.4.2--Topography.

Topography over the town site is slightly rolling terrain except for a pronounced valley caused by a creek running from northwest to southeast through the approximate center of the site. The steepest slopes near the valley are from 5 to 10 percent. Elsewhere, they average about 3 percent. Approximately 80 percent of the site is wooded, most of it by comparatively young stands of pine with smaller patches of older pine and hardwood.

2.4.3--Climate.

The climate of the west central section of Georgia is classified as subtropical humid. This area is influenced by its location near the foothills of the southern Appalachian Mountains to the north and the Gulf of Mexico to the south, with the total effect being slight modification of both winter and summer temperatures and ample precipitation.

Summers are warm, but long periods of excessive heat are rare. The maximum is 90 degrees or higher on about one-half of the days from June through August, but a temperature as high as 100 degrees occurs in only about one summer out of three. There is usually a 20 to 25 degree drop from maximum to minimum during the summer months, resulting in rather pleasant mid to high 60's for morning low temperatures. The average minimum recorded during June through August is 66.7 degrees.

Winters are not severe, but moderately cold temperatures can be expected. Freezing temperatures occur on about one-half the days from December through February, and on about one-fifth of the days during

November and March. Due to an abundance of solar radiation, winter-time maxima are modified greatly and normally result in temperatures of 50's and 60's with 70-degree temperatures not at all unusual, even in mid-winter. The average maximum temperature for the winter months is 56.8 degrees.

The wind direction which predominates during all seasons is from the northwest. Light winds (less than 8 miles per hour) predominate during all seasons and steady winds of more than 21 miles per hour rarely occur.

The maximum directional frequency for winter, spring, and fall months is from the northwest and is seldom from the northerly direction, regardless of season.

During spring, summer, and fall months, winds out of the easterly direction indicate a high probability of precipitation. At times, however, the southwesterly winds bring stormy weather. It is generally the southwesterly winds that bring instant showery precipitation during the summer.

The annual rainfall for Newnan averages about 53.5 inches, but has varied from 74.97 inches in 1961 to 28.99 inches in 1954. The total is between 50 and 60 inches during one-half the years. March is normally the wettest month and October the driest month. The greatest amount of rainfall in one month was 18.46 inches in February 1961, and at the other extreme, no rainfall occurred during the month of October 1963. Snow flurries do occur in most winters, but appreciable accumulations are rare.

Humidity is the measure of relative wetness or water vapor contained in the air. Relative humidity is moderately high in the study area due to the frequency of low-pressure wind flow from the Gulf of Mexico. The average mid-day relative humidity is around 56 percent.

Mean daily solar radiation measurements have been recorded at the Griffin, Georgia experimental weather station. The measurements taken include both direct and diffused sky radiation received on a horizontal flat plate surface. The mean daily radiation received ranges from 601

Study Area

Langleys in May to 226 Langleys in December. This data was recorded from 1950 through March 1966.

2.4.4--Shenandoah development program.

Development will occur slowly, neighborhood by neighborhood, and village by village, to a projected population of 42,000 people over a 25-year period. Each of seven villages is planned around an elementary school. Shenandoah will provide a wide range of housing, varying from single-family homes to medium-rise apartment buildings. In addition to shopping facilities in each village, the Town Center will feature a shopping mall containing department stores and diverse entertainment facilities.

Employment opportunities are under development in the Shenandoah Industrial/Business Park. To date, twelve industries and five commercial businesses have purchased land. Seven companies have begun operations, one on three shifts, with an eventual total employment of 3,000 persons.

2.4.5--The study area.

The Shenandoah study site is contained in Village One as shown on Map 2.3. The study area contains approximately 235 acres. It will ultimately include residential areas, high school, church, fire station, commercial, and recreational facilities. Almost half of the area (approximately 85 acres) is scheduled for development in 1981; the remainder in 1982-83. The area is bounded on the north by Georgia 34; on the east by Tracts B and C and by Proposed Road C; on the south by Neighborhood Two; and on the west by White Oak Creek.

The study area is situated in the Greenville Slope District of the Midland Georgia subsection of the Piedmont Physiographic Province. The elevation is nearly 1000 feet above sea level, and the terrain ranges from rolling to slightly hilly, with 2-10 percent slopes. The depth of weathered material is variable and ranges from 10 to 70 feet. In general,

SHENANDOAH

PRELIMINARY SUBDIVISION PLAN
BASED ON ORIGINAL GENERAL DEVELOPMENT PLAN

**PRELIMINARY SUBMITTAL: THE
BASED ON ORIGINAL ORIGINAL DEVELOPMENT PLAN**

sandy and sandy-clay loams are characteristic. The soils have low to moderate shrink-swell potentials, implying relatively stable soil conditions for foundations.

About 20 percent of the site is cleared land: abandoned pastures, fields, and farm land. In the past, it has been maintained in stands of Fescue and Bahia grasses. The rest of the proposed site is covered with varying densities of second-growth mixed pine-hardwood canopy, with pines predominating. Scattered individual trees represent ages beyond 30 years.

The eastern boundary of the site is intended as a boulevard and is already cleared and grubbed. Some vegetation was replanted and other land cover has developed in the right of way.

2.4.6--Development of the conventional plan.

In order to have a "baseline" to measure energy savings, it is necessary to have a beginning point which reflects the currently-existing situation. Providing such a baseline is the function of the "conventional" plan. Here the term "conventional" refers to a physical plan layout, types of home construction and heating/cooling one would expect to find in the average residential American subdivision on the market today. Lot layout and road patterns are generally curvilinear, well fitted to the prevailing topography, and generally oriented toward use of the automobile. Home construction is of the conventional type, providing 3.5 inches of insulation in the walls, 6 inches of insulation in the ceiling, and offering central gas heat supplemented with electric air conditioning. Residential densities are low, reflecting for the most part single family development.

Development of the conventional plan began with the general development plan for Shenandoah indicated above in Map 2.4. Proposed land uses in the study area consist of areas for single-family housing (both detached and attached); townhouses; apartments; high school; police and fire station and other community facilities; commercial use; golf course and other open space; bicycle paths; and roads. One site is to be held in reserve for an undesignated use.

CHAPTER 3

TEAM STRUCTURE

3.1--The Decision Making Team.

This section of the report covers the decision-making team, technical team, their respective roles, and their interrelationships.

Shenandoah Development, Inc. evolved from several earlier organizational forms, including the parent organization Shenandoah, Limited. In the late 1960s Shenandoah, Limited created Shenandoah Development, Inc. as its development arm. In 1977 another subsidiary, Shenandoah Realty, Inc. was formed to market residential land in the Shenandoah community. The marketing of industrial and commercial land continues to rest with Shenandoah Development, Inc. The Shenandoah management is responsible to a board of directors. The chief executive officer and general manager, is responsible for overseeing operations of the organization's Comptroller, governmental relations, and special projects, while Shenandoah's president is responsible for development and marketing of the project. The internal decision-making is only part of the total decision-making process because Shenandoah Development must also reach decisions in an external environment where it must interact with other organizations, principally governmental, in the process of reaching a decision. Usually these are federal and state agencies which have regulatory responsibility. Less frequently they are regional agencies with review responsibility over a multi-county area. The makeup of the team varies from one decision situation to another, depending upon the nature of the decision to be made. Some decisions can be made with input from the local level alone, while others require input from state or federal agencies. The various periodic participants in the decision-making process are shown below:

1. Shenandoah Development, Inc.
2. Coweta County Government
3. Board of Education
4. Coweta County Hospital Authority
5. Newnan Water and Light Commission
6. Chattahoochee-Flint APDC
7. Utility Companies:
 1. Georgia Power Company
 2. Coweta-Fayette EMC
 3. Atlanta Gas Light Company
8. Georgia State Government
9. United States Government

Shenandoah Development Inc. has been discussed previously.

The Coweta County government functions as a decision-maker in such areas as building construction, subdivision approval and zoning. When Shenandoah interfaces with the county government it is generally with the County Commission, the Building Department, or the Planning Commission. While the County Commission and Building Department have approval power, the Planning Commission has only advisory powers, and in this role functions as a decision modifier.

Two other county organizations enter the Shenandoah decision-making process as the community grows: the Board of Education and the Hospital Authority. The former has the power to approve schools, curricula and other educational standards in Shenandoah. As such, the Board functions as a decision-maker. The Hospital Authority controls the location of hospitals and health care facilities in Coweta County. Should any such facilities be developed in Shenandoah they would have to be approved by this authority.

The Newnan Water & Light Commission is independent of the city government and is responsible for providing water and sewer service to the City of Newnan. Generally, it has a policy of not providing service outside of the city. However, the Commission recently approved plans for

supplying water to Shenandoah through Coweta County. The commission determined on what terms it would make water available to the county (and, hence, Shenandoah) but it also provided Shenandoah with an alternative to go elsewhere for water.

The Chattahoochee-Flint Area Planning and Development Commission is a multi-county planning agency and acts as a decision modifier in that it has A-95 review responsibility and thereby must determine if actions proposed by Shenandoah conform to area plans. Following review by the APDC there is additional review through the State Office of Planning and Budget. The APDC can suggest modifications to Shenandoah plans to bring the plans within guidelines.

The Shenandoah area is provided electric power through two suppliers: the Georgia Power Company and the Coweta-Fayette Electric Membership Corporation (EMC), a member of Oglethorpe Power Corporation. Each supplier has a specific territory to serve within Shenandoah, although one may bid against the other to serve a particular customer where electrical loads exceed a specified limit. Consequently, the two utilities must work with Shenandoah when determining electric supply within the community. The Atlanta Gas Light Company provides the gas service to the community and works with Shenandoah in the planning of gas supplies.

Various state agencies become involved in the Shenandoah decision-making process from time-to-time depending upon the nature of the decision being made. As mentioned above, the Office of Planning and Budget has become involved through the A-95 review process as has the Environmental Protection Division of Georgia's Department of Natural Resources, which processes environmental impact statements.

As in the case of the Georgia government, various federal agencies are periodically involved in the process depending on the type of decision under consideration, and each tends to function as a decision modifier.

The Department of Housing and Urban Development (HUD) is deeply involved in planning because Shenandoah has obtained financing guarantees

from that agency under Title VII of the Urban Growth and New Community Development Act of 1970. Various actions, and proposed decisions, of Shenandoah are subject to review by HUD and must conform to HUD guidelines.

3.2--The Technical Team.

As a decision-maker, Shenandoah Development, Inc. must have accurate, reliable data input upon which to base its decisions. For this study, Shenandoah needs highly technical data to devise the conservation plans as well as to decide which of the plans it should pursue. The technical team functions to provide this type of input. For purposes of this study, the technical team includes the Finance and Marketing Advisory Committees in addition to the designers, engineers, energy specialists, etc. generally considered to comprise the technical team. To make its decisions Shenandoah's management requires information about such things as energy consumption, savings, type of construction, cost of construction, life cycle cost of buildings, equipment, and plans, marketability, etc. In turn, the technical team must have input from Shenandoah concerning its development requirements

The technical team consists of four private, professional consulting organizations, in addition to the Georgia Tech Engineering Experiment Station and the Marketing and Finance Advisory Committees. Laubman-Reed & Associates is a landscape architecture and planning firm. L-R is responsible for the passive site analysis of the study area, preparing the passive and central utility site plans and building layouts. Williams-Russell and Associates is a civil engineering group and its role in the study involves researching institutional and legal barriers and producing detailed infrastructure cost estimates for the various plans developed by Laubman-Reed and Associates. Finch, Alexander, Barnes, Rothchild & Pascal (FABRAP) is the architectural consultant. FABRAP's role involved designing building configurations on the conventional plan, defining building parameters, calculating capital costs of each building type, and designing construction alterations necessary to accommodate the passive siting options, such as overhangs and additional insulation as well as the associated costs. Newcomb and Boyd is a mechanical engineering consulting firm. Its

role in the study involved calculating energy loads for each building type, selecting end-use systems, calculating system efficiencies, capital costs of systems, operating and maintenance cost and cyclical renewal costs for the several plans. Georgia Tech's role in the project is to examine alternative energy supplies, examine central utility options, design the central utility plan, examine decentralized energy systems, design the Level 2 energy conservation plan, develop a life-cycle cost model, perform an economic analysis on each plan, and serve as project director. Shenandoah Development Corporation is the prime contractor. Shenandoah chose the study site, determined the land uses, and provided input into the conventional development process. In addition, Shenandoah aided in coordination of the sub-contractors as well as the Advisory Committees.

The Financial and Marketing Advisory Committees were most important to the study team as a screening system for ideas to be implemented in each of the three conservation plans. In joint meetings the study team and each committee would discuss the various options and plans under consideration and would eliminate those which were either not financially feasible or not marketable, or both. In this way the Advisory Committees assisted in making the plans implementable in the marketplace. The Financial Advisory Committee was comprised of bankers, both commercial and savings and loan and both local and non-local. The Marketing Advisory Committee was comprised of builders, government agency personnel, and real estate market research people.

Shenandoah
Development
Corporation

Laubmann & Reed
Associates

Williams-Russell

Georgia Tech EES

FABRAP Inc.
Architects

Newcomb & Boyd
Engineers

- o Select building types
- o Define building quality
- o Define project Scope & parameters

- o Perform general site analysis

- o Prepare passive site plan

- o Prepare central utilities site plans

- o Research institutional barriers

- o Conventional plan
- o Detail infrastructure costs

- o Passive plan
- o Detail infrastructure costs

- o Research life cycle cost methodology

- o Research central utilities system alternatives

- o Research energy supply
 - Alternatives
 - Costs

- o Design central utilities plan configuration

- o Develop life cycle cost model for analysis of alternatives and sensitivity

- o Conventional plan
- o Design building configurations
- o Define building parameters

- o Conventional plan
- o Calculate
 - Capital cost by building type ex end use systems
 - O&M cost ex energy
 - Cyclical revenue cost & intervals

- o Passive plan
- o Define building parameters

- o Conventional plan
- o Calculate energy requirements by
 - Type
 - Orientation

- o Conventional plan
- o Select end-use systems
 - HVAC
 - Domestic H.W.
 - Lighting
 - Site specific

Shenandoah
Development
Corporation

Laubmann & Reed
Associates

Williams-Russell

Georgia Tech EES

FABRAP Inc.
Architects

Newcomb & Boyd
Engineers

- o Passive plan
 - Produce suitable renderings for presentation and reproduction
 - Assist with cost and energy calculations

- o Central utilities plan
- o Detail infrastructure cost

- o Central utilities plan
- o Produce suitable renderings for presentation and reproduction

- o Research solar rights legislation

- o Conventional plan
- o Calculate energy supply
 - Requirements
 - Costs

- o Define central utilities plan system parameters

- o Research alternative end-use systems
- o Determine substitution
 - Feasibility
 - Capability

- o Apply life cycle cost analysis to conventional plan data base

- o Passive plan
- o Calculate energy supply
 - Requirements
 - Costs

- o Passive plan
- o Calculate
 - Capital cost by building type ex end-use systems
 - O&M cost ex energy
 - Cyclical renewal cost and intervals

- o Central utilities plan
- o Prepare necessary design modifications to passive plan

- o Calculate or furnish efficiencies
- o Conventional plan
- o Calculate
 - Capital cost by end-use system
 - O&M cost ex energy
 - Cyclical renewal cost and intervals

- o Passive plan
- o Calculate energy requirements by
 - Type
 - Orientation

- o Passive plan
- o Select end-use systems
 - HVAC
 - Domestic H.W.
 - Lighting
 - Site specific
- o Calculate or furnish efficiencies

- o Passive plan
- o Calculate
 - Capital cost by end-use system
 - O&M Cost ex energy
 - Cyclical renewal cost and intervals

Shenandoah
Development
Corporation

Laubmann & Reed
Associates

Williams-Russell

Georgia Tech EES

FABRAP Inc.
Architects

Newcomb & Boyd
Engineers

- o Central utilities plan
- o Calculate
 - Capital cost for central utility facility and interface
 - O&M cost ex energy
 - Cyclical renewal cost and intervals

- o Central utilities plan
- o Calculate energy supply
 - Requirements
 - Costs

- o Apply life cycle cost analysis to passive plan data base

- o Apply life cycle cost analysis to central utilities plan data base

- o Central utilities plan
- o Calculate energy requirements by
 - Type
 - Orientation

- o Central utilities plan
- o Calculate cost by end-use system
 - .central connect
 - .backup
 - O&M cost ex energy
 - Cyclical renewal cost and intervals

Level 2

- o Passive plan
- o Select active alternative end-use systems
 - HVAC
 - Domestic H.W.
 - Lighting
 - Site specific as indicated
- o Select backup end-use systems as indicated
- o Calculate or furnish efficiencies

Shenandoah
Development
Corporation

Laubmann & Reed
Associates

Williams-Russell

Georgia Tech EES

FABRAP Inc.
Architects

Newcomb & Boyd
Engineers

- o Formulate "model codes" for solar rights on
 - Individual
 - Community levels

- o Formulate "model codes" for energy conservation

- o Apply life cycle cost analysis to Level 2 passive plan data base

- o Active augmented passive plan
- o Calculate
 - Capital Cost by end-use system
 - .Active alt.
 - .Backup
 - O&M cost ex energy
 - Cyclical renewal cost and intervals

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CHAPTER 4

METHODOLOGICAL CONSIDERATIONS

4.1--Factors Influencing Approach

4.1.1--Contract prerequisites.

The original proposal and the contract with the Department of Energy agree on performance of certain tasks. Although some minor changes have been made through consultations with the involved technical and DOE staff, the proposal stands essentially unchanged. In the contract the research team states that three energy conservation plans will be selected, evaluated, and compared with the conventional plan; this is the basic approach taken in the study. As mentioned in the Introduction, the team decided that it would be beneficial to place additional emphasis on the passive building design. Some of these possibilities are discussed below in the Level 2 alternatives analysis. Although some format changes were made for the final report, the general output of the study corresponds with the original proposal.

4.1.2--Team capabilities and specialized expertise.

Because of the nature of the research team itself, contractual commitments presented the only limits to the approach taken. The study team represents a wide range of expertise in energy, economics, architecture, landscape architecture, land planing, mechanical engineering, central utility energy systems, private developers, and civil engineers. In addition, the Advisory Committees provided access to authorities in the fields of building, marketing, commercial lending, and mortgage lending.

4.1.3--Development program.

The planned development of Shenandoah on the proposed site will not begin until some time in early 1981. This meshes with the study program very easily because the site is in the near-development stage, but nothing has been done that would require re-planning or retrofitting. Consequently, the study team assumed the build-out schedule which was provided by Shenandoah would be followed in all four plans. This assumption created no major or minor problems and improved consistency among the four plans.

4.1.4--Site location.

The site location had less effect on the approach the study team took than on the particular energy conservation options which were analyzed. Because the site is on relatively flat to gently rolling land, and not near a large body of water, certain passive siting options are feasible. Those options would have been different had the terrain been substantially different or if the site were located adjacent to a large body of water. Similarly, had the site been adjacent to a large industrial site with appropriate water supplies, the central utility options may have been slightly different. In addition, had the site been larger or smaller, the central utility options would have been somewhat different.

4.1.5--Degree of comprehensiveness.

One aspect which had an effect on the approach the team took has been mentioned in other portions of this report. Because this study is a community-wide, siting study, we did not venture into the buildings themselves. The team did consider two generalized forms of construction, a standard level of construction and a revised form which employs a minimum of conservation techniques, namely increased R-values in the walls and ceilings and the use of double glazing. We felt this was necessary, although we do not go into great detail on building techniques because that is beyond the realm of this study and there are many extant works in this area.

Rather, the problem we encountered was designing a site passively without being able to design the buildings passively. Therefore, we decided on the following approach. Instead of increasing the total square feet of windows on each or some building types on the southern exposure, we would simply keep the total window area the same from the conventional to the energy plans and move 80% of the windows to the southern exposure. Since the first-best solution of optimizing a passive building design was outside the realm of the study, the second-best solution of minimizing changes from one plan to the next was used.

There were some cases where passive siting techniques were used on specific building designs and both costs and energy consumption increased; this obviously is not efficient planning. Therefore, we made some concessions in our "passive" designs. In particular, we added overhangs on the southern windows which extend out from the building three-fourths of the height of the window. This will eliminate some of the summer direct solar gain. Next, we examined the use of insulated shutters over the interior side of the windows; these should be closed during winter nights to maintain the maximum amount of energy gained during the day as well as reduce natural conduction between the spaces of different temperatures. These shutters ideally would also be used during the summer to reduce solar gain and heat conduction into the building during the day, but we did not assume this.

Finally, the study team attempted to make our assumptions as realistic as possible, given today's lifestyles and thoughts on energy conservation. Through intra-staff meetings and meetings with the Advisory Committees, we limited our degree of comprehensiveness to those options and plans which we felt the consumer, home buyer, and utility company would accept in the near term. Perhaps with the energy intensity of the United States, the vulnerability to unreliable sources, and the shortages and price increases experienced in the first half of 1979, the energy conservation plans may seem to be too conservative; however, each of the three levels of conservation can be implemented and can show a reduction in energy consumption. In most cases this will require an increased level of investment, most of which will be passed on to the home buyer. When

analyzed with respect to continued increases in the costs of all forms of energy and when analyzed over the life of the homes or other buildings, most of the options show a positive net present value. Although important in itself, the explanation and dissemination of this information to builders, developers, and home buyers is the ultimate goal of a study such as this and should be looked upon as the upper level of the degree of comprehensiveness. The achievement of this limit rests with the involved government agencies and private enterprise and, consequently, lies beyond the range of this study.

4.1.6--Utility interface.

The team members have not had to adjust their approach because of the utility interface. The three utilities located on Shenandoah are Georgia Power Company, Oglethorpe Power Corporation, and Atlanta Gas Light; the 235 acre site under study lies in the Oglethorpe territory. All three utilities have graciously offered and supplied their expertise where needed as well as their reactions to various aspects of our study. Consequently the overall approach has been basically unaffected by the utility interface; rather, the utility companies have been a resource to enhance the project.

4.2.1--The Program Plan as Executed

Execution of the project, or program plan, revolved around development of three plans in conjunction with a base, or conventional, plan and development of the necessary inputs to permit evaluation of each plan level. The end result was to be the choice of the best conservation plan from the alternatives; the best plan being the plan with the lowest life-cycle cost.

Four professional consulting firms in addition to Shenandoah Development Inc. and Georgia Tech were involved in project execution. These were discussed in Chapter 3. Initial research began with the selection of a study site within Shenandoah. Site selection was based upon Shenandoah's land development schedule, in that the site selected was an area of approximately 235 acres intended for development over the next five

years. Once selected, the site was analyzed for topography, vegetation, physiography, zoning and existing land use and climate. Following the analysis maps were developed showing results of each phase of the analysis. At this same time a conventional plan was developed to provide base values for construction costs and energy consumption levels. These values would serve as comparison values for the later plans to determine the changes in costs and energy consumption.

Along with development of the three plans other research was undertaken which would be needed later. This research involved determining the institutional barriers to utilizing solar energy and development of solar rights solutions. Other research undertaken at this time included developing a life-cycle cost model, determining the central utility system alternatives and energy supply alternatives available and their costs, and developing a central utility design.

The conventional plan, as its name implies, reflects the traditional form of development familiar to the American subdivider for the past two decades. Streets are wide and curvilinear, lots generally large and houses oriented toward the street. The conventional plan offers heating with natural gas in the winter and air-conditioning by electricity in the summer. Window glass is single-glazed and insulation conforms to FHA minimum requirements.

The first alternative plan to the conventional plan to be developed was the Level 1, or passive, plan. As its name implies, the major emphasis of the plan was on energy conservation through passive site design. In the passive plan, streets are generally oriented along an east-west axis and the structures are oriented to the south to achieve maximum solar heat gain. In addition to the southern exposure, the majority of the window area is moved to the southern wall and the window glass is double-glazed to reduce heat loss in the winter and heat gain in the summer. The residential structures are also designed with increased insulation in the roof and walls and Arkansas construction, which is a tighter construction. The Passive Site Plan also features higher density and some smaller lot sizes. The analysis which follows takes these additional features, measures

changes in energy consumption and costs, and compares the plan with the conventional plan.

The Level 2 Plan is designed to take the process one step beyond the Level 1 Plan. This plan is referred to as the passive site plan with decentralized systems, both active and passive, added to the residential structures. Again, both conventional and improved construction techniques are analyzed with the decentralized systems.

The Level 3 Plan, or Central Utility Plan, examines the possibility of using some form of cogeneration plant to generate electricity for the study area and for sale back to the grid; hot and chilled water would then be distributed throughout the study site to provide the needed thermal loads. A number of central plant systems were studied, including solar, coal, and wood systems.

A common methodology was used to compare all three alternative plans with the conventional plan. Infrastructure costs, energy consumption and price levels, building costs, and energy end-use systems were all examined for differences and changes from plan to plan. For additional consistency the same number of single-family, apartment, and townhouse units was used in each of the plans. It was felt this would be easier to compare than calculating costs and energy usage per square foot. Consequently, even though the passive plan, for example, shows more apartments and single-family dwellings, the energy and dollar figures are for the same number as is indicated for the conventional plan.

Given all of these plans, the economic analysis was made to determine the life-cycle costs of each entire plan. The final output of this analysis is a determination of the total costs of the 235-acre development over 25 years including site development costs, lot development costs, construction costs, and energy costs. By comparing the present value of additional investments in each alternative level to the present value of savings (primarily from reduced energy consumption), a final savings-investment ratio is calculated for each comparison with the conventional plan.

4.3.1.--Economic Analysis Model

L3MODEL is a community level life cycle cost model for project analysis and evaluation. The analytical technique employed is a computer coded application of the familiar total net present value of costs method. Automated data processing and formatted input/output techniques are used to produce a variety of reports.

The model employs a mix of interactive and batch processing for maximum efficiency and flexibility. The user interactively establishes the values of the constraining variables and selects one or more of the processing options. The descriptive data base is prepared as a file organized by building type and cost category.

Using this basic set of data containing project parameters, construction and development costs and energy consumption, the model calculates project costs on an annual basis over the expected life of the development. Several processing options are available for utilizing these basic results to produce a variety of analytical reports for evaluation.

4.3.1.1.--Data Structure.

L3MODEL uses a data base composed of one or more files, each of which describes the construction and development costs and energy utilization of an alternative community development plan. Project parameters and assumptions, processing option and data file selection are solicited at runtime.

4.3.1.2.--Data Files.

Each file in the selected data base describes an alternative community plan. A file is composed of a header line and one or more data blocks, each of which describes a single building type.

A data block consists of thirteen lines of free format information comprising selected building cost and performance information.

- Line 1 - Building Type Code
- Line 2 - Building Type Descriptor
- Line 3 - Number of Units, Percentage of Gross
Developed Space
- Line 4 - Construction Unit Cost
- Line 5 - Passive Design Element Costs
(five elements: overhang, perimeter
shelterbelt, shading, and berming)
- Line 6 - Revised Construction Element Costs
(three elements: wall, roof, and
double glazing)
- Line 7 - Level Two Element Costs (as many
as three elements may be selected)
- Line 8 - Percentage of Construction for year 1
through year 3
- Line 9 - Site Unit Cost, Incremental Site
Unit Cost
- Line 10 - Lot Unit Cost, Incremental Lot
Unit Cost
- Line 11 - Electric Energy Unit Cost,
Annual Consumption, Conservation
Plan Savings, Level Two Add-on
Savings, Thermal Fuel Offset
- Line 12 - Natural Gas Energy Unit Cost,
Annual Consumption, Conservation
Plan Savings, Level Two Add-on Savings,
Thermal Fuel Offset
- Line 13 - Thermal Fuel Unit Cost, Annual Consumption,

There will be as many data blocks as there are building types in the alternative being considered. Ordinarily, it will be desirable to compare two or more development options and, accordingly, a like number of data files will be required.

4.3.1.3.--Runtime Information.

At runtime the program will solicit values for the constraining variables. They are analysis and construction periods in years, construction financing, discount rate, return on invested capital, construction cost escalation rate, and escalation rates for electric, natural gas, and thermal costs. This method allows the same development alternative to be analyzed over a broad range of economic assumptions.

The program then solicits user's choice of processing options and turns on logical switches for the chosen section of the program. In all cases, L3MODEL produces a basic set of cost reports: the summary report by cost center, an elemental report by building type, and a cost category report. Each option selected causes additional reports to be generated.

Finally, the program solicits the names of the data files to be used in processing. It will in turn attach them, assign them identifiers, and open them at the appropriate point.

4.3.1.4.--Analytical Method.

L3MODEL employs the total net present value of costs method coded for computer solution to arrive at a comparison of alternative costs that is equivalent in basis. The model is limited to a consideration of construction and development costs, stated as a set of base and incremental plan specific costs, and energy cost and consumption information. This limitation is imposed to isolate the construction cost and life cycle energy cost and consumption relationship, which, of course, is the focus of the study.

1. Construction Costs. Construction costs are entered on a unit cost basis for each building type. These are scaled by number of units, then inflated to the appropriate year in the development program and discounted to base year dollars. For alternative development schemes, these costs are stated as base and multicomponent incremental values. Component costs for passive design elements, revised construction elements, and level two add-on elements are first subtotaled and then summed to comprise a total incremental construction cost. Costs for each building type, when summed for the entire development scheme, are the total net present value of construction costs for the alternative being considered.
2. Development Costs. Similarly, development costs are entered as two categories: site development costs and lot development costs. Each is expressed as a base and incremental cost pair. These costs when summed for the entire development scheme are the total

net present value of development costs for the alternative being considered.

3. Annual Energy Costs and Consumption. Annual energy costs are computed from inputs of unit cost and annual consumption by fuel type for each building type. These are then scaled by the number of units and inflated to produce an annual series of costs. The resulting series is then discounted to base year dollars. Unit consumption (savings) for each conservation plan, level two add-on elements, and thermal energy fuel offset are summed and used in like fashion. These costs for each building type when summed for the entire development scheme are the total net present value of life cycle energy costs for the alternative being considered.

4.3.1.5.--Capabilities.

For the purpose of this study, it is only the cost implications of a given site planning alternative and the associated effects on energy consumption and their relationship that is at question. This relationship may meaningfully be reported in a variety of ways, levels of analysis, and degrees of detail.

1. Basics. No matter what processing options are chosen, the program automatically produces a basic set of reports for each alternative development scheme analyzed. They are the economic evaluation of the alternative in terms of cost center, building type and total project cost. Often this will be enough information for an initial evaluation or to aid in establishing realistic initial assumptions.
2. Options. However, it will usually be desirable to employ one of the available processing options to provide more information and allow for comparison of alternatives. The report generating capabilities are increased as required. Concurrent selections are acceptable permitting the user to tailor a report to desired limits. Available options include: input data option, annual cost option, opportunity cost option, and sensitivity analysis option.
 1. Input Data Option. This option summarizes in tabular report format the input data file and the runtime economic assumptions. If the opportunity cost option is concurrently selected, the information is reported for both options considered.
 2. Annual Cost Option. Annual costs are reported for each of four cost centers and as a total for each year of construction and occupancy of the assumed analysis period. The figures are reported in undiscounted cost year dollars. (1)
 3. Opportunity Cost Option. This option compares total net present value of costs between alternative configurations. The program makes the standard economic calculation of opportunity cost of the differential cost. This option requires data files for the two options to be compared, the names of which are solicited at runtime.
 4. Sensitivity Analysis. The standard method of sensitivity analysis is employed. One of the constraining variables is varied over a specified range at a specified increment while the others are held constant. These values are specified by the user at run time in response to interactive solicitation. The user may choose one variable from the following list by code:

Code Variable
 A Analysis Period
 F Construction Financing
 C Construction Cost Escalation Rate
 E Electric Fuel Cost Escalation Rate
 G Natural Gas Fuel Cost Escalation Rate
 I Discount Rate
 T Thermal Fuel Cost Escalation Rate
 R Return on Invested Capital

The program responds by calculating the total net present value of costs for each increment over the range. Both terminal and print reports are produced if desired for the convenience of testing a variety of sensitivity assumptions quickly while only printing those selected as meaningful.

4.3.1.6.--Reports.

Depending on the option selected, L3MODEL is capable of producing a variety of reports. Certain basic reports are always produced. Each processing option causes certain additional reports or groups of reports to be concurrently produced.

1. Basic Reports. The summary report by cost center reports cost data by cost category with totals and the total net present value of costs for the alternative being considered. The elemental report by building type reports base and incremental cost data by cost category with totals. The cost category report of building type reports base and incremental cost data and percentages by cost category. Each offers more detail at a lower level of aggregation.
2. Optional Reports. The input data reports are a series of three reports by cost category. The annual cost summary is an undiscounted cost listing by year for the selected analysis interval of the undiscounted annual cost by cost category. The opportunity cost report is an economic comparison of the total net present value of costs of two alternatives and the differential cost considering the time value of the required incremental investment. If the input data option is concurrently selected, that report is produced for both alternatives being considered.

The sensitivity analysis report is available both at the terminal and in print. The print option may be suppressed until the analysis has been sufficiently narrowed. The total net present value of costs is reported for each increment over the selected range. The basic report set is, however, printed only for the base case to avoid the indiscriminate generation of output. Obviously, any cases for which the basic reports are desired may be run individually after sensitivity analysis has identified the most sensitive variables, ranges, and combinations of assumptions.

4.3.2.--Energy consumption estimation and simulation model.

A crucial step in the evaluation of the community design alternatives is an analysis of the probable energy consumption of each alternative.

Traditionally, predictions of building energy consumption have been based on empirical "rule-of-thumb" numbers, such as degree-day calculations. These methods are not accurate or sensitive enough to adequately evaluate the kinds of changes involved in community planning. An example of this problem is a typical passive solar building. On a sunny day, the total daily solar heat gain through the windows can be more than the daily heat loss from the building. The problem is that the solar heat gain does not occur at night, when it is needed most. As a result, only an hour by hour analysis of the interaction of the building, solar transmission, and internal loads with the space conditioning system can provide a reliable estimate of a building's designed energy consumption. Due to the number of calculations required to analyze a building for 8760 hours of the year, a computer simulation is a necessity.

For this project, the ESP-1 program developed by APEC (Automated Procedures for Engineering Consultants) was used to predict energy consumption. This program uses hourly weather data and information about a building's architecture, occupancy, and internal loads such as lights to calculate the thermal building loads for each hour. The program then simulates the action of a space conditioning system in response to each hour's loads.

Weather data used in this analysis was based on the 1975 Atlanta weather data. When the need for accurate and reliable weather data for energy analysis became apparent, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the National Bureau of Standards (NBS), and the National Oceanic and Atmospheric Administration (NOAA) joined forces to establish some standard. From this, the concept of a "Test Reference Year" was developed. This involves the use of a set of criteria to determine a specific year for which the weather in a particular locality is most representative of the conditions encountered at that location. The test reference year for Atlanta is 1975. Data used includes

temperature, humidity, pressure, wind speed and direction, solar position, cloud cover, and direct and diffuse radiation. This data was modified to represent Shenandoah. The modifications corrected the solar position for latitude and longitude, and corrected air density for altitude variations. Since Shenandoah is quite close to Atlanta, the resultant weather data should be as accurate an indication as is possible of representative conditions at Shenandoah.

The next step was the calculation of building loads. Since the purpose of this study was to determine the effects of community planning, and not to evaluate what can be done in a specific building, the input was tailored to reflect a general case rather than the specific architecture of a building. Since the program was developed to perform a detailed analysis of very specific building parameters such as wall color and window location, this caused some conflict between the program requirements and the project purpose. The solution involved modeling "typical" buildings. In all cases, the wall and roof construction was input layer by layer in great detail. This was necessary because ESP-1 calculates thermal transmission loads using the response factor analysis technique. Additional information required for each building type was the orientation, percent of glass in each direction, the type of glass used, and the size and direction of walls. For each building type, hourly profiles of the occupancy and lighting loads were also developed for use by the program. Once a computer model of a building type was completed, it was run with the weather data to produce a computer file containing the hourly thermal load for each space. Since many residential buildings are controlled by one thermostat, only one space was required to simulate the building.

Once the building loads had been calculated, the second portion of the program was run to simulate the building mechanical system. Although this computer program has the ability to simulate the large, complex systems and controls which characterize large commercial buildings, most of the building HVAC systems in this project are not that sophisticated. In addition, some system options such as time clocks and economizer cycles can potentially have a great effect on the energy consumption in a building. Since a study of mechanical system design was not the intention of this

project, the systems were kept as simple as possible. This is also consistent with the usual practice in residential structures. For most of the residential type buildings, the systems were simulated as direct fired gas heat at 80% efficiency and split system air conditioning with a COP of 2.0, as prescribed in the Georgia Energy Code. The only building which was large enough to warrant a more complex system than this was the high school. The system in this case was a central boiler and chiller providing hot and chilled water to variable volume air handling units with economizer cycles. The system was controlled by time clocks and night setback thermostats. Since this is already a system which is quite efficient, it produced estimates for the high school which are conservative.

In order to predict the energy consumption of the community for the various alternatives, each building type was run for each plan (i.e., conventional or passive), and each construction type. The building types were also run for each major orientation within a plan. By multiplying each building type by the number of that type in a plan, the energy use profile for the community for four different alternatives was developed.

In spite of the complexity and speed of the computer program used, several factors which could affect the energy consumption of the community could not be evaluated by this means. For some cases, such as the use of shutters to reduce the night heat loss in the passive plan, this was not anticipated by the developers of the program. In other instances, such as the effects of wind channeling by vegetation, no mathematical method of predicting the effects of these changes has been developed. As a result, some adjustments were necessary to account for these factors.

4.4.--Conservation Options.

4.4.1.--Passive Site Plan.

4.4.1.1.--Alternatives Considered.

The types of architectural passive systems geared for a particular building type often create a framework from which the site design may begin. For example, the types of solar collection systems will often

north & west walls have greater exposure to winter winds & late afternoon summer sun on north slopes.

Northwesterly winds

winter sun penetration

breeze movement

winter sun penetration

4-15

cold air drainage

lower north slopes have high humidity levels, less evaporation & ventilation.

North slope buildings receive less solar radiation, because of smaller wall areas & less reflection of incoming rays during winter.

North & West slope buildings will need additional site preparation costs in order to achieve energy efficiency of south slope land uses.

suggested use: low density residential for adequate solar access
mean consumption: 2.06×10^8 btu/ac./yr. for single family residential

high density residences where best micro-climates exist.

site preparation costs & energy use are lowered.
mean consumption: 3.7×10^8 btu/ac./yr. for multi-family in this climate

lower areas on site trap summer heat & achieve high humidity levels.

Surface Soil Temp. differences in a ridge - furrow profile.
Temp. in ($^{\circ}\text{C}$)

microclimate/topography

dictate the size and length of adequate solar access corridors in the site plan. The following text summarizes passive options that were considered applicable for the Shenandoah Site Plan. They include: Solar Access, Building Orientation, Cluster Layout response to Sun and Wind, Microclimate Evaluation, Shading, Berming, and Reorientation of Planning Policies.

A. Solar Access.

Solar access depends on the means by which the solar collection takes place. It is obvious that many different collection systems will give direction to land use density and layout.

Stein devised three methods in which solar access would work.(2) The first method which he described allows the sun to penetrate a target wall within a 30 degree angle off the perpendicular of due south. The second method assures solar access between certain hours of the day, say between 8 and 4, for all seasons where the sunlight would be unimpeded. At all other times, partial sunlight would hit part of the wall. The third method provides all sunlight where the sun is 15 degrees altitude above the highest part of the wall.

When comparing the three methods, the results of solar availability are quite different. Each method will result in different percentages of efficiency. The first method favors winter sun access, but that is less than either of the second or third methods.

B. Building Orientation.

Olgyay (Olgyay, 1963) conducted tests which involved optimum building placements for energy conservation. In his method, known as the "Sol Air" approach, he found that for buildings within the hot-humid region an orientation at 5 degrees East of South was an optimum building position for human comfort. In some cases the living areas of buildings might face orientations other than the optimum when restricted by grade.

C. Cluster and Group Layout Responses to Sun and Wind.

The climatic conditions which prevail in the Shenandoah area dictate slightly greater heating requirements. The goal here is to provide

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From Stein, 1977.

adequate solar access to each building unit and create protection from winter winds by the arrangement of the buildings. That same layout shall provide adequate air ventilation and protection from solar loads by relieving some of the adverse weather impact.

D. Microclimate Evaluation.

Microclimates are extremely difficult to measure with much accuracy because of the high number of variables involved in creating them. The variables which make up a microclimate are air temperature, sun and radiation intensity, winds, precipitation, humidity, absorption of heat from sky and ground, topography, aspect, surface cover, and ground material. (Foster, 1978).

The site at Shenandoah, because of its sloping terrain, soil and vegetation diversity, and abundance of water has many different microclimates. In order to locate and accurately define the microclimates which exist on site, a detailed inventory and site analysis of natural site factors will provide direction for the development of the passive plan. By qualifying potential microclimatic areas that are most favorable for intense development and limiting development of unfavorable microclimatic areas, the structure of the passive land plan will begin. The highest energy-using land uses must be sited in microclimates that, for the most part, contain air temperatures, humidity, and wind levels near the "human comfort zone" as stated by Olgyay (Olgyay, 1963).

When siting for microclimate control, certain trade-offs must be made. Although many areas may be favorable for certain development, different land uses may not be compatible with one another. Or, certain sites may have difficult access requiring extensive site preparation costs. That in itself requires additional energy for the construction of roads. Proximity, accessibility, and land use compatibility will also need to be evaluated in the development of the passive plan.

E. Shading and Cooling.

Reducing heat build-up during the summer involves three design objectives, according to Egan (Egan):

1. Reduce penetration of solar radiation
2. Improve evaporative cooling conditions by proper building layouts.
3. Lower the heat gain from reflectant surfaces.

Reduction of solar radiation gain involves planting or preserving trees on east and west exposures of structures since the low sun angles are closer to perpendicular to the building in early morning or mid/late afternoon. Another way of lowering direct solar gain is to reduce east and west wall areas and to eliminate most of the windows in those areas. Egan shows that mature hardwood trees allow about 20-25% of radiation to pass through.

Any shading device may be expressed by its shading coefficient. The coefficient describes the fraction of incident solar energy that is transmitted through the device.

Percent of illumination of forest floors recorded by Geiger (Geiger, 1950) under different types of old stand trees are given below.

Illumination on forest floor in percent of outside illumination		
	Leafless	Leafed Out
Red Beech	26 - 66	2 - 40
Oak	43 - 69	3 - 35
Ash	39 - 80	8 - 60
Birch	-----	20 - 30
Evergreen		
Silver fir		2 - 20
Spruce		4 - 40
Scotch pine		22 - 40

Deciduous trees also prevent ground temperatures from increasing greatly. Ground surfaces, depending on their chemical and physical nature, transfer heat in four ways:

1. Absorption of radiant heat.
2. Conduction into the solid.

3. Dissipation of heat by

convection by wind.

4. Evaporation.

The amount of radiation absorption of a ground surface depends upon texture and density, its heat conductivity, and capacity, as well as moisture content and color. As stated by Plumbly (Plumbly, 1977) ground surfaces generally provide more radiant heat exchange than either vertical surfaces or significant overhead surfaces. Trees prevent light and heat load from building on exposed ground surfaces as well as vertical surfaces. Therefore the air temperatures are lower and the lagtime of heat build-up in air temperature is increased to three hours, as stated by Ray.

Proper placement of excessive heating surface away from cool air openings in buildings will become an important consideration in the planning process. Deciduous shrubs might be used to protect dwellings from radiant heat by providing a buffer zone of absorption where in winter, when loss of leaves occurs, the radiant heat from the parking lots may be absorbed by the dwelling. However, improper shrub placement may result in air stagnation.

Shrubs and trees may be used to buffer the reflectivity of a hard surface. Plumbly (Plumbly, 1977) reports that ground reflectivity during midday significantly increases solar radiation on vertical surfaces.

By proper location of trees and shrubs and the correct selection of such species, or the maximum preservation of existing species, a significant reduction in energy for space cooling would occur.

F. Berming.

Partial earth berming on north and west exposures of the building was also a consideration in the overall site planning of the project. Although berming may not be suitable for some buildings, the plan was allowed the flexibility of providing berming for all structures on site. The cost effectiveness of berming will involve a study of soil nature,

grade, and structural requirements of the building. It is known that partial berming will create a reduction in heating and cooling loads by eliminating wall exposure and using the thermal lag in the heating and cooling cycle of the soil. However, it is not yet known whether this savings is a substantial factor for justification of construction for Shenandoah.

G. Reorienting Planning Codes and Policies.

The reorientation of existing planning codes and policies at Shenandoah enforcing builders to comply with passive site design standards was also a consideration. The planning policies might require adequate sun access and breeze channelization, yet be flexible on setback and minimum lot size requirements.

Proper north-south lot orientation with lower side lot setback distances would provide some protection from low summer sun and winter winds by allowing shading. Setback distances from the street might be made more flexible where optimum building orientation is needed for maximum sun access or where air circulation is needed.

Another planning reorientation consideration in the site design was the reduction of street widths from 24 feet to 20 feet and right-of-ways from 50 feet to 40 feet. It is obvious that a considerable amount of energy and money expended in the construction of the roads can be saved. The reduction of R.O.W. widths saves more valuable land and reduces sprawl, not to mention a reduction in non-point pollution. Narrow streets bring the scale down to a pedestrian level and can be shaded more easily.

4.4.4.2--Methodology for Evaluating Options.

The evaluation methodology for the development of mixed land uses at Shenandoah involved a complete and thorough site resource inventory and analysis of existing site conditions and the development of building criteria and site design guidelines. Through the study process, two main objectives became clear:

1. To provide long range passive energy conservation design measures

and guidelines which (a) must be compatible with normal construction costs on the base plan, and (b) could be used for immediate implementation.

2. The implementation of these long range energy measures.

The following section presents the evaluation methodology by: discussing site conditions, long-range passive energy conservation measures, and short- term construction costs.

In order to determine the specific site areas within the development plan for Shenandoah that are the most attractive for site construction and energy conservation, a detailed inventory and analysis of existing environmental factors was prepared. Natural site characteristics such as wind effects, seasonal solar angles, slope, slope aspect, soils, physiography, hydrology and vegetation were mapped and analyzed. The analysis delineates specific areas of similarity that pose potentials for or constraints to the construction and energy efficiency.

A. The Site Resource Inventory.

The site resource inventory involved a detailed study of the physical aspects and overall character of the site. This inventory includes topography and landform, slopes, slope aspect, soils, hydrology, vegetation, and wind/climate. These site conditions offer direction for development and energy efficiency and were carefully regarded with respect to the potential they offer and the limitations they propose.

A.1. Physiography.

The site is characterized by gently to moderately sloping terrain. Two large landforms enter the site from the northeast and southeast, with elevations ranging from 900 to 822 feet and 875 to 820 feet, respectively. A large drainage swale runs east and west dividing the site equally. White Oak Creek borders the western boundary of the site and is the main drainage corridor for the surrounding area. The 100 year flood level for White Oak Creek reaches a maximum elevation of 825 feet which envelops about 1/4 of the project site. Constraints for high-intensity development within this area are imposed to insure that damage or restrictions of the floodwater do not occur.

SHENANDOAH

COWETA COUNTY

GEORGIA

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**PASSIVE
SITE ANALYSIS**

VEGETATION

- OPEN W/ UNDERSTORY
- HARDWOOD UNDERSTORY
- PINE-HARDWOOD
- PINE

SCALE: 1"=200'

0 100 200 400 600 800 1000

SHENANDOAH

OWETA COUNTY

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PASSIVE SITE ANALYSIS

A.2. Hydrology.

The site lies within the headwaters of the White Oak Creek watershed. Studies have shown that the average annual runoff in the watershed is 1.2 cubic feet per second per square mile. During summer and fall drought, runoff has been as low as 0.2 cubic feet per second per square mile.

A.3. Vegetation.

The vegetation study identifies and maps vegetational types. Various vegetational types have different impacts upon the microclimate of the site. Vegetation is an effective windbreak because it permits jet air movement through it. It also provides a more extended area of protection than any other object. Various types of vegetation allow various degrees of wind filtering and solar radiation. Existing vegetation will play an important role in reducing energy consumption and in final site development. Four types of vegetation have been labeled on the map. They are: open with understory, hardwood with understory, pine-hardwood with understory, and pine. About 20% of the site is cleared land which is abandoned pastures and crop farmland. Hardwood second-growth stands are characteristic of the flood plain. Pine stands resulting from natural succession are abundant on the side slopes. The rest of the site contains a mixture of pine and hardwood stands that have competitively grown together.

A.4. Wind and Climate.

The predominant wind direction during most of the year comes from the northwest. A building totally exposed on a northwesterly slope can have an increase in heating costs of 30%.(3) Using this information, sheltered areas, seasonal wind directions, air movement, and cold pockets were labelled. Cooling spring and summer breezes frequently come from the southwest. Cold nighttime air-flow moves down the swales to low spots which are located within the floodplain area. Warm daytime air moves up the swales and hollows to higher elevations. It therefore becomes important not to impede the movement of cold or warm air.

SHENANDOAH

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**PASSIVE
SITE ANALYSIS**

SHENANDOAH

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**PASSIVE
SITE ANALYSIS**

SHENANDOAH

COWETA COUNTY, GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

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**PASSIVE
SITE ANALYSIS**

Sheltered areas have been identified on the map. The areas most sheltered from the wind are those located below the ridgeline on south-southeasterly slopes.

A.5. Slopes.

Another determinant of planning constraints was slope. The site has been categorized and mapped according to the following slope ranges: 0 to 8%, 8% to 16%, and greater than 16%. The 0 to 8% slope categories are best suited for limiting construction costs on this particular site. Excluding the flood plain, about 50% of the site is composed of 0-8% slope ranges. Slopes between 8-16% become more limiting to heavy use development since grading costs will increase. These areas may be suited for less intensive development such as single-family residential. Approximately 15 to 20% of the site is in this category. Under 5% of the site has been categorized as greater than 16%. These slopes should be protected and held in place.

A.6. Slope Aspect.

Slope aspect, or the direction of the slope, was delineated on another map. The slope aspect is a great determinant of the microclimatic conditions that exist on site in terms of winter solar heating or summer cooling. This map will have a great impact upon the positioning and orientation of buildings. The categories for slope orientation were mapped as: southern exposure (S15 W to S20 E), eastern exposure (S20 E to N62 E), northern exposure (N62 E to S15W). For this particular site, the optimum orientation is 5 E of south. The least efficient orientation in terms of energy conservation would be West and Northwest.

A.7. Soils.

Soil properties are an important concern in the design and construction of the site. Properties such as permeability, depth to water table, stability, erodability, and fertility determine the suitability for building and vegetation development. The site is composed of three different soil series. Generally, sandy loams and sandy clayloams are characteristic. The soils have a low to moderate shrink/swell potential, implying relatively stable conditions for foundations. The most fertile soils are the chewacla series located within the flood plain. These soils

SOILS

- CHEWACLA LOAM RIVERVIEW
- CHEWACLA
- CECIL SANDY LOAM
- CECIL SANDY LOAM DISTURBED
- CECIL SANDY CLAY LOAM ERODED

SCALE: 1" = 200'

0 100 200 400 600 800 1000

SHENANDOAH
COWETA COUNTY GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

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**PASSIVE
SITE ANALYSIS**

SLOPE / ASPECT

- SOUTH AND EAST EXPOSURE
0-8% SLOPE
- SOUTH AND EAST EXPOSURE
8-16% SLOPE
- NORTH AND WEST EXPOSURE
0-8% SLOPE
- NORTH AND WEST EXPOSURE
8-16% SLOPE
- NORTH AND WEST EXPOSURE
16% SLOPE AND ABOVE
- 100 YEAR FLOODPLAIN

AVG. SOLAR RADIATION
IN LANGLEYS

SHENANDOAH
COMBIA COUNTY GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

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PASSIVE SITE ANALYSIS

MICROCLIMATE

- AREAS W/CANOPY VEGETATION PROTECTED FROM NW WINDS
- AREAS PROTECTED FROM NW WINDS
- WINDBLOCKS OF EVERGREENS ON NORTH AND NW SLOPES
- AREAS EXPOSED TO NW WINDS
- AREAS OF FROST POCKETS AND COOL NIGHT AIR FLOW
- AREAS EXPOSED TO HIGH AIRSTREAMS
- RIDGETOPS

SCALE: 1"=200'

0 100 200 400 600 800 1000

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PASSIVE SITE ANALYSIS

SHENANDOAH

LOWELL COUNTY GEORGIA

are usually located on less than 2 % slope. The soils located out of the flood plain are Cecil Sandy Loams and Sandy Clay Loams. These soils are potentially erodable when found on steeper slopes, but pose low to moderate limitations for construction.

B. The Site Analysis.

The site analysis involved creating composite maps from the site inventory study. This analysis involved three maps: the slope/ slope aspect, microclimate, and land use intensity.

B.1. Slope/Slope Aspect.

This analysis combined the slope and slope aspect inventories in an attempt to delineate areas which gain variable amounts of solar radiation. This was done in order to isolate areas of slight slope (0-8%) and southern orientation for optimum solar exposure. By overlaying the slope map with the slope aspect map, a range from the best to the worst slopes for the passive energy plan was established. The areas mapped ranged from the most attractive (a south and southeastern exposure slope of 0-8% gradient) to the least attractive (a slope of western exposure at 16% gradient). This map became an important step for determining land use intensity.

B.2. Microclimate.

By overlaying slope aspect and wind climate inventory maps, a composite of specific microclimatic areas was defined and mapped on a separate overlay. The following microclimatic areas were defined and mapped: areas exposed to north and west winter winds, areas protected from winter winds, and areas protected from winter winds and covered with canopy vegetation. Areas that are the most desirable microclimates are those located on south-southeasterly sloping areas exposed to summer breezes. Areas which are least desirable are low areas of frost potential, hot humid areas of no air movement for ventilation, or open areas on a northwest slope exposed to high winds. Existing evergreens would be most beneficial as windblocks if preserved on north to northwest slopes.

B.3. Land Use Intensity.

By overlaying the microclimate, slope/aspect, and soil analysis maps, a final map was generated labelling the areas of suitability for various land use intensities and high energy users. In terms of reducing energy consumption and construction costs by optimizing on natural site conditions, the map was delineated and labelled according to proposed land use density and energy performance. The map is labelled as follows:

1. High Density/High Energy Use: (school, garden apartments) would be most suited to areas of:
 1. Slopes -- below 8% gradient
 2. Soils -- Cecil Sandy Loam and Cecil Sandy Clay Loam
 3. Aspect -- south, southeast, east, and north
 4. Cool summer breeze exposure
 5. Protection from north wind
2. Medium Density/Medium Energy Use: (single family dwellings, townhouses) would be suitable in all areas left from above and:
 1. Slopes -- 1-16% gradient
 2. Soils -- Cecil Sandy Loam and Cecil Sandy Clay Loam Loam
 3. Aspect -- south, southeast, east, and north
 4. Cool summer breeze exposure
 5. Protection from north wind
3. Low Density/Low Energy Use: (golf club, church/day care center) would be suitable in all areas left vacant above plus:
 1. All slope gradients
 2. Aspect -- north and west
 3. Cool breeze exposure
 4. Vegetated on north and west slopes
4. Low Density/Low Energy Use with Site Modifications: (convenience store, maintenance building, police/fire station) would occupy areas characteristic of:
 1. Slopes -- 8-16% and above
 2. Aspect -- north and west slopes

LAND USE INTENSITY

- HIGH DENSITY
- MEDIUM DENSITY
- LOW DENSITY
- LOW DENSITY WITH SITE MODIFICATIONS
- OPEN SPACE

SCALE: 1"=200'

0 100 200 400 600 800 1000

SHENANDOAH

COWETA COUNTY,

GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. EM-78-G-01-4215

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WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

PASSIVE SITE ANALYSIS

SOLAR DATA - Dec. 22 - Lat. 33° 16' N. Building Height - 33 Ft.					
Sun time	8am	10am	12n.	2pm	4pm
Azimuth	124°	149°	180°	149°	124°
Altitude	10°	25°	32°	25°	10°
Shadow Length	150'	63'	49'	63'	150'

For determining shadow lengths on different slopes:

$$s = \frac{h}{\tan(A+B)} \quad \text{where:}$$

s = length of shadow

h = height of building

B = solar altitude

A = slope angle

Apartments
South Slopes

Shadow Analysis
winter

3. Drainage channels
 4. Ridgetops
 5. Exposure -- open north and west slopes
 5. Open space/No Energy Use: (golf course, recreational activity) would occupy floodplain.
- The land use intensity map is shown on page 4-35.

C. Energy Option Evaluation.

Each of the building types were analyzed with the options discussed above. The land use intensity provided a base in which to construct each building type in terms of siting relationship response to sun and wind orientation and additional climate modification measures. All of these factors had an effect upon the site planning for Shenandoah. Each of the planning and design passive measures evolved from two categories of Long Range Conservation Measures and Short-Term Construction Costs.

C.1. Long-range conservation development program.

1. Maximize Solar Access Potential.

1.A. Requirement:

1. Insure a greater amount of solar energy to reach site and maximize the gathering and collection potential of each unit.

1.B. Planning Strategy:

1. Maximize orientation of active living zones within each unit to south.
2. Maximize southern wall and window area for optimum solar gain during winter.
3. Maximize use of open areas or selectively thinned forest areas for optimum solar penetration within each unit.
4. Layout should maximize solar penetration within each unit.

1.C. Analysis:

The investigation involved layout organization for each site type on different slopes in order to determine adequate separation between buildings for sun access. Also, areas where vegetation should be

Area to be void of 40' trees for optimum solar access during 9 a.m. & 3 p.m. Jan 21. - 4% West Slopes Lat 33° N. Long. 84° W.

Plan north ↑
Scale: 1"=100'

Proper Placement of heavy shading deciduous trees - 40ft. maximum height - reducing direct solar gain to walls & pavement.

Section labels ultimate height & proper setback of plant material from South Wall - Jan. (not to scale)

Single Family
West Slopes

Solar Access

July Solar Shadows at 5p.m. will provide protection of west wall areas from direct afternoon solar gain by proper building layout

9 a.m. shadow
July 21 - 40 Ft.
4% West Slope

5 p.m. shadow
July 21 - 85 Ft.
4% West Slope

Recommended Distances Between Building Are Shown (Roof Peak - 32 Ft.)

Summer Shadows

July 21 - 2 story building
Lat. 33° N. Long 84° W.

3 p.m. Shadow
Jan. 21 - 120 Ft.
9 a.m. Shadow
Jan. 21 - 200 Ft.
on 4% West Slope

It is Recommended the Entire South Wall Area Not have shade cast on it between 9 a.m. & 3 p.m. during Jan.

Winter Shadows

Jan 21 - 2 story building
Lat. 33° N. Long 84° W.

Single Family
West Slopes

Plan north ↑
Scale: 1" = 100'

Solar Shadow Analysis

Winter Solar Collection Areas

areas should be absent of objects obstructing sun's rays to south wall or roof of building

tall, fast growing heavy shading trees (deciduous)

rooftop collectors

low-wide spreading deciduous trees protect parking lot from solar heat buildup.

Dec 22 sunset
126° Azimuth

Dec 22 sunrise
126° Azimuth

When collectors are not used on buildings, light shading, horizontally spreading shade trees may be used to lower summer ground temp.

average daily solar radiation falling on south wall in Dec. = 39×10^7 cal. per wall area

unobstructed area 100' min.

Dec 22 Sun rays Alt. 32°

rooftop solar collectors

area of absorption 35 ft.

65' parking

max. tree height 45'

60' unobstructed area

max. tree height 38 to 40 ft.

solar collection walls reflection from area directly in front aids in heating building

area of absorbing sun's radiant heat on ground & in plants. plant deciduous shrubs 6' height max.

Apartment's South Slopes

solar access

Side Elevation

Front Elevation

Proper Vegetation Locations for Solar Loading Control - June 21

Apartment South Sides

solar loads/mitigating measures

selectively cut or saved were defined. The sketches on the following pages of solar access and winter shadow analysis begin to define adequate separation between residential buildings.

2. Minimize Adverse Weather Impacts.

2.A. Requirements:

1. Minimize solar loads on east and west walls for each unit.
2. Utilize natural barriers for protection from adverse winds (vegetation and landform).
3. Maximize ventilation by layout.
4. Reduce humidity by location and layout.

2.B. Planning Strategy:

1. Reduce east and west wall areas to lower solar loads from morning and late afternoon sun.
2. Reduce west, east, and north window areas to improve interior heating and cooling during summer and winter months.
3. Site types should utilize existing deciduous vegetation on east and west exposures to reduce summer heat.
4. Site types utilize existing coniferous planting vegetation on north th northwest side of building to reduce winter wind effects.
5. Layout of site types should encourage shading. Optimum site type layout is to orient building types S 5 degrees E with close side distance between each unit for shading.
6. Roads and streets should be oriented to each unit or site type and run east-west for maximum summer ventilation.
7. Layout should discourage dead air spaces which trap summer heat and minimize heat pockets in layout.
8. Road and parking pavement widths should be reduced to a minimum to avoid excessive summer heating.
9. Cooling areas should be planned within the design. These areas should be shaded and well ventilated.

2.C. Analysis:

In order to fulfill the requirements of relieving adverse weather impacts, the investigation involved layout organization of several buildings in one type in order to: gain adequate ventilation, reduce solar gain, and reduce air infiltration. The following sketches and discussion evolved:

Reduction of solar gain: Reducing direct solar gain during the summer months involved a study of shadows cast by building and vegetation. After orientation S 5 degrees E, proper linear arrangement of buildings, and reduction of wall areas, some east and west protection from solar gain had evolved. Slope and aspect were accountable in the scheme. Apartments

SOLAR DATA - June 21 - Lat. 33° 16' N.
Building height - 33 Ft.

Sun time	6am	9am	12n.	3pm	6pm
Azimuth	75°	94°	180°	94°	75°
Altitude	11°	48°	77°	48°	11°
Length of Shadow	137'	28'	6'	28'	137'

5pm. Sun
June 21

Apartment
South Slopes

Shadow Analysis —
summer

Directional Percentage of Winter Surface Winds

Maximum distance between homes for adequate protection - 100 ft. recommended

Recommended Maximum Distance - 50 ft.

Planting of conifers & dense shrubs will reduce wind velocity up to 75%

House on West Slope - Berm & Planting incorporated with Open Air Garage for Breeze & protection.

Single Family West Slopes

Wind Shadows Created by Homes from N.W. & W.N.W. Winds. The shadow created is 5 x height of home

Area of protection created by conifer planting - distance at 2 x the height of planting

Plan north
Scale: 1" = 100'

Wind Shadow Analysis

and townhouses were single loaded so that each unit had control of all its accountable space from the north to south wall. Since around 80-90% of solar gain can be reduced by heavy shading species, the remaining exposed walls were buffered by deciduous plant material. The following sketches on apartments and single family dwellings indicate the development requirements for reducing solar gain.

Shelterbelts and minimizing air infiltration: Adequate protection from air infiltration during the heating season will aid in reducing energy consumption significantly. Adequate protection may be achieved in two ways:

1. By arranging buildings to have them protect one another from the predominant winter wind flow, and
2. By the use of berms and coniferous planting belts or by preserving existing vegetation perpendicular to predominant winter wind direction adjacent to the building.

Our studies estimate that approximately 17% to 20% of heat savings can be achieved during the entire year with proper building arrangement and planting belts. (4)

Ventilative cooling: Since humidity for the Shenandoah site is relatively high, summer, fall, and spring breeze access will be important as design criteria. Wind promotes evaporative cooling, lowers air temperature levels caused by direct sun radiation on ground surfaces, and lowers ground temperatures. The main goal here is to capture breezes close to the ground at night and allow free air movement during the day. The study involved an investigation of surficial breeze pattern analysis where breeze may be promoted by layout and planting. Primarily, the building arrangement being a loose open structure allows the most free air movement. Secondly, trees will have a cooling effect on ground surfaces allowing breezes to pass over cooling wells and directly into architectural openings. And thirdly, trees and shrubs will be used to channel breezes towards architectural openings thus increasing their velocity by creating higher pressure areas. These tests may be confirmed by White (White, 1954) who states that when shrubs are moved 5, 10, and 15 feet from the building opening, they cause an eddying motion of air to enter the building creating increased air circulation. According to his test, the points of greatest speed occur under the canopy since air speed is forced. The following

Stagger Units in order.
to promote summer air
flow from S.West direction
Recommended Distances
- shown.

Trees provide Cooling Wells
for breeze

Planting along street
for shade & breeze
channelization

Dense Shrubs - should
not be placed in area between
buildings or along street
in order to assure
maximum ventilation
to buildings.

Summer Ventilation

Recommended
Garage Placement
Reduce high reflective
and heat absorbing
pavement in this
area.

Recommended Outdoor
Living Area.

Single Family
West Slopes

Plan north ↑
Scale 1" = 100'

Ventilation Analysis

Apartment's
South Slopes

ventilation analysis
humid weather

directional percentages of summer surface winds

Apartment
South Slopes

ventilation analysis
summer breeze

	Land Use:	Apartment	Townhouse	Golf Course	Single Family	Store	Church	School	Fire/Police	Maintenance
Land Use:										
Apartment										
Townhouse		●								
Golf Course		●	●							
Single Family		○	◐	●						
Store		●	●	○	●					
Church		◐	◐	◐	◐	◐				
School		●	●	◐	●	●	●			
Fire/Police		○	○	◐	○	◐	◐	○		
Maintenance		○	○	●	○	○	○	◐	◐	

LAND USE COMPATABILITY

Requires:	Land Use:	Apartment	Townhouse	Golf Course	Single Family	Store	Church	School	Fire/Police	Maintenance
Close proximity to service and goods		●	●	◐	◐	●	◐	◐	◐	◐
Open space frontage		●	●	◐	●	◐	◐	●	◐	◐
Street visibility		◐	◐	◐	◐	●	●	●	●	◐
Pedestrian walkways		●	●	●	●	◐	●	●	◐	◐
Direct service delivery access		◐	◐	●	◐	●	●	●	●	●
Visual screen		◐	◐	◐	◐	◐	◐	◐	◐	●
Open space visibility		●	●	●	●	◐	●	●	◐	◐

MATRIX OF USE ASSOCIATIONS

Strong relationship

Neutral relationship

sketches depict proper building placement and indicate where trees and shrubs will help air circulation.

3. Promote the Functional Framework of the Site:

3.A. Requirements:

1. Site types should be sited in order to insure close proximity to shopping, school and recreation.
2. An open space plan or common area network should be incorporated into the plan in order to provide pedestrian access to each site type.
3. Each site type should maximize privacy for the resident holder.
4. Each site type should have adequate outdoor areas.

3.B. Planning Strategy:

1. Provide proper access to each site type.
2. Provide proper service access to each site type.
3. Provide easy open space access on foot or by bicycle.
4. Provide proper outdoor living areas for each site type that gain adequate privacy.

3.C. The matrix above provides a base from which to test land use compatibility, ease in both pedestrian and vehicular circulation, privacy potential, and aesthetic qualities.

4. Promote Additional Climate Modification Practices:

4.A. Requirements:

1. Maximize intensive high density uses in proper site location in order to minimize site and structure modifications for climate control.
2. Improve energy savings through use of architectural extensions, additional planting and earth berming.
3. Improve energy savings by maximizing natural lighting during daytime within each unit.

4.B. Planning Strategy:

1. Land use density concentration on southeast to southwest slopes for maximum sunlight penetration within each unit for natural lighting.
2. Preservation of evergreens on north to northwest side of structure.
3. Use of earth berming for insulation on north to west.
4. Use of adequate fences, trellis extensions, and overhangs in order to relieve summer solar radiation.
5. Selection of proper materials (low heat absorbing materials).

school & soil temperature regimes

microclimate control
next to building
south side elevation

north side elevation

Apartment
South slopes

building/microclimate control

4.C. Analysis:

Since earth berming may reduce heating needs by as much as 75% due to the elimination of heat loss and soil temperature lag, the investigation led to planning partial berming of residential building walls and total berming of the north, south, and eastern exposures of the high school. (5) The sketch above depicts the possible treatments of partial and total earth berming which was planned in the passive plan.

C.2 Short-term construction costs

1. Reduce Pavement Construction

1.A. Requirements:

1. The site types and activity types should be located in order to reduce excessive road lengths.
2. Lower pavement area in order to insure reduction in excess runoff, heating, and non-point pollution.

1.B. Planning Strategy:

1. Reduce road lengths.
2. Reduce road widths.
3. Utilize porous road material, parking areas.

1.C. Analysis:

The analysis of this phase was conducted by the Civil Engineers.

2. Reduce Grading Costs:

2.A. Requirements:

1. Road and parking layout should be patterned by contours of site in order to reduce grading.

2.B. Planning Strategy:

1. Reduce grading costs by proper road and building configuration to contour and slope.

2.C. Analysis:

The analysis promoted building density and placement with the contour of the land allowing natural drainage processes to continue.

3. Reduce New Vegetation Planting:

3.A. Requirements:

1. Insure that proper placement of site types maximizes on existing vegetation - utilization for climate control.

3.B. Planning Strategy:

1. Reduce deciduous plantings on south side of building type by proper placement of intensive uses near existing deciduous trees.

2. Reduce coniferous planting on northwest side of building type by proper placement near existing evergreen trees.

3.C. Analysis:

The investigation insured that no excess grading would occur by proper contour alignment of roads and porous pavement material and that the use of retaining walls may be necessary in some situations.

4. Utilize Natural Drainage Courses:

4.A. Requirements:

1. For surface drainage, maximize existing swales for runoff in order to insure reduction of ditch and subsurface draining construction.

4.B. Planning Strategy:

1. Maximize open space use areas for runoff.
2. Minimize subsurface structures (culverts, pipes).
3. Potentials for runoff irrigation of site type areas.

4.C. Analysis:

The investigation insured the protection and preservation of all natural drainage courses on site.

5. Reduce Utility Structures

5.A. Requirements:

1. Reduce excessive utility structure lengths by proper site type location.

5.B. Planning Strategy:

1. Minimize sewer line extension.
2. Minimize gas lines.
3. Minimize electric line extension.
4. Minimize water line extension.
5. Minimize drainage/sewer lines

4.4.2. Level 2 Conservation Options

4.4.2.1.--Methodology for Selection.

We initially considered an assortment of dispersed energy options for the Level 2 Passive Site Plan. Dispersed energy options are devices that can be incorporated into individual buildings. Thus, options such as district heating were not considered in this phase of the study. Table

TABLE 4.4.2.1

Dispersed Energy Alternatives

A. Passive Solar Devices

Shutters
Direct Gain System
Solar Window Unit
Convective Loop Collector
Attached Solar Greenhouse
Trombe Wall
Solar Chimney

B. Active Solar Devices

Heating and Hot Water - water medium
Heating - air medium
Space Cooling
Solar Supplemented Heat Pump

C. Photovoltaics

D. Solar Heat Engines

E. Wood

Direct Combustion in Residence
Fireplace
Furnace
Stove

4.4.2.1 lists the options examined. A preliminary screening used the following criteria to select specific alternatives for further analysis:

Technical feasibility

Cost Effectiveness

Marketability

In the screening process for the Level 2 Plan, we considered installation of the dispersed options mainly in single family units. The options selected for inclusion in Level 2 were evaluated in other land use settings to determine their total potential for implementation.

4.4.2.2.--Technical Feasibility Criterion.

The devices listed in Table 4.4.2.1 are all basically feasible. The technical criterion questioned how well the device worked and whether it was suited to the climate and community under investigation. Disadvantages that may impinge on the acceptability of different options, such as safety hazards or environmental hazards, were also identified.

4.4.2.3.--Cost Effectiveness Criterion.

The economic analysis played a critical role in selecting dispersed energy options for the Level 2 Plan. A discounted cash flow identifies the annual costs of two options and compares them by computing the net present value. Typically, one option is labelled conventional or status quo, and the other is called the alternative. Our conventional energy option in this analysis was a 1,600 square foot house built using revised construction and located in the Passive Site Plan. The house consumes 41.2 million Btu's of natural gas annually for space heating, 38.4 million Btu's of natural gas for hot water heating, and 4.3 thousand kilowatt hours of electricity for cooling. (6) Natural gas will cost \$3.22 per million Btu's in 1981, the first year of operation. Costs will increase at an 11% annual rate in subsequent years. Electricity will cost 4.78 cents per kilowatt hour in 1981 and will increase at an 8% annual rate thereafter. Thus, the total heating and cooling costs in 1981 will be \$482.

The discounted cash flow analysis first assumes that the initial costs of the dispersed options received financing at a 10% annual rate compounded monthly over the next 25 years. At this rate, annual payments would be 11% of initial costs. We assumed that maintenance costs would increase at the rate of inflation, about 6% annually. Systems eligible for the federal solar tax credit would receive a 30% rebate for costs less than \$2,000, and 20% for costs greater than \$2,000, up to \$10,000. The annual costs of the dispersed options were compared with fuel savings to obtain annual net benefits. Using discounting procedures, we brought all net benefits back to 1981 terms and added them to obtain the net present value. If the net present value was greater than zero, the system would be economically viable; if not, the system would operate at an economic loss to the consumer.

4.4.2.4.--Marketability Criterion.

The marketability criterion should determine which systems produced potentially uncomfortable living environments (e.g. wide temperature fluctuations with some passive solar equipment) or were otherwise unappealing.

Several groups participated in the screening process. The study team evaluated information on technical feasibility and cost effectiveness. The marketing and financial advisory committee members gave their views on the marketability of the various alternatives. The options that were selected for further evaluation are as follows:

- Insulated Window Shutters
- Direct Gain Passive Heating
- Trombe Walls
- Attached Solar Greenhouses
- Active Solar Water Heating

The discussion that follows will evaluate each option in Table 4.4.2.1 separately and describe why it was or was not selected.

FIGURE 4.4.2.1
Direct Gain System

4.4.2.5--Passive Solar Devices

The general category of passive solar devices includes a variety of options for using the house itself to collect and store the sun's energy. The options listed in Table 4.4.2.1 are quite different in design, but all basically work on the principles of convective heat flow, radiant heat transfer, and heat storage in materials. Shutters are an exception, since they are additional insulation for the structure. Insulating shutters will decrease the U-value of double-glazed windows from 0.64 to 0.0975. Depending on how often residents use shutters on winter nights, fuel savings ranging from 24,000 Btu's to 42,000 Btu's can be realized for every square foot of shutter area. The present worth of fuel savings per square foot ranges from \$2.00 to \$3.40. According to FABRAP architects, shutters cost about \$6 per square foot. At this price, shutters do not meet the economic criterion.

Shutters may be more economical in passive houses built with standard construction. The U-value of the single-glazed windows will decrease from 1.1 to 0.1 when the shutters are in place. The present worth of fuel savings will range from \$3.67 to \$6.28 per square foot. Thus, shutters may be cost effective in houses built with single glazed windows.

The simplest passive concept is direct gain. The basic components of a direct gain system are glazing and a mass capable of storing thermal energy. The most frequently used storage materials are cement, sand, rock, and water. A common design for a direct gain system, the solarium window, is shown in Figure 4.4.2.1.

Douglas Balcomb estimated the performance of direct gain systems in a workbook for a series of recent workshops, (Balcomb, 1979). In the article, Balcomb claimed that direct gain systems operate at approximately the same efficiency as water wall systems. He described an evaluation technique for determining the amount of heating fuel that can be replaced by passive systems. Table 4.4.2.2 details the computation of fuel displaced by a 240 square foot direct gain system. The heating fuel load decreases about 25%. If nighttime shutters are installed, the heating load can be reduced 30%. A direct gain system that occupies the entire southern wall could displace up to 72% of the heating fuel consumed originally.

The economic analysis hinges on the cost of the direct gain components--glazing and thermal mass. If extra glazing is installed, the net cost of the wall surface is actually reduced by \$0.50 per square foot. Although additional glazing for a direct gain system may decrease a building's heating requirements, it may increase annual cooling requirements significantly. The passive system must be carefully designed to avoid significant additions to cooling load. To minimize cooling, overhangs costing \$18 per linear foot should be installed over any additional glazing.

The thermal mass for the direct gain system is installed in the floor. The cost differential between a conventional floor and a floor with thermal mass is about \$3 per square foot. We assumed that the mass would occupy about three-fourths as much floor area as window area. Thus, the 1,600 square foot house would have 180 square feet of thermal storage flooring.

The additional costs for glazing in the direct gain system would be relatively minor. The original house contained 192 square feet of windows, all 6-feet high with overhangs. The additional 48 square feet would save \$24 in glazing costs, but require \$144 worth of overhangs. The thermal mass would cost \$544. Thus, the total cost of the direct gain system would be about \$664.

The benefits of the direct gain system are annual fuel savings. The 1,600 square foot house consumed 41.2 million Btu's annually for space heating. According to Balcomb's procedure, the direct gain system saved 25% of space heating fuel consumption, or 10.2 million Btu's each year. The fuel cost savings would be \$35 in 1981, \$90 in 1990, and \$255 in 2000. In this cursory analysis, we have no estimated additional cooling costs. If direct gain systems appear attractive, we will evaluate the energy tradeoffs in greater detail in the final analysis. Discounting the stream of steadily increasing costs to 1980, we calculated the present worth of fuel savings as \$821. The savings are higher than the projected costs; thus, the economic criterion has been satisfied.

TABLE 4.4.2.2
Heating with Direct Gain System

Month during year	(1) Heating load estimate (MM Btu's) ¹	(2) Solar radiation absorbed (M Btu/ft ²)	(3) Solar radiation (MM Btu)	(4) Solar load ratio (3)÷(1)	(5) Solar heating fraction ²	(6) Remaining heating load (MM Btu's) ³
Oct	3.36	23.3	5.6	1.67	1.00	0.00
Nov	6.03	24.8	5.9	.85	.59	2.49
Dec	10.37	23.7	5.7	.55	.33	6.95
Jan	0.95	24.3	5.8	.65	.39	5.47
Feb	7.57	22.2	5.3	.70	.42	4.39
Mar	7.21	21.3	5.1	.71	.42	4.15
Apr	3.87	17.6	4.2	1.08	.65	1.35
					TOTAL	24.80

New natural gas heating consumption (MM Btu's) ⁴	31.0
Former natural gas heating consumption (MM Btu's)	41.2
Percentage of heating supplied by direct gain system	25%

¹With no solar gain

²We assumed that the fraction of heating supplied by solar is approximately 60% of the solar load ratio . (7)

³The remaining heating load is computed as: (1) X [1-(5)]

⁴Computed as the total remaining heating load divided by natural gas heating efficiency (.8)

FIGURE 4.4.2.2
Passive Window Unit

A number of passive solar devices, including solar window units, solar collectors on earth berms, and Trombe walls function on the convective loop basis. Figure 4.4.2.2 shows how convective flow works in solar window units. Cooler air is drawn through floor vents into the solar window units. As the air is heated by the sun's radiation, it rises and re-enters the living space through the top vents. This air flow is created naturally without aid of mechanical devices; thus, the process is passive in nature.

The unit shown in Figure 4.4.2.2, conceptually designed by Walter Kroner and David Haviland of Rensselaer Polytechnic Institute in Troy, New York, contains 58 square feet of collector area and would provide 7.8 million Btu's to a room of a house located in New York State. Assuming the same unit would supply approximately 8 million Btu's in Georgia, the annual energy cost savings in a natural gas-heated home would be \$25 in 1981. Over a 25-year time horizon, the discounted present worth of the energy cost savings would be \$644. If the maintenance costs of the conventional heating system are reduced by an amount approximately equal to the maintenance costs of the window unit, the present worth of breakeven cost of the unit would be \$644 or \$11 per square foot. It is quite conceivable that these devices could fall into this price range.

The convective loop collector works on the same principle as the solar window unit, but is larger in scale. As shown in Figure 4.4.2.3, the collector forms the bottom of the exterior wall of a house. The diagram combines the collector with an earth berm. One major advantage of this design is that storage has been included. A south wall 30 feet long may contain 210 square feet of collector surface. The collector could replace about 24 million Btu's of natural gas each year. The savings in fuel costs have a present worth of about \$1,932. Cost estimates for materials to build the collectors are as follows:

Glazing	420 square feet at \$1.61/sf	= \$676
Ducts	120 lineal feet at \$1.50/lf	= \$180
Framing	390 feet at \$0.45/foot	= \$175
Rock	10 cubic yards at \$5.95/yd	= \$59
	TOTAL COST	\$1,090

Additional installation and material costs would probably not exceed \$842;

FIGURE 4.4.2.3

Convective Loop Heating Device

thus, the system is well in the range of cost competitiveness.

The Trombe-wall, designed by Frenchman Felix Trombe, contains the features of most effective passive designs. As Figure 4.4.2.4 shows, the design features glazing through which the sun's rays travel and strike a large thermal mass, usually a thick concrete wall or water-filled barrels. In the colder months, air in the space between glazing and mass is heated during the day. As it warms, the air rises through the top vent and flows into the living quarters. Cooler air that is near the floor of the living quarters is pulled into the air space to be heated. Throughout the day, this convective process continues. At night, the mass, which has stored a significant amount of thermal energy, releases heat into the living quarters via radiation.

In the warmer months, the Trombe-wall system can theoretically cool a building. The wall can pull cooler air from the shaded area just north of the building into the living quarters and exhaust it to the exterior by opening and closing certain vents. The consequent breeze acts much like an attic fan to cool the occupants of the structure. Unfortunately, the wall itself tends to overheat and may add too much thermal energy to the structure. In such cases, shutters may have to be placed over the Trombe-wall glazing in the summer.

The technical feasibility of Trombe walls has been established. A number of buildings with such systems have been built. Some buildings with Trombe systems have utilized only 10% to 20% of a conventional building's heating fuel. The economic efficiency of Trombe walls is difficult to determine because of the uncertainty associated with cost estimates received. The owners of a house in Maryland with a Trombe system estimated its cost as \$2,500 more than a similar conventionally heated home, while the Kelbaugh house in New Jersey cost an estimated additional \$8,000. The extra costs for a passive 2,500 square foot home near Fayetteville, Georgia were in the range of \$3,000 - \$4,000. Ric Sibly, an Atlanta architect who designs and constructs passive solar buildings, estimates that the thermal mass for a Trombe wall system costs about \$6 per square foot. The cost of exterior glazing is more than balanced by the cost of a framed wall

that is no longer needed; thus, the additional cost is near \$6 per square foot. We estimate the costs for a 280 square foot Trombe wall system to be \$1,680. According to an analysis similar to that used for direct gain systems, the Trombe wall can supply 23% of the heating load, or 7.5 million Btu's each year. (8) The present worth of the energy savings will be \$756. The cursory analysis shows Trombe walls not be cost competitive. However, Sibly projects that prefab Trombe walls can be built for \$2 per square foot. If so, the economics would be very favorable.

Another passive design is the solar chimney. This device, contrary to its name, does not require combustion to function. Solar chimneys are cooling devices that work by creating an air flow within the living quarters. Their cooling process is similar in concept to the Trombe wall. The chimney itself is a structure insulated from the rest of the house that operates much like a convective loop device. They are usually located in attics and have glazing on the southern roof exposure. Air heats up as it moves through the chimney and is exhausted through an external vent. Cooler outside air from the north side of the house replaces the air exhausted through the chimney. The circulation provided cools the living quarters much as an attic fan. At the moment, few cost estimates for solar chimneys are available. Estimates of the amount of cooling they would provide are difficult to determine. One major problem with using solar chimneys in conventionally cooled homes is that they are not compatible with central air conditioning.

The marketing committee addressed the potential consumer acceptance of the different passive convective loop systems described above. The committee members discussed the relative youth of many passive designs, as well as the lack of experience these devices have in the marketplace. The aesthetics of passive heated buildings was also a major concern. On the basis of these constraints, the committee felt it would be very risky to utilize most of the convective loop systems in the Shenandoah community under investigation. However, because of the potential payoffs and relatively unnoticeable appearance of Trombe walls, we selected them for further study.

Trombe Wall

The attached solar greenhouse is another device that depends on the convective heat flow. By solar greenhouse, we mean a structure that is independent, but connected to a house and that serves both as a collector of thermal energy from the sun and as a location for growing plants all year. A solar greenhouse depicted in Figure 4.4.2.5, contains water or sand-filled containers for storage. Reports of greenhouse performance in Georgia have been very good. For example, a greenhouse in Moultrie kept the home to which it was attached above 55 degrees F during nights with temperatures below 20 degrees F.

Three problems may limit the effectiveness of solar greenhouses. The humidity of the greenhouse may transfer to the living quarters, causing both comfort and health problems. If designed or maintained improperly, the greenhouse may require more heat from the house's back-up system than it actually supplies to the house. In such instances, however, the greenhouse does have value as a space for growing food in the winter. In the summer, the greenhouse can become very hot, so it must be adequately ventilated to prevent heating of the living quarters and overheating of the plants.

Attached greenhouses can provide heat, food, and a nice aesthetic appearance. The amount of space heating supplied depends on the design of both the greenhouse and the living quarters. Data on the performance of greenhouses is very sketchy. If the structure has 210 square feet of glazed surface, it will provide from 5 to 10 million Btu's to the living quarters. The present worth of the energy savings ranges from \$402 to \$805. Owner-built attached greenhouse costs about \$2.50 per square foot, according to the Solar Greenhouse Book. Commercially built greenhouses would probably cost at least \$5 per square foot. If the greenhouse in our example has a floor area of 162 square feet, it would cost \$810, which may be cost competitive for energy purposes alone if performance and design were nearly optimal. Quantifying the additional benefits of food production and aesthetics is difficult due to the uncertainties involved. However, we can accept that attached greenhouses may well meet the economic criterion.

FIGURE 4.4.2.5
Attached Greenhouse

The marketing committee did not specifically address greenhouses or direct gain systems. However, Ray Moore of Shenandoah believed that they would be acceptable. On the basis of their economic payoffs and attractive appearances, we selected both options for inclusion in the final analysis of the Level 2 plan.

4.4.2.6--Active Solar Devices

When many people think of solar energy, they think of active solar systems. Active systems use collectors through which fluid or air is pumped to capture heat from solar radiation. The fluid gains heat which it transfers to a storage medium. When thermal energy is needed for heating, heat is transported from the storage system and distributed in the house. A diagram for an active solar heating, cooling, and hot water system is shown in Figure 4.4.2.6.

Active solar systems have been technically feasible for several years. Some problems, most of which have been solved, have occurred. A major need in water collectors is for freeze protection. Some designs use "drain down" systems. When temperatures in the collector of these systems approach the freezing point, valves automatically open and expel the fluid. In some drain down systems, the same water that travels through the collectors is piped to the hot water heater. A heat exchanger is not required in the storage tank. Therefore, the system has a lower cost. Experience to date has shown drain down systems to be unreliable; that is, some water remains in the collectors. The alternative is to put anti-freeze in the water that travels through the collectors. In such cases, a heat exchanger is needed to separate the water with anti-freeze from water used by the household. A safety hazard evident in this approach is the possible contamination of the household water supply with anti-freeze that could leak in the heat exchanger. Leaks in general pose problems in buildings heated with active systems. They can be prevented if solar equipment of good quality is installed properly. Costs of water collectors range from \$40 to \$145 per square meter (\$3.70 to \$13.30 per square foot).

FIGURE 4.4.2.6: Residential Heating and Cooling with Solar Energy

Source: AEC, 1974: A.5-17.

TABLE 4.4.2.3
Economics of Solar Hot Water Heating

<u>Costs</u> (50 ft ² system)	Annual (1981)	Present Worth
Capital Cost		\$1,362
Maintenance Cost	\$27	426
<u>Electricity Cost</u>	\$26	<u>517</u>
	Sub Total	\$2,304
<u>Savings</u>		
Tax Credit		319
<u>Fuel Savings (60%)</u>	\$74	<u>1855</u>
	Sub Total	\$2,174
<u>Net Present Value</u>		\$ -131

TABLE 4.4.2.4

Economics of Solar Space and Water Heating

<u>Costs</u> (352 ft ² system)	Annual (1981)	Present Worth
Capital Cost		\$ 8,783
Maintenance Cost	\$176	2,811
<u>Electricity Cost</u>	52	<u>1,027</u>
	Sub Total	\$ 12,620
<u>Savings</u>		
Tax Credit		\$ 1,779
<u>Fuel Savings (83%)</u>	\$213	<u>5,318</u>
	Sub Total	7,097
<u>Net Present Value</u>		\$ -5,522

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We selected the active solar system for the passively sited 1,600 square foot house by using the F-chart method summarized in The Solar Decision Book. The F-chart method uses local climatic characteristics and the heating load of the building to determine how much of the heating load can be met by collectors of different sizes. The heat load for the house was 480 Btu/hour/degrees F. Using F-chart, we found that 352 square feet of collector could provide 83% of the space heating and water heating load. A solar hot water system having 50 square feet of area would provide 60% of the water heating load. Total system costs for a 350 square foot heating and hot water system in a 1,600 square foot home having revised construction would average about \$9,000. In many cases, the collectors themselves can become the roof. The Office of Technology Assessment estimates that by eliminating all but the structural components, \$8.53 per square meter (\$0.79 per square foot) could be saved. The heating and hot water systems would cost about \$8,783. Estimates for installing an active solar water heating system for a family of four ranged from \$1,000 to \$2,500. One relatively large distributor of solar equipment said that if 100 housing units were being outfitted with solar hot water, the cost would be \$1,400 per unit. With savings due to elimination of some roof components, the cost would be \$1,362.

Additional costs of a solar space heating system are maintenance costs, estimated to be 2% of the initial cost of the system and electricity costs for operating the pumps that circulate water through the collectors. Table 4.4.2.3 shows the economic analysis of a solar water heating system installed on a 1,600 square foot house. Given the assumptions in the analysis, the system almost breaks even at a 10% rate of interest. If the proposed solar bank bill passes, lower interest loans will be available. If the loan was at a 7% rate, the net present value would be \$221, which represents a net benefit to the consumer. Thus, active hot water systems meet the economic criterion if low interest loans are available. Solar space heating has a difficult time competing with natural gas. As shown in Table 4.4.2.4, the net present value of solar space heating is negative. Even with a 7% loan interest rate, the systems would not be competitive.

Another type of solar collector is the trickle collector, popularized by Dr. Harry Thomason. Thomason's device has been the subject of controversy for many years. Recent tests conducted in a 2,990 square foot home near Washington, D. C. showed that the Solaris system could provide 59% to 72% of a home's heating demands. The solar heating system uses 960 square feet of collectors. Water is pumped to the top of the collector panels and flows down inside the collectors, absorbing solar radiation as heat. The heated water is piped to a 1,600 gallon storage tank mounted inside a rock bed. Air blown through the rocks absorbs heat and enters the living quarters.

The Solaris unit also provides hot water. Functioning as a preheater, the unit provided 31 to 38% of the home's hot water needs during the unseasonably cold winter of 1977. In our analysis, we assumed that the solar heating system can provide 50% of the home's hot water needs.

The trickle collector also provides cooling in the summer. Since no quantitative measures of its cooling performance were available, we chose not to include cooling savings in the economic analysis.

Thomason estimated that the installed cost of the Solaris unit was \$4,968. The collector costs were based on 1974 wholesale prices, and labor was valued at \$6 per hour. Assuming collectors were at an advancing stage of development from 1974 until 1977, we inflated the costs at only 3% annually. After 1977, we assumed that collector costs rose at the rate of inflation. Because the 1974 costs were based on wholesale prices and on labor priced without regard for overhead and profit, we increased the original cost estimates by 50%. We estimated that the costs in 1981 for a Solaris unit installed commercially in a 2,990 square foot home would be \$10,280. The costs for a 1,600 square foot home, assuming a 0.75 economy of scale factor, would be \$6,430. The system size could be decreased 10% further because we are using revised construction. The installation costs were thus \$6,110. The present worth of operating and maintenance costs were \$2,164.

The annual fuel savings contributed by the Solaris system are 56 million Btu's for space and hot water heating. The fuel savings had a present worth of \$4,500. The federal tax credit added another \$1,293 to the benefits. The net present value is \$-2,481; thus, the Solaris system is still not competitive with natural gas in the passive home with revised construction. A low interest loan would not enable the system to meet the economic criterion.

In the passive home with standard construction, the 352 square foot Solaris collector could provide about 75% of the space heating and hot water load. The present worth of the fuel savings would be \$4,806; however, the net present value is still negative. On the basis of these results, we conclude that active space heating systems cannot compete very well with natural gas systems.

Active solar systems can also be used to cool a building. Solar absorption cooling has the highest near-term potential. Absorption cooling uses water heated by either a conventional boiler or a solar collector. In the refrigeration cycle, a chilled liquid (usually water) is permitted to expand in the evaporator. When the water expands, its temperature decreases. Air flowing through the evaporator is cooled and reenters the building. The resulting water vapor is then recompressed, and the heat that has been transferred to the water is rejected to the atmosphere. The recompression is achieved by absorbing the low-pressure water vapor in a concentrated salt solution. The solution is derived from a distillation unit heated by solar energy.

Solar absorption units are inherently more expensive than electric cooling systems because of the larger number of heat exchangers required and because of the investment in solar collectors and in back-up, conventionally-fueled boiler capacity. Solar absorption cooling is currently recognized as economically unviable. However, the Office of Technology Assessment projects that by 1985, this technology will be competitive with electric heat pumps and with natural gas absorption cooling if natural gas prices escalate rapidly (5.5% annual rate more than the rate of general inflation). Because of its economic drawbacks, solar

absorption cooling was not considered further in this study.

4.4.2.7--Photovoltaics.

Photovoltaic power cells have high potential for use in dispersed electrical systems. Photovoltaic cells use the nature of semiconductor materials to create a flow of electrical current. Three major barriers currently exist.

The cost of photovoltaic cells is quite high. Current prices range from around \$5 to \$10 per peak watt. A peak watt refers to optimal operating conditions, that is, with the sun at the zenith on a clear day. Photovoltaic cells in the \$10 per peak watt range can be installed to generate electricity at a cost of about \$1.50 per kilowatt hour, or about 40 times current electricity prices. The Department of Energy has a goal of \$1 or \$2 per peak watt in 1982, a goal which is deemed feasible by the Office of Technology Assessment. At these prices for cells, stated in 1965 dollars, electricity generated will cost \$.10 to \$.40 per kilowatt hour, as compared to conventional electricity costs in the range of \$0.04 to \$0.06 per kilowatt hour. The Department of Energy goals are for photovoltaic cells to reach cost competitiveness by 1990.

Adequate storage systems for photovoltaics still have not been developed. The most viable option in dispersed systems is the conventional lead acid battery. The major problem with conventional batteries is their relatively low storage capacity per unit weight. Commercial batteries weigh about 100 pounds per kilowatt hour stored. To obtain 40 kilowatt hours of storage, which is sufficient for a typical summer night, 2 tons of batteries would be needed. Advanced battery designs, such as zinc chloride and REDOX batteries, are currently in the research and development phase.

Photovoltaic systems can avoid the necessity for battery storage by using a back-up power source of some kind. The most convenient approach is to connect the building to the regular electric utility grid. However, widespread implementation of photovoltaic systems that utilize the grid for auxiliary power will create relatively complex interface problems. Some

FIGURE 4.4.2.7: Ideal Stirling and Ericsson Cycles

STAGES OF THE IDEAL STIRLING AND ERICSSON CYCLES

MOVING FROM STAGE 1 TO STAGE 2

- compression at constant low temperature raises the pressure
- energy is rejected into the cold heat exchange surfaces
- work is done on the system through the compressor piston

MOVING FROM STAGE 2 TO STAGE 3

- working fluid is forced through the regenerator and is heated as it absorbs heat from the regenerator
- no work is done on the system and no heat enters or leaves the working fluid except through the regenerator
- the process takes place at constant volume with increasing pressure in the Stirling cycle (as shown in the figure) and at constant pressure with increasing volume in the Ericsson cycle

MOVING FROM STAGE 3 TO STAGE 4

- the working fluid is allowed to expand at a constant temperature and the pressure decreases
- energy is absorbed from the hot heat exchange surfaces
- work is performed on the working piston

MOVING FROM STAGE 4 TO STAGE 1

- working fluid is forced back through the regenerator and is cooled as it gives up heat to the regenerator
- no work is done on the system and no heat enters or leaves the working fluid except through the regenerator
- the process takes place in constant volume with decreasing pressure in the Stirling cycle (as shown in the figure) and at constant pressure with decreasing volume in the Ericsson cycle

In actual engines, these stages will not be distinct.

utilities may want to charge a higher rate for solar customers. Solar customers, on the other hand, may wish to sell power generated by their photovoltaic systems back to the utilities.

Photovoltaic systems were not considered as a viable near-term alternative. Therefore, they were not selected as an option for a distributed energy system in Shenandoah. The outlook for photovoltaics, however, seems very promising.

4.4.2.8--Solar Heat Engines

Researchers are investigating a number of alternative designs for solar heat engines that can generate electricity, and in many cases, provide thermal energy as well. Alternatives that appear to be most feasible on a dispersed scale are the Stirling and Ericsson cycles. These cycles both are externally fired and use two pistons in a single cylinder. The stages of the cycles are shown in Figure 4.4.2.7. According to the Office of Technology Assessment, both cycles should be capable of long lifetimes and of quiet, reliable operation. They supply a low rate of revolution, and therefore, do not require expensive gear reduction systems. The heat rejected from the cycles is in the form of a heated liquid; thus, a heat-recovery boiler is not needed. Stirling and Ericsson cycles are applicable in dispersed settings since efficiency is not sacrificed in decreasing the scale of the units to a few kilowatts. A number of design problems still exist before electricity generation using these cycles becomes commercially feasible. The Office of Technology Assessment reports cost estimates for Stirling engines of about \$100 per peak kilowatt. The solar receiver system capable of supplying a 15 kilowatt Stirling engine would have to provide about 36 kilowatts of thermal energy (Stirling engines have an efficiency of about 42%). A receiver capable of supplying the Stirling engine may cost from \$650 to \$1,500 per kilowatt. Thus, at cost projections ranging from \$750 to \$1,600 per kilowatt, Stirling heat engines are not quite competitive with the 1986 goal for photovoltaic systems (\$500/kilowatt). However, the small scale heat engines do appear to have promise for the future, but they will not be competitive at the time the Shenandoah Community is under construction.

4.4.2.9--Wood.

Several alternatives for utilizing biomass in distributed building energy systems exist. Biomass systems use agricultural wastes, forestry residues and products, or municipal solid waste to produce a useable fuel. All of these sources except wood require conversion to another form, such as a gas or pyrolytic fuel to be useful. One possible conversion alternative for a dispersed energy system is a small scale gasifier, which converts organic matter into a low or medium Btu gas. However, little data are available on the costs of performance of such systems. At the moment, they are in the early commercialization stage. Gasifiers were not considered appropriate as dispersed options for the type of development under investigation.

Direct combustion of wood in fireplaces or wood stoves is a well-developed process. Most conventional fireplaces have a low efficiency of about 10%. New outside air-supplied fireplaces are about twice as efficient. The efficiency of wood stoves ranges from 30-55%, and multi-fuel furnaces can achieve better than 65% efficiency. The following problems are inherent in wood energy systems:

1. The cost of firewood from commercial wood lots is very high (\$2.32-7.00/million Btu).
2. Individual wood harvesting may rapidly deplete surrounding woodlands; for example, at least 30 acres of woodlands would be consumed for one year's worth of heating in the 99 single family homes in the community.
3. Insurance rates may be higher for buildings with wood heat than those with conventional heating.
4. Air pollution, especially from particulates, could be a major problem in a relatively dense community that relied on wood combustion.

On the basis of the above problems, dependence on wood energy as a primary distributed heating mode in dispersed systems does not appear attractive. However, wood may be an excellent auxiliary heating source to back-up other alternatives such as active or passive solar energy systems.

TABLE 4.4.2.5

Summary of Evaluation of Dispersed Energy Options

	Criteria			
	Technical	Economic	Marketing	Potential Fuel Savings(if selec
PASSIVE SOLAR SYSTEMS: Shutters	No Problems	Potentially economic in houses built with standard construction	Require resident to put into place	Up to 25% space heating needs
Direct Gain System	May increase cooling load	Economical only with increased southern window exposure	Aesthetically pleasing but glare and fading problems may occur	About 25% of space heating needs
Convective Window Loop	Few proven units are in existence	Economically feasible	Unconventional appearance, not yet proven commercially in the marketplace	Not selected
Attached Solar Greenhouse	Possible problems of humidity and overheating in the summer	Look very feasible especially with added benefits of food production	Aesthetically pleasing. Requires some effort on the part of the resident	Varies, a greenhouse along the southern exposure of a house will provide up to of the home's heating needs.
Trombe Wall	Possible problem of overheating in the summer	Negative net present value, but estimates had high uncertainty	Peculiar appearance cited; requires effort by resident	Not selected
Solar Chimney	Appears feasible, but little data on performance	Too little data to evaluate	Is not compatible with central air conditioning	Not selected

TABLE 4.4.2.5 (Cont'd)

	Criteria			
	Technical	Economic	Marketing	Potential Fuel Savings
ACTIVE SOLAR DEVICES: Solar Space Heating, Water Fluid Enclosed in Pipes	Potential leak and freezing problems are not very likely with proper design	Negative net present value	--	Not selected
Solar Space Heating, Trickle Collectors	Recently studied, no major technical problems	Net present value was negative	Questionable aesthe- tics. Recent deve- lopment of North Atlanta "Solar Suburb" will help. Liked by marketing committee	Not selected
Solar Water Heating, Water Medium	Leak, freezing and contamination prob- lems are now minor	Positive net present value with low interest loan	Questionable aesthe- tics. Most popular active solar approach	60% of hot water fuel needs
Solar Supplemented Heat Pump	Potential leak and freezing problems are not very likely with proper design	Negative net present value	Still early in commercialization	Not selected
PHOTOVOLTAICS	Possible cooling problems if con- centrated. Mass production tech- niques need deve- lopment; storage systems need re- search	Not yet cost competi- tive	--	Not selected
SOLAR HEAT ENGINES	Still need research	--	--	Not selected
WOOD	Problems of fire & creosote build-up if not properly op- erated & maintained	Competitive only if wood is scavenged or supplied through community wood supplier	Pollution, defores- tation and safety problems	Not selected

4.4.2.10--Summary

Table 4.4.2.5 summarizes the evaluation of dispersed energy options. Those systems that were selected have the potential energy savings indicated in the right-hand column. In the next chapter, we will analyze application of selected systems throughout the community.

4.4.3 -- Central Utility Plan (Level 3) Analysis

4.4.3.1 -- Introduction

The availability of conventional grid supplied energy sources such as electricity and natural gas most often preclude the consideration of complex central energy plants by the community developer. Even when energy supplies must be obtained from private oil and L.P. gas companies, there has been little incentive for private developers to undertake long range planning and construction of an on-site centralized energy supply system.

Factors influencing the developers' decisions not to pursue central energy schemes include: (1) industry precedents which give responsibility for energy supplies to electric utility companies and gas and oil suppliers. (2) insufficient technical competence in the area of energy supply and utilization (3) lack of market expectation and financial incentives make it unattractive for the developer to generally consider the planning and construction of a central energy plant.

Today's uncertainty of energy availability and costs are rapidly changing thoughts in all sectors of our economy. New home buyers are looking more at utility costs for their prospective home and are willing to pay more for energy conserving features. Developers too, are evaluating higher initial cost items which will result in life cycle savings.

Although not proven yet, inflation and high mortgage interest rates may further change consumers' home buying habits by lengthening the time prospective buyers view their stay in a house. Such a trend would further strengthen consumer interest in the energy conserving house.

From the standpoint of the project developer engaged in satisfying market demands with a product and a shareholder's expectations of his

return on investment, new and bold concepts are being undertaken. Like the developer, private utilities are also seeking unique and innovative solutions to help meet future energy needs.

The small scale central plant concept is a venture that may possibly unite the interests of consumer and utility in providing dependable and stably priced energy supplies in the future. The developer is a key ingredient in meshing these two interests in the community planning and early construction stages. Appropriate initiative taken by the developer in early stages of planning and construction may pave the way for implementation of on-site community electric power generation and thermal energy conversion which will stabilize energy costs and make more efficient use of energy resources.

4.4.3.2 -- Development of the Central Plant Plan

From the standpoint of integrating community energy use, the central utility scheme seems to offer a number of unique advantages: First, the complex energy conversion equipment involved in heat recovery and efficient energy use are more easily dealt with by the trained operating personnel found at central plant facilities. Second, economies of scale available in large installations favor a central utility plant. Third, the use of fuels such as coal, heavy oil and wood are usually prohibited at the individual's level due to handling, storage and pollution abatement considerations. These problems could be dealt with more easily in a central plant configuration.

Several arguments are commonly pursued when justifying the decision to build a central plant facility. It is instructive to review the most common of these as they apply to the Shenandoah Development, since some of these common arguments do not apply to this case.

1. Increased efficiency is commonly cited as a reason for building central energy sources. Unfortunately, it is not always true that the use of a central plant proves to be more efficient on a community scale.

Individual components such as boilers and refrigeration equipment installed at the central plant are almost always more efficient than incremental machines installed in individual buildings;

however, parasitic components of the plant such as pumps, fans, and thermal distribution system losses etc., can severely penalize overall performance. A way of countering these losses is proper design and, of course, a method of increasing overall efficiency such as cogeneration.

2. Lower cost is another commonly quoted reason for central plant installation. Generally, this argument is true when considering dense groupings of commercial or institutional buildings. Residential structures, on the other hand, tend to be more sparse and typically use very inexpensive natural gas heating systems when built conventionally. New piping materials and community planning utilizing common infrastructure trenches can help overcome the cost of residential central plant installations.
3. Use of lower cost fuel is a generally valid argument for central plant construction. Larger, more sophisticated equipment can typically utilize lower cost fuels such as coal, heavy oil, wood or refuse. These systems, due to their size and design, are suited for this type of use where individual buildings are not.
4. Building space savings can also be attributed to a central plant scheme since the majority of heating and cooling equipment is remotely located. This advantage is important to commercial and institutional building designers, but is rarely considered in residential situations.
5. Reduced maintenance costs are also considered when evaluating central plant options. The reduced overall maintenance for heating and cooling systems generally accrues to the individual buildings served by a central plant since individual heating and refrigeration equipment is removed. This savings can prove to be significant for large commercial and institutional buildings.
6. Decreased adverse environmental impacts are usually attributed to central plant schemes since it is felt pollution problems can be dealt with more effectively at a central plant. This argument is certainly true if one assumes the individual buildings served by the central plant to be burning oil or coal; however, the argument may be discounted in the case of residential communities where heating fuel use may be shifted from clean burning natural gas to coal or oil. On the other hand, some small scale central plants may be able to use non-polluting fuels which lessen the burning of polluting fuels such as high sulfur coal at central electric generating stations.

In the case of the Shenandoah development it was felt that a central plant could conserve energy through the more efficient use of primary fuels, stabilize energy costs and accrue savings to the residents of the community in the areas of capital outlay cost, maintenance and operating costs. To do this, the plan had to be feasible within the constraints of financing, current technology, phased construction and marketability to the end-user.

4.4.3.3 -- Alternatives Considered

Two levels of central utility plant schemes were considered. The first level considered the total 7400 acre Shenandoah development as being

the ultimate build out and service area of the central utility plant. It was anticipated that a central power plant in the capacity range of 30 to 60 megawatts could be constructed on a site adjacent to the Shenandoah Industrial park. The design of the plant would include provision for district heating, cooling and process steam for industrial customers. Electricity from the plant would be cogenerated with the steam and thermal energy uses and tied into the Georgia Power Company electrical distribution grid in a TIES mode of operation. This option was eventually abandoned due to site specific technical considerations and the long build out period of the Shenandoah Development.

A second plan was to consider a small central utility plant located within our 235 acre site which was phased to serve our site and possible adjacent sites. The small site central utility plant would be designed to provide thermal energy for heating and cooling and electric energy which could be sold into the electric utility company's power grid.

In both cases several alternative central utility plant schemes were considered, taking into account their relative cost, advantages and disadvantages. In all cases it was apparent that the heavy front-end costs associated with central utility plant schemes appeared prohibitive from the developer's standpoint. This is especially true since competing energy sources in this area are relatively inexpensive. It was evident that the decision to build a central utility scheme must be based primarily on long term commitments to stabilize energy costs and avoid fuel shortages.

1. Site Arrangement

To decrease the cost of thermal energy distribution it is desirable to densify and cluster energy users as close as possible to the central utility plant. Additionally, it was felt that passive design and proper site orientation of the buildings within our development should be accomplished first, before any innovative energy supply schemes were explored. For these reasons, the central utility site plan was developed by modifying our proposed passive site plan.

Several factors significantly hampered the densification of thermal energy users toward a central location. First, the restriction that building could not be undertaken within the 100 year flood plain caused the parcel to be divided into two building zones on opposite ends of the site. Secondly, the hilly topography coupled with the developer's desire to minimize disturbance of the site by excessive grading precluded laying out the site in any type of concentric circular patterns or perpendicular grid systems. Third, marketing constraints also dictated that the school, church, and convenience food shop locations be placed at the north end of the site adjacent to the main road. Projected market analysis also indicated minimum lot sizes for single family dwellings and the maximum number of apartment units that would be required for this area. Other factors affecting site densification were the desire to accomodate a specified number of dwelling units and aesthetic requirements for bikeways, open spaces and a proposed golf course.

Although the type of central utility unit was uncertain, two planning criteria were known for the development of the plan. One, the location of higher density land uses nearer the unit is more efficient because of the energy and costs of extending the lines and the reduced loss of energy efficiency in that line over a great distance. Secondly, a passive layout and siting organization would improve the energy efficiency in each building and place less demand on the central utility plant.

Two site locations were chosen for further evaluation for the central unit. One area is located just south of the high school adjacent to the flood plain, and the other area is located next to road "C" adjacent to the flood plain.

The land use plan for the central utility south of the high school reverses the apartments with single family and relocates the high school near the south boundary of its parcel. The positive aspects of this location of the central utility are: that it's easy to service, it totally utilizes unbuildable land leaving prime building area available, and, because of setback from roads, it is not as apparent visually.

CENTRAL UTILITY SITE PLAN

LEGEND

- 6 GARDEN APARTMENTS
- 2 TOWNHOUSE UNITS
- TYP SINGLE FAMILY DWELLING
- BICYCLE & PEDESTRIAN PATH
- TOT LOT or PLAY AREA

115 KVA POWERLINE (GEORGIA POWER COMPANY) 1,000 LIN FT. FROM E. BOUNDARY POWERLINE R.O.W (200 FT) RUNS PARALLEL TO ROAD 'C'

HIGH SCHOOL with Track, Football, Baseball Fields & 400 Capacity Parking Lot - 56 Ac.

32 SINGLE FAMILY 11 Large Lots, 23 Regular Lots Large Lot - 0.15 Ac, Regular Lot - 0.034 Ac

OPEN SPACE

11 SINGLE FAMILY 25 Ac. Lots

GOLF CLUBHOUSE & MAINTENANCE BUILDING 0.5 Acres

CHURCH & DAY CARE CENTER 9.7 Acres

PROPOSED COMMERCIAL 1.9 Acres

CONVENIENCE SHOP & GAS 4.5 Acres 4,000 sq. ft.

FIRE & POLICE STATION 2.2 Acres 2,400 sq. ft.

106 GARDEN APARTMENTS & CLUBHOUSE 11.0 Ac; 10.0 PU per Acre

GOLF COURSE

Central Utility Site

50 TOWNHOUSES 10.2 Ac; 5.7 PU per Acre

70 SINGLE FAMILY DWELLINGS 15 Large Lots; 55 Regular Lots Large Lot - 0.15 Ac, Regular Lot - 0.034 Ac

SCALE: 1"=200'

0 100 200 400 600 800 1000

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. EN-78-0-01-4215

TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY - ENGINEERING EXPERIMENT STATION
SHENANDOAH DEVELOPMENT, INC.
LAUBMANN-REED AND ASSOCIATES - LANDSCAPE ARCHITECTS AND ENVIRONMENTAL PLANNERS
FINCH, ALEXANDER, BARNES, ROTHSCHILD, AND PASCHAL, INC. - ARCHITECTS
NEWCOMB AND BOYD - MECHANICAL ENGINEERS
WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

CENTRAL UTILITY SITE PLAN

SHENANDOAH

COMBIA COUNTY

GEORGIA

The negative aspects of such a location are that: it removes the highest energy using buildings from the most favorable slopes and exposures and replaces them on the worst slopes and exposures creating additional clearing and grading with a loss in energy efficiency and crowds the high school next to the apartment buildings.

When the central utility is located next to road "C", the fifty townhouses are reversed with ten single family dwellings creating a plan that continues a layout comparable to the passive plan. The positive aspects of that location for the central utility are: it may service future development across road "C" more easily and the high density apartment dwellings are located on the most favorable slopes and exposures creating less energy loss.

The negative aspects of this location are: if the central utility is a ten-acre power tower, a small portion of prime south sloping terrain must be utilized. The visibility of the utility plant will be prominent from road "C", although some screen may be provided, and the golf course will be interrupted by the construction of the facility. Also, the 1-acre lots were lost plus the single family residents would have to drive by the apartments to get to their homes.

The final central plant site plan included most of the passive site plan rearrangement features with a movement of the one area of townhouse clusters and the relocation of the proposed high school closer to the central plant location.

2. Central Plant Design Considerations

A central plant system designed for energy conservation must incorporate site planning as well as energy supply and distribution system design. Site planning consists of arranging and orienting the buildings to minimize energy use without inconveniencing the residents and consistent with aesthetic considerations. This was considered from inception of the community plan.

Haphazard planning and inappropriate phasing lead to much of the energy waste associated with large central plant designs. Design of the

energy conversion system itself determines how much and what kind of fuels will be used in the community. It is desirable that the community operate on a fuel that will not be in short supply in the future, so that a stable economic situation will exist for the residents.

In evaluating any energy conservation options, total energy analysis should be used. Energy needed to operate all equipment and buildings starting from raw materials and proceeding to end-use was considered using the methodology presented in ASHRAE Standard 90-75, Section 12.

3. Conventional Energy Sources

Biomass or coal are the most desirable fuel choices for compliance with the national energy strategy. The United States is well endowed with coal and a long-term, continuous supply of coal fuels is assured pending a stable economic situation. The cost of coal is expected to rise steadily, however, with increased production and general inflation. Pollution effects must be considered and transporting and burning coal in the proximity of residents could be hazardous, even if standards are met.

Oil and natural gas are a less desirable energy source and should be considered for short term uses only. These fuels are nonrenewable and their cost can be expected to rise dramatically in the coming years. The cleanliness and current price of natural gas make it highly desirable as a residential fuel, but shortages can be expected.

Using any of the fossil fuels, including coal, puts the community at the mercy of economic and political changes that the country may undergo. Use of alternative renewable fuels (wood, wind, solar) assures a continuous, stable supply of energy, making the community more independent of these changes.

4. Solar Energy

A central station solar power plant is possible for the Shenandoah site; however, this does not provide a dependable supply of thermal energy in this climate and is probably not economical at this time. Other

TABLE L3-1

Central System Options - By Energy Source

1. Natural Gas		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Boiler		steam/electric
B. Turbine		hot/chilled water
C. Heat Pump		steam/chilled water
D. IC Engine		steam
2. Oil		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Boiler		steam/electric
B. Turbine		hot/chilled water
C. IC Engine		steam/chilled water
		steam
3. Coal		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Boiler		steam/electric
		hot/chilled water
		steam/chilled water
		steam
4. Biomass (Wood)		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Boiler		steam
B. Gasifier		steam/electric
C. Pyrolysis		hot/chilled water
D. Gasifier/IC Engine		steam/chilled water
E. Gasifier/Turbine		
5. Municipal Waste		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Incinerator		steam
B. Pyrolysis		steam/electric
		hot/chilled water
		steam/chilled water
6. Solar		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Flat Plate/Thermal		steam
B. Concentrator/Thermal		hot/chilled water
C. Photovoltaic		
7. Sink/Source (Heat Pump)		
	<u>Conversion Technology</u>	<u>Configuration</u>
A. Electric Heat Pump		hot/chilled water
B. Gas Heat Pump		

TABLE L3-2

Central System Options - By Energy Conversion Technology

Electric - Thermal Systems

- 1) Steam Boiler
 - a) Fuel
 1. Natural Gas
 2. Fuel Oil
 3. Coal
 4. Wood
 5. Solar
 6. Other Biomass
 7. Waste
 - b) Turbine
 1. Condensing
 2. Non Condensing
- 2) Combustion Turbine
 1. Natural Gas
 2. Fuel Oil
 3. Coal Gas
 4. Wood Gas
- 3) IC Engine With Heat Recovery
 1. Gas
 2. Diesel
 3. Wood Gas
- 4) Fuel Cell
 1. Natural Gas
 2. Naphtha

Thermal Only Systems

- 1) Hot Water/Chilled Water District Plant
 - a) Hot Water or Steam
 1. Natural Gas
 2. Fuel Oil
 3. Coal
 4. Wood
 5. Solar
 6. Other Biomass
 7. Waste
 - b) Solar Collectors
 - c) Electric Chillers
 - d) Steam Drive Chillers
 - e) Absorption Chillers
- 2) Steam District Plant
 1. Natural Gas
 2. Fuel Oil
 3. Coal
 4. Wood
 5. Solar
 6. Other Biomass
 7. Waste
- 3) Heat Sink/Source
 1. Electric Heat Pump
 2. Gas Heat Pump

Electric Only Systems

- a) Fuel Cell
 1. Natural Gas
 2. Naphtha
- b) Engine-Generator
- c) Condensing Turbine
- d) Solar
 1. Solar Power Tower
 2. Photovoltaics

TOTAL INTEGRATED
ENERGY SYSTEM (TIES)

TOTAL ENERGY
SYSTEM (TES)

DISTRICT HEATING/COOLING

DISTRIBUTED HEAT
SINK/SOURCE

ELECTRIC GENERATION

alternative solar energy uses include the use of photovoltaics. Photovoltaics can be obtained for as low as \$10 per peak watt installed, but is not cost effective.

Central plant solar heating and cooling applications are possible with existing technology and were explored. Various active solar applications may be used to augment the community energy system allowing for smaller component design and less nonrenewable fuel usage.

5. Wind Energy

Wind energy was considered for Shenandoah, however its relatively unpredictable nature and low power density precluded further serious consideration.

6. Other Energy Sources

Hydro and geothermal energy sources are not available at or near the Shenandoah site. No serious consideration was given to these sources.

4.4.4.4 -- Central Plant Configurations

Evaluation of the type of central plant configuration, energy conversion technology and various energy using components proceeded, taking into account the criteria of 1) technical feasibility 2) site specific requirements 3) departure from conventional approaches 4) financing, ownership, and operation and 5) phasing.

Table L3-1 lists the systems considered by energy source. Table L3-2 lists systems considered by energy conversion components. Previous work performed in the HUD-MIUS program and D.O.E. ICES programs were also used extensively. Figure L3-2 is a graphic representation of several of the generic system types considered.

Detailed investigation into the various systems caused the planning team to select an (I.C.E.S.) Integrated Community Energy System concept which would cogenerate electric and thermal energy. This type of system

would offer the greatest energy conversion efficiency with existing technologies and would help offset the high initial costs and parasitic energy penalties associated with central energy plants.

Integrated Community Energy Systems are a comprehensive approach to energy conservation involving an entire community. Incorporating ICES into our society involves innovative technology, energy conserving community design and unique financial and regulatory mechanisms. Partial or complete integration of a community's energy supply and demand system are possible. The degree to which the concept is applied depends on various economic, social and environmental criteria as well as the energy conservation goals of the community. Some of the specific goals of an ICES are: to reduce the demand on scarce fuels, to lower and stabilize energy costs to consumers and to minimize unwanted effects such as noise and air pollution.

ICES conserve energy by making appropriate use of each unit of fuel. This is done by supplying energy in steps that are matched to end-use with a decrease in quality with each step. For example, coal is used to produce high pressure steam that generates electricity (at a 30% efficiency), then the lower pressure steam exhausted from the electric generating process can be used to produce hot water to provide space heating and/or cooling and domestic hot water. If the same initial energy can be used by more than one process, there is an increase in overall efficiency.

There are four components to an ICES - Resource, Central plant, Distribution and Storage, and End-Use systems. The resources system supplies primary fuel. It is desirable to use the most abundant, least polluting fuel in the local area. The central plant provides the initial conversion of high quality energy such as electricity. The distribution and storage system takes the products and wastes of the central plant and delivers them to the appropriate end-use or storage system.

Community design is an important element of ICES. By siting the central plant near residences and buildings, allowing growth along existing energy transportation lines and considering energy usage in land use planning, a great deal of energy can be saved. The result is lower initial

and operating costs of energy systems to the consumer.

ICES is a new idea, and some changes in lifestyle will be necessary to incorporate them. These may include minor inconveniences, allowing slight temperature variations in buildings, and energy use awareness on the part of the consumer.

Presently there is no public or private policy regarding ICES. Energy supply must be matched with community growth and management of development is necessary for a successful ICES. Some attractive ICES forms along with their associated technologies are described in the following paragraphs.

1. TES

In a Total Energy System (TES) electric power, heating media and cooling media are produced by conventional means. The system is totally self-contained and no energy conversion is required by the users within the system's boundaries.

A total energy system is most efficient when waste heat byproducts of power generation coincide with heating and cooling demand of the users. This seldom occurs so auxiliary energy is used to meet the varied needs of the community. A self-contained energy system is attractive using thermal or electric storage. The system could be thermally controlled with excess electric power stored in batteries or as mechanical energy (flywheels, pumped storage, etc.). Auxiliary systems would still be required, but would not be used often if equipment for the TES was sized to meet community demand.

2. MIUS

Modular Integrated Utility Systems are on-site combined package plants that provide communities of limited size with electricity, heating, air conditioning, water, and liquid and solid waste treatment and disposal. They are modular in that they are located near users and are designed to be in phase with the demands of the community. Resource requirements of one

service are met by utilizing the waste of another where possible. Electric generation is placed near consumers in order to utilize waste heat. Solid and liquid waste treatment systems are also integrated with the total energy system.

The primary goals of MIUS are to conserve natural resources, reduce energy consumption, minimize adverse environmental impact, provide utilities in phase with demands of the community, eliminate impact of local restrictions on waste treatment and reduce the total cost to the nation for utilities.

Some technologies used to incorporate MIUS are internal combustion engines, gas turbines, solar energy, heat pumps, pyrolysis and biological treatment of waste.

3. TIES

In a Total Integrated Energy System (TIES), the electric power output of a local power generation plant goes into the utility company distribution grid rather than to the user. The user is served with electric power from the grid and receives heating and cooling media from the local power plant's waste heat. The utility grid provides a large source-sink for electric energy. The TIES plant is controlled by thermal demand, without auxiliary energy requirements at individual buildings. Sizing to the plant is dependent on economics and waste heat demand.

Some conditions that must be met to incorporate a TIES are:

1. The plant should be utility company operated, but not necessarily owned.
2. The TIES electric capacity should not exceed 20% of a utility company's minimum demand.
3. The utility company should pay a monthly demand charge as well as a per KWH charge to the TIES plant owner since the maximum output of the TIES plant is available to the utility upon demand.

4. Cogeneration

Cogeneration systems combine the production of electric power with thermal energy needs. This provides a higher overall cycle efficiency than generation of electricity and heat separately since the same energy source is used to provide more than one service. German studies indicate that cogeneration is now economical for populations of 40,000 or greater. In the U.S.S.R., 30% of the electricity is cogenerated using plants of up to 250 MWE capacity. The cogeneration plant must be sized appropriately to the community for effective energy use.

Some of the major items considered in evaluating the various central plant configurations are discussed below.

A. -- Internal Combustion Engines

These produce electricity by driving a generator. Various sizes are available to meet the needs of the community. The engines can be fueled by natural gas, fuel oil, propane, butane, or sewage gas, or a combination of these (dual fuel engines). Different types of heat recovery equipment are available for utilizing waste heat to heat homes and domestic water. These include jacket water cooling, lube oil cooling, radiator type heat exchangers, and exhaust gas boilers. Combined packaged units are available.

B. -- Heat Pumps

There are a number of options available for incorporating heat pumps into the community energy system. Water-to-air or air-to-air heat pumps could be used for space heating and cooling of buildings. These can be solar assisted. Air-to-water heat pumps can be used to heat domestic hot water. The use of heat pumps is a more efficient use of electricity since it is possible to get 2-3 times the heat output (COP) for the same electric input as in conventional resistance heating. Heat pump operation can be reversed to provide cooling with the same equipment.

C. -- Cooling Systems

Cooling requires approximately as much energy in the summer as does heating in the winter in this climate. Absorption and vapor compression cycles should be considered. In a vapor compression cycle, waste heat can

run a Freon cycle which drives a turbine-compressor for the cooling cycle. Stirling and Rankine cycle machines are being developed for this purpose. The exhaust from the turbine could be used to run a Lithium Bromide absorption cycle, resulting in maximum use of waste heat.

D. -- Gas Turbines

These are presently used for peak power generation by electric utilities and have proven very reliable. Most liquid and gaseous fuels can be used. Similar heat recovery equipment is available. Various sizes of gas turbines are available. Gas turbines are more efficient than IC engines, but have a higher initial cost.

E. -- Steam Turbines

The advantages of steam turbines are that coal or wood can be used as fuels and both are plentiful in the U.S. Various heat recovery equipment include exhaust gas boilers, steam to water heat exchangers, drawing off low pressure steam from the turbine to drive an absorption chiller, etc. Various sizes are available.

F. -- Roesel Electric Generators

These provide constant frequency electric output regardless of speed variations. Assuming ICES systems operate on thermal demand, speed variations will occur in the prime mover coupled with changes in the thermal load. A constant frequency output allows uncomplicated regulation of output voltage and facilitates coupling of multiple on site power installations (with other ICES) and fly wheel energy storage. Various sizes are available for different prime movers.

G. -- Absorption Chillers

These are Lithium Bromide chillers and use waste heat from electric generators to chill water that is distributed to nearby buildings for air conditioning. Chilled water storage provides cooling during off peak hours. Three to sixteen-hundred ton capacity machines are available.

4.4.4.5--Thermal Distribution System

The thermal transmission and distribution system should be capable of conveying the thermal energy produced in the ICES plant to the consumers economically and efficiently. In the case of cogeneration systems the energy of the district heating system comes as a by-product from the power plant. Either steam extracted at intermediate pressures from the turbine or exhaust steam can serve as a source of energy. This steam can be transported directly by the distribution network if steam is the heat transport media or it can transfer heat to water in a heat exchanger (condenser) if hot water is used. Extracted or exhaust steam pressures and temperatures should be selected so as to satisfy the heating requirements and at the same time allow for an increase in electrical output and overall efficiency of the cogeneration plant. The proposed central plant scheme at Shenandoah will optimize plant components such as turbines, heat exchangers and the operating conditions to allow for the simultaneous supply of thermal energy for the district heating system and the production of electric power.

The practice of district heating and cogeneration has been in existence for several decades in Europe and North America and the technology is well developed.

The requirements of the thermal distribution system should include the following:

1. the system should deliver energy to the consumers efficiently and economically;
2. the system should utilize a thermal transport media suited for the best utilization of the thermal energy available in the cogeneration plant resulting in maximum output of electrical power and efficiency;
3. the system should be reliable and easily maintainable;
4. the system should be easily adaptable at minimum cost to the consumers.

In view of these requirements, the selection and design of each of the components of the thermal distribution system should take into consideration:

1. the capital cost of the distribution system that include the pipe lines and conduits, valves, pumps, fittings, insulation, construction of trenches, etc.,

FIGURE L3-3

2. the cost of operation which is dependent on the thermal losses, leakage, drainage, and maintenance,
3. reliability, safety and ease of maintenance.

Both steam and water have been used as heat transfer media in district heating systems in Europe and the United States. The majority of the existing district heating systems in the United States use steam whereas in Europe, the number of district heating systems using steam or hot water vary depending on the country and the particular situation. However, in recent years due to the relatively lower efficiencies and the operational problems associated with steam, water is preferred for district heating schemes. European experience seems to confirm this trend. The factors that influence the selection of the heat transfer media are discussed in the following particular situations.

Steam contains a greater amount of energy per unit mass than water, but on a volume basis, the thermal content of steam is far less compared to water. For example, the latent heat of steam at atmospheric pressure and 212 degrees F is 970 Btu/lbm compared to 180 Btu/lbm for water under the same conditions, whereas the density of steam at the same pressure and temperature is 0.0373 lbm/cubic foot compared to 59.83 lbm/cubic foot for water. But, on a volume basis the internal energy content of water would be 268 times that of steam.

Thermal supply characteristics have a strong bearing on the size of the pipe lines, storage, heat losses, insulation, etc., and the costs associated with steam and hot water distribution systems.

4.4.4.6 -- Energy Conservation Potential

Each central energy system holds promise for altering energy use patterns within the community and for conserving energy. In the case of Shenandoah, all end-users within the service area would normally rely on electric energy for cooling and natural gas for heating.

The procedures outlined in ASHRAE Standard 90-75, ENERGY CONSERVATION IN NEW BUILDING DESIGN, SECTION 12, "Determining Annual Fuel

and Energy Resource Utilization," were followed in order to compare energy consumption of the conventional system to the conservation arrangement.

Each residential service zone was treated identically since their source of energy for heating is the same--i.e. natural gas.

The energy consumption for the conventional plan was determined for the heating and cooling requirements projected by the computerized load estimate. An efficiency factor of 65 percent was used for natural gas heating. Cooling requirements were assumed to have been met electrically at a C.O.P. of 2.0.

4.4.4.7 -- Central Plant Phasing

In general, it is advisable to plan and construct central plant facilities for a high growth area (such as this residential community) in several stages over a given planning period. This procedure avoids committing large sums of money for excess capacity at the central plant which may not be needed until much later in the planning period. The growth potential of the subject area can be taken to be approximately 200% of the initial planned number of structures in the area over a 10 year planning period. The bounded land area in the community, however, puts an effective ceiling on the ultimate expansion in the immediate area. The combination of the above factors results in the estimate that the area may reach its potential in three to eight years. Considering this estimate and the fact that central station capacity may be limited somewhat by physical and environmental considerations, it was deemed advisable to plan for installation of the bulk of central station support facilities and one-half of the ultimate planned capacity during the initial construction. A plant expansion would then be planned to totalize central station capacity in approximately five years.

4.4.4.8 -- Community Heating and Cooling Load Projections

A simplified methodology was developed to estimate thermal demands imposed on the central plant equipment. For the level of analysis required in the feasibility studies, it was decided that monthly Btu consumption

TABLE 4-3
PEAK ENERGY DEMAND

<u>Building Type</u>	<u>Floor Area</u>	<u>Electric KW</u>	<u>Space Heating MBTUH</u>	<u>Space Cooling MBTUH</u>	<u>Domestic Water Heating MBTUH</u>
Single Family	174,000 s.f.	261.0	8,595	4,628	1,980
Townhouse	69,000 s.f.	122.8	3,111	1,711	1,000
Apartment	232,000 s.f.	793.4	13,456	7,680	4,000
High School	160,000 s.f.	580.0	1,462	3,744	100
Shopping	4,000 s.f.	12.0	122	104	0
Golf Club	14,700 s.f.	42.0	447	381	60
Fire/Police	2,400 s.f.	8.0	112	73	30

TABLE 4-4
TOTAL ANNUAL ENERGY LOADS

<u>Building Type</u>	<u>Floor Area</u>	<u>Electric (MWH)</u>	<u>Space Heating & Water Heating 10⁶ BTU</u>	<u>Cooling From Space 10⁶ BTU</u>
Single Family	174,000 s.f.	1,476	6,928	2,850
Townhouse	69,000 s.f.	636	2,257	2,238
Apartment	232,000 s.f.	2,682	7,164	10,254
High School*	160,000 s.f.	1,270	570	938
Shopping	4,000 s.f.	66	33	72
Golf Club	14,700 s.f.	246	122	265
Fire/Police	2,400 s.f.	<u>57</u>	<u>24</u>	<u>65</u>
TOTALS		6,433	17,098	16,682

* Does not include summer session.

figures would be adequate for estimating purposes. Peak loads were determined using projected temperature demands and other service factors.

Three types of thermal loads were considered. The first load considered was space heating. Space heating loads are comprised of: heat losses through building shells and outside air tempering from ambient conditions to comfort conditions within building spaces which occur due to infiltration or mechanical ventilation. The second type of load considered was cooling load. Cooling load consists of heat gain to conditioned spaces from the building envelope, internal heat sources such as lights, equipment and people, and tempering of outside air from ambient conditions to comfort conditions within the conditioned space due to infiltration or mechanical ventilation. The third type of load considered is the energy requirement for domestic water heating. This load is determined by the quantity of hot water used, and the temperature rise required between incoming water conditions and water heater outlet conditions.

Unitized energy consumption data was developed on an annual basis by using computerized energy consumption figures. The categories of buildings are presented in Table L3-3 with their corresponding heating, cooling domestic water heating peaks. Table L3-4 presents total annual energy loads.

Weather data from the national climatological center were utilized to obtain average heating and cooling degree days. Heating and cooling loads were assumed to be at peak when the outside air temperature reached the ASHRAE design temperatures for 97 1/2% cooling and 99% heating. One useful statistic to determine overall desirability of providing central heating and cooling media for use by the community is to determine the total number of hours per year when some heating or cooling is required by most residences. In order to do this, cumulative hours were developed from the hourly temperature distribution data to indicate the number of hours per year when heating or cooling were required. Heating was assumed to be needed when the outside air temperature was 60 degrees F and below. This resulted in approximately 4,650 hours per year when some form of heating energy was required by most buildings. Likewise, cooling was assumed to be

required when the outside air temperature was above 75 degrees F. For the Shenandoah area this resulted in less than 2,440 total hours per year which required some form of cooling. On the basis of this observation it would generally be concluded that simultaneous use of cooling and heating media would be utilized only slightly during the annual period and would probably not justify the large capital expense required to provide a year-round cooling media to normal residential areas.

Domestic water heating requirements were developed on a unit basis assuming a dwelling unit was the lowest increment for analysis. Water heating energy consumption was projected as constant year round; however, in actuality there will be some increase in energy required during winter months when entering water temperatures are lower than the yearly average. This fluctuation is considered minor for the purposes of this analysis.

The total loads used in the study are as follows:

Total service area(235 acres) :

Peak cooling: 1700 tons
Peak heating: 38×10^6 BTUH
Peak base electric: 2000 KW

.4.4.9 -- System Analysis

After reviewing the entire Shenandoah Development site of 7,500 acres, initial consideration was given to three sites for relatively large scale central energy plants. These plants would have been based primarily on the MIUS technologies and be fossil fuel fired. Consideration of this scheme was terminated, however, because of extremely limited water availability on the site and the long build out period of the Shenandoah Development, which would severely hamper phased construction of a large central plant scheme.

After evaluating the previously presented energy source and technology options, the central plant selection was narrowed to six alternatives.

Total energy systems which would supply all energy needed within the project boundaries without grid connection was eliminated from consideration early due to its demonstrated low overall energy utilization efficiency. The TIES system (Total Integrated Energy Systems) were the most favorably considered for the Shenandoah Project since they provided the highest overall energy utilization efficiency. Total service schemes such as the MIUS scheme were eliminated from consideration since other community services had been contracted for and since consideration of the total Shenandoah Development central plant was eliminated. Thermal schemes such as district heating and cooling were eliminated due to their relatively low energy efficiency and because of the sparse thermal density requirements of the 235-acre site. The heat sink-source distribution system for individual heat pumps was eliminated due to the lack of a convenient heat source and heat sink for the project. Likewise, the CASES heat pump system received only minimal consideration since current Georgia Tech work in heat pump ICES indicate that an air source heat pump would probably demonstrate superior energy efficiency than the CASES system for this area of the country. (9)

The six alternatives are as follows:

1. Fuel cell ICES-TIES mode
2. Internal combustion engine with heat recovery ICES-TIES mode;
3. Wood fired thermal/electric ICES - TIES mode;
4. Photovoltaic ICES - TIES mode;
5. Solar thermal central plant;
6. Solar thermal/electric ICES - TIES mode.

A preliminary feasibility analysis is presented in the remainder of this section on each of the six concepts.

1. -- Fuel Cell Power Plant

Fuel cell power plants presently being developed for commercial application have the capability to generate electricity efficiently over a wide power range. Characteristics provided in this report are based on a

power plant design which utilizes the 4.5 MW Demonstrator concept with some advances in heat recovery technology.

The 4.5-MW Demonstrator is a 4.8-MW dc fuel cell electric power generator designed and constructed by the Power Systems Division of United Technologies under a jointly sponsored program with the U. S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI). The Demonstrator is to be installed and operated by Consolidated Edison Company of New York, Inc. The objective of this program is to demonstrate the installation and operation of a multimegawatt fuel cell generator by a utility company.

A. -- Description of Central Plant Scheme

(1) Components -- The 4.5 MW fuel cell power plant requires a site of approximately 1,400 sq. meters (15,000 sq. ft.) and has an elevation of less than 6 meters (20 feet).

Figure L3-4 is a typical site plan showing the major pieces of equipment. The equipment supplied by the manufacturer (UTC) is all located in the island at the center of the site. These parts of the power plant will be described further in this report. The remainder of the plant is standard commercial equipment, which will be supplied by the community or the host utility.

Figure L3-4

(2) Basic cycle -- The 4.5 MW power plant consists of the fuel cell dc module, a power conditioner system, a control system and numerous auxiliary subsystems, as shown in Figure L3-5.

Figure L3-5

-- Fuel cell dc module. This element consists of two subsystems, the reactant supply subsystem or reformer, and the power section subsystem or fuel cell. The reformer converts the fuel--either naphtha or, in an emergency, natural gas into a hydrogen-rich gas.

Next, the gas is dried and filtered, then sent to the power section subsystem or fuel cell where dc power is actually produced. (The fuel cell operation is described below). Waste heat can be removed from the dc module to supply Shenandoah's thermal loads.

-- Power conditioner. This element converts dc power from the 4.8 MW dc module to three-phase, 60 HZ ac power at 13.8 kilivolts with a 4.5 MW capacity.

-- Control system. A machine known as the site controller, located at the fuel-cell installation, operates the power plant by coordinating and sequencing the actions of the various subsystems via subsystem controllers. These subsystem controllers are intermediate links in the chain of command; they handle all the logic and sequencing within their respective subsystems.

-- Fuel cell cycle. An individual fuel cell shown schematically in Figure L3-6 consists of two electrodes separated by an electrolyte. The fuel cell electrochemically combines fuel and oxygen to produce electricity. Hydrogen-rich fuel gas is passed across the cells fuel electrode (anode), where it dissociates into hydrogen ions and electrons. The ions migrate through while the electrons move through an external

circuit to the cathode. At the cathode, oxygen, hydrogen ions, and electrons join to form water. The flow of electrons through the external circuit is electricity.

Figure L3-6

(3) Discussion of similar projects -- Research and development to commercialize fuel cell power plants and to apply them to utility applications has been underway in earnest since 1967. More recently (1973), nine major electric utility companies and United Technologies undertook the development of a modular 27 MW fuel cell power plant for application with electric utility networks. The program culminated in the successful test of a 1 MW fuel cell pilot plant in early 1977. This plant provided the first demonstration that subsystems could be scaled up to commercial sizes and that substantial power for utility use could be generated efficiently by a fuel cell. Other research and development programs are being pursued based on this technology.

The objectives of these efforts are:

1. Fuel cell power plants for insertion into the electric utility system. This effort has focused on multimegawatt-sized power plants capable of operating on air and conventional liquid and gaseous hydrocarbon fuels.
2. Fuel cell power plants intended to be located on-site and to supply the electric and other energy needs of a building or

industrial process, usually independent of the electric utility system. A catalogue of power plants ranging in size from a few to several hundred kilowatts is envisioned.

(4) General advantages and disadvantages -- The benefits of fuel cells fall into two main categories. One set of benefits stems from the fact that fuel-cell power plants will be compact, "civilized" packages of modest capacity that are amenable to dispersal in the heart of communities. They include:

1. Siting will be easy because, unlike conventional plants, they are quiet and clean, require no large supply of water for cooling, and are efficient in all sizes and over a wide loading range.
2. Because they can be geographically located near the loads they serve, fuel cells require minimal additional costs of transmission and distribution.
3. Modular construction of fuel-cell power plants --with much of the work performed in a factory--should reduce both the lead time for new generation and the amount of construction required in the field.
4. Capital will be used more effectively, as generation can be tailored more precisely to the size and location of load growth.

The second set of benefits are based on improvements in system operation that fuel cells are expected to provide:

1. They will be an inexpensive source of peaking reserve because fuel cells promise to be as efficient at low output as they are at rated power output. Also, they can be brought from 35% to 100% of rated output within only 0.5 seconds.
2. Their load-following capability will relieve other less flexible units from the tasks of error--and frequency-control, so they operate more efficiently.
3. Dispersed fuel cells with fast load-following capability would improve system stability.
4. Due to their dc/ac inverter, fuel cells can provide smoothly variable reactive power control, whether leading or lagging, up to the inverter's MVA rating. This reactive compensation can be used to maintain local voltages, minimizing the need for capacitors.
5. Fuel cells are practically free of all pollution with negligible emissions and little noise. Waste heat is available at temperatures suitable for producing steam or hot water, so cogeneration may be a viable option.
6. Fuel cells are free of the limitation on efficiency that is imposed by the Carnot cycle because they are not heat engines. Efficiencies of 38% to 40% have already been achieved, and those in the range of 50% to 55% appear possible. Conventional fossil-fueled units have efficiencies of about 40%.

Some of the system's drawbacks are::

1. Fuel cell technology is still in the development stage. We have yet to reach a point of full commercialization and "off the shelf" components.
2. Initial costs are higher than conventional power plants at this time.
3. Actual expected values on lifetime, maintainability, and reliable unattended operation have yet to be provided through in-service use.
4. Research still is in progress on suitable fuel sources for production of hydrogen-rich gas.

(5) Phasing of construction -- Fuel cell power plants are designed for simple installation. Connections are the fuel line, electrical output, surplus water discharge, and provision to vent clean exhaust gases if mounted indoors. Such power plants can be operated at any altitude to 6,000 feet without performance penalty. Heat recovery imposes no penalty on the electric generation efficiency. This type of fuel cell power plant typically weighs approximately 125 pounds per kilowatt.

The large power plants are designed for ready installation. The power plant consists of sections or pallets, which are designed for truck transportation. Representative pallet size is 10 by 24 feet. Installation requires appropriate connections between sections, as well as the external fuel, electrical, water discharge and possibly heat recovery connections.

B. -- General Operation of Plant

(1) Ownership -- Private ownership of the plant is anticipated with suitable grid connections and electrical power purchase agreements made with the public utility involved. Possibilities exist for the establishment of a demonstration plant, funded by DOE and supplied by UTC.

(2) Full load - Part load Operation -- The power plants are capable of operating continuously at any output electrical power level from zero to rated load over the life of the system without varying relative efficiencies. Operating at full load, the system will provide 4.5 MW ac of power and 1.8×10^7 BTU/hr available energy (210 degrees hot water) for thermal loads. At 25% of full load, the system will supply 1.1 MW ac of power and 3.15×10^6 BTU/hr for thermal load.

To accomodate consumer transients, the power plant will supply up to 40% real power overload for periods up to one second. Also, in the event of a fault, the power plant will provide up to 200% rated current for up to four seconds. If for any reason the fault is not cleared within five seconds, the load will be automatically disconnected to provide an additional level of protection for the consumer. The fuel cell power plant responds to the consumer's demands automatically and instantaneously. No operating personnel are required. Both the consumer's equipment and the power plant are protected by automatic disconnect and shutdown provisions.

The fuel cell power plant provides regulated voltage, frequency and maintains voltage regulation during overload transients with up to 30% load unbalance between phases. Voltage recovery is within two cycles. Operation at 50 Hertz instead of the standard 60 Hertz imposes no performance penalty. Typical output voltages for the small-size power plants are 120/208, three phase, or 277/480, three phase.

(3) Auxiliary power and back-up systems -- The system is sized to accomodate the maximum estimated thermal load of the Shenandoah community. The modular-type construction of the fuel cell makes it possible to easily meet future increases in the loads with additional units.

Back-up system protection can be supplied by an emergency diesel-generator system.

(4) Fuels -- The fuel cell power plant is fueled on naphtha-- a liquid fuel with a heat capacity of 5,248,000 BTU's per barrel or 125,000 BTU per gallon. Emergency back-up fuel is natural gas.

(5) Reliability -- The fuel cell power plant being essentially a static device does not require maintenance normally associated with conventional machinery. Typical maintenance is expected to include an annual visit to replace air filters and absorbent materials. Overhauls with major parts replacement are anticipated every five years. The life of the power plant is expected to be 20 years.

Since fuel cells represent an emerging technology which has not reached the commercialization stage, dependability evaluation must be based on estimates. With data from over 200,000 hours of field experience with embryonic experimental power plants, projected dependabilities indicate about one unscheduled shutdown per power plant per year. Fuel cell power plants are modular and it is unlikely that more than one module will be out of service at any time.

C. -- Grid Connection

The power conditioner inverts the dc power output of the fuel cell module to 3 phase, 60-HZ ac power, at a voltage of 13.8 KV. This ac power then flows into the utilities grid.

The unregulated dc-output voltage of the fuel-cell module is fed to three inverter bridges, which convert it into a square wave. Then each of the three phases of the inverter-bridge outputs is fed into a harmonic-cancellation transformer. When the inverter bridges are operated with power timing, the magnetic circuit of such a transformer can effectively remove harmonic-frequency voltages, of up to 17 times the fundamental frequency, from the ac output. Next, a 3-phase transformer combines the output of the harmonic-cancellation transformers and steps it up to line voltage. Series reactors connected between the cancellation transformers and the output transformer provide an inductive impedance to the utility for control purposes.

The inverter chosen for the power conditioner is self-commutated, so energy for commutation is stored within the inverter itself. Such an inverter is preferable to one that is line-commutated, because it can generate a voltage that is independent of both the magnitude and phase angle of the line voltage. Therefore, the fuel-cell power plant can be controlled with the same degree of flexibility as a conventional rotating machine-- with much faster response.

Also, real and reactive power can be made to flow in either direction. The fuel-cell power plant equipped with this self-commutated inverter can be designed to operate as an independent source during

emergency conditions when ties to the remainder of the system have been lost.

D. -- Efficiency Discussion

(1) Cycle description -- The thermal management configuration of the baseline electric generator is shown schematically in Figure L3-7. The basic fuel cell power plant consists of (1) a dc module with its reactant supply or dual conversion subsystem and the fuel cell or power section subsystem; (2) the dc to ac conversion or power conditioner subsystem; and (3) the heat rejection system, a dry cooling tower. Power plant waste heat is removed from the dc module via the water recovery condensers, the process air cooler, and the cell stack thermal control heat exchanger (HEX), and rejected to the environment by the dry cooling tower (DCT). Cooling tower coolant is circulated through the module heat rejection heat exchangers and heated to 210 degrees F before flowing to the DCT.

Figure L3-7

Heat recovery application requires the minimum modification to the base-line electric generator. Waste heat is removed from the dc module heat rejection exchangers (water recovery condensers, process air cooler and cell stack thermal control heat exchanger) in the normal manner by the cooling tower coolant. As shown in Figure , the coolant, heated to 210 degrees F, is then pumped to the user's heat recovery heat exchangers instead of through the DCT heat exchangers. If there is no thermal energy

demand, the coolant flows through the DCT heat exchanger in the same manner as in the baseline electric generator. Controls (not shown) regulate the coolant flow rate to maintain the proper system temperature over the operating range. To maximize the amount of useful thermal energy, heat is also recovered from the air supply turbine exhaust.

(2) Inputs and outputs -- As shown in Figure L3-8, the system inputs are relatively simple in fuel cell power plant consumes a hydrocarbon fuel (naphtha) and oxygen (air) and produce conventional alternating current electricity and waste heat for thermal load. The exhaust stream consists of surplus liquid water discharge and a gas stream of predominantly air with carbon dioxide and waste vapor.

Figure L3-8

(3) Overall efficiency -- Rated power electric generation efficiency is expected to be about 41% average over power plant life (based on lower heating value) as shown in Figure L3-9. This translates to a heat rate of about 9,000 BTU/KWH (based on higher heating value as shown in Figure L3-10. When equipped with the necessary hardware, waste heat equivalent to 49% of the total input fuel energy can be recovered. This yields an overall fuel utilization (electric plus recovered thermal output) of 90% at rated electric output. As shown in the figure, the overall fuel utilization remains high over a wide electric turndown range. Minimum fuel utilization shown is 80%. As shown, waste heat can be used to generate 210 degree F hot water.

Figure L3-9

Figure L3-10

Figure L3-11

Figure L3-11 defines the amount of thermal energy available at 210 degree F hot water over the range of 1/4 to rated electrical output. At rated output, each 4.5 MW ac unit will supply 1.8×10^7 BTU/hr to Shenandoah's thermal load.

E. -- Specific Application at Shenandoah

(1) Plant capacity --

To satisfy the majority of annual energy requirements a plant consisting of (2)-4.5 MW modules would be required. This plant would provide approximately 75% of the thermal energy required through cogeneration. The remaining 25% would be provided by oil back-up boilers.

(2) Size of plant -- The fuel cell power plant requires a site of approximately 45,000 sq. ft. and has an elevation of less than 20 feet.

(3) Annual energy consumption -- The power plant will be fueled with naphtha, which has a heat content of 125,000 BTU's per gallon. The overall fuel utilization for the power plant remains relatively constant over a wide electrical turndown range. Using 30% efficiency for waste heat recovery and a total thermal load for Shenandoah of 4.09×10^{10} Btu's

annually:

The annual energy consumption is $((4.09 \times 10^{10}) \times 0.75)/0.30$
 $= 10.23 \times 10^{10}$ Btu's

or 820,000 gallons of naptha. The oil back-up system would require 90,000 gal/yr.

F. -- Cost Data

(1) First costs -- It is estimated with current technology that such a plant could be built for \$500 per KW or \$4,500,000.

(2) Operating costs --

Fuel costs - annual consumption of naptha = 820,000 gallons

- annual consumption of fuel oil = 90,000 gallons

820,000 gallons naptha @\$0.90/gal = \$738,000 per year

90,000 gallons fuel oil @\$0.60/gal = \$54,000 per year

Total operating costs = \$792,000 per year

(3) Maintenance costs --

Maintenance costs are estimated to be \$2.60/KW-yr fixed costs and 2.85×10^{-3} per KWH variable cost.

Fixed cost = \$23,400

Variable cost = 72,890

Total maintenance costs = \$96,290.

(4) Replacement costs -- Overhauls with major parts replacements are anticipated every five years. The life of the power plant is expected to be 20 years and the 5 year overhaul cost = \$100,000.

G. -- Summary

Conceptually the fuel cell approach is well suited for the Shenandoah community. It is quiet, clean, safe and highly efficient throughout all operating ranges. However, there are also many drawbacks with such a system. Most of the problems with fuel cells involve the state of the art today. Fuel cell components for such a central system have not been commercialized and the expertise has not been fully developed yet. First, costs and operating costs (due to fuel costs) are quite high. Maintenance and servicing procedures, as well as day-to-day operation would require skilled labor in a new field.

Figure L3-12

Funding for demonstration projects such as Shenandoah is a possibility; however, without such financial aid a fuel cell central utility for the community would not be a wise recommendation.

2. -- I.C. Engine/Generator with Waste Heat Recovery

A. -- The use of an engine/generator system with waste heat recovery has been tried in numerous "total energy" schemes and has been used for numerous European district heating systems. The concept applied at the Shenandoah site would improve the utilization of this type of system by using a grid connection to absorb generated electricity.

(1) Components--

- (1) 6,213 HP Diesel Engine,
- (1) 4,385 KW, 60 HZ A.C. Electric Generator
- (1) Heat Recovery System to Recover Heat from

Cooling Water,

- (1) Heat Recovery System to Recover Heat from

Engine Exhaust,

- (1) Synchronizing and Regulating Circuit for

Output from Generator to Power Network, and

- (1) Start Up System

(3) General Advantages--

- 1. Mechanically Reliable
- 2. Compact
- 3. Rapid Installation

(4) General disadvantages--

- 1. Extremely Difficult or Impossible to Successfully
Connect a Conventional Diesel Engine/Generator

to Power Grid;

2. Very High Operating Costs
3. High Initial Cost
4. Complete Dependence on Fossil Fuels of Highly

Variable Availability

5. Substantially Increased Local Air Pollution
6. Possibly Unacceptable Noise Levels

B. -- General operation of the plant

(1) Full load - Part load operation-- In order to maintain a constant rpm for the generator, the diesel engine would have to have controls which automatically adjusted the torque output of the diesel engine to match the torque needed to drive the generator at constant frequency under the changing power load on the power grid as experienced by the generator. The heat rejected from the diesel engine would be dependant upon the electrical load on the power grid, and not the BTU needs of the community. Thus, at times, the diesel engine may not reject enough heat to meet the needs of the community, and at other times, the diesel engine may produce too much heat, necessitating its dissipation.

(2) Auxiliary power required -- A start-up system would be required. It could be of the types listed below:

1. An electric motor powered by the power grid.
2. An electric motor powered by a large bank of storage batteries.
3. An auxiliary gasoline engine.
4. A compressed air system.

(3) Fuels used -- fuel oil.

(4) Reliability-- One comprehensive study (Parisian, 1970) found an overall availability of about 96% for piston engines. Of the 4% downtime observed, 1% was due to forced outages and 3% to scheduled maintenance actions.

C. -- Grid Connection

It would be extremely difficult to successfully connect a conventional diesel engine/generator to the power grid. The primary problem is matching the generator frequency to the frequency of the power grid. The frequencies must be exactly matched in order to prevent disruption of the power grid. The frequency of a conventional generator is completely dependant upon its RPM. Thus, the diesel engine powering the generator must have very fine, accurate, and precise speed control to keep the generator RPM constant. This would be very difficult to do, but there are additional problems. One is that the frequency of the power grid is not stable, it may vary by as much as 4% over a given time interval. The diesel powered generator would have to vary its RPM to match the changing power grid frequency, meaning that the diesel engine would have to be equipped with feedback controls to sense the change in frequency and to adjust the generator RPM to match frequencies. This accuracy of control is not obtainable at the present. A further problem, as mentioned in section B., is that a load on the power grid would be experienced by the generator as an increased torque required to keep the generator running at the proper RPM. Thus, the torque output of the diesel engine would be a function of load on the power grid. This is an undesired situation because it is desired that the load on the engine be a function of the amount of waste heat needed, instead of being a function of power grid load.

.D -- Efficiency Discussion

(1) Cycle description-- See section A.

(2) Inputs:

Air

Fuel oil = 2,485 lb/hr or 770,781 gal/yr

(3) Outputs:

Heat recovered =

Electrical output =

(4) Waste energy

	Percent of total input energy
Mechanical losses	8.5
Waste heat not recoverable	25.5
Energy lost in mechanical/electrical conversion	3.0

Total Energy Lost 37.0%

(5) Overall efficiency:

Percent of input energy utilized = 63%

E. -- Specific Applications at Shenandoah

(1) Size of Plant--

Engine Size 6,213 HP

Generator Size 4,385 KW.

(2) Annual Energy Consumption--

770,781 Gal/yr (see attached notes).

F. -- Cost Data

Total first costs \$2,000,000

Annual operating costs \$476,000

G. -- SUMMARY

It appears that a conventional diesel engine/generator would not be suitable for meeting the needs of the Shenandoah community. This is primarily because of the high cost of such a system and because of its incompatibility with the power grid.

There is a non-conventional diesel engine/generator system which is potentially compatible with the power grid. The main difference between this system and a conventional system is the use of a Roesel generator in the place of a conventional generator. The Roesel generator is capable of maintaining a constant frequency output over a wide range of RPMs, and it can be easily synchronized with the power grid frequency. A major drawback of this system is first cost. A diesel engine/Roesel generator system of a size sufficient to meet Shenandoah thermal needs would cost over \$5,000,000 at present.

3. -- Diesel Engine Heat Balance

Heat balance	% of heat input
Useful work	34.5
Cooling water	30.0
Exhaust and radiation	27.0
Mechanical losses	8.5

Maximum isentropically recoverable heat == 57%

Maximum heat rejection rate required of diesel engine for cooling purposes is:

$$1.546 \times 10^7 \text{ Btu/hr}$$

Only a portion of the maximum recoverable heat can actually be recovered from the isentropically recoverable heat:

35% of heat available in exhaust gases (exhaust gases must not be cooled below 350 degrees F to prevent condensation of acids.

50% of heat available in cooling water.

The total recoverable heat would then be calculated as follows:

	% of heat input to engine	
	cooling water	exhaust
Maximum available heat	30	27
Recoverable heat	21*	9.5**
* $0.7 \times 30 = 21$		
** $0.35 \times 27 = 9.5$		

The total recoverable heat = $21\% + 9.5\% = 30.5\%$ of input heat.

The heat input to the engine to produce 1.546×10^7 Btu/hr of recoverable heat is:

$$\text{Heat input to engine} = 5.069 \times 10^7 \text{ Btu}$$

A typical diesel engine operating at full load consumes 8,160 Btu/HP-hr. The HP of a diesel engine capable of producing the amount of recoverable waste heat desired is:

$$\text{Engine horsepower} = 6,200 \text{ H.P.}$$

A diesel engine/generator of this size would be capable of generating approximately 4,385 KW of electricity and would cost approximately \$1,000,000 excluding installation.

An engine of 6,213 HP would consume approximately 0.4 lbs. of fuel oil per hour per HP under full load. The fuel consumption per hour for this engine would be $0.4 \text{ lbs/HP-hr} \times 6,213 \text{ HP} = 2,485 \text{ lbs/hr fuel oil}$.

Therefore, the total costs can be calculated as follows:

First costs

Diesel engine/generator	\$1,000,000
Shipping and installation	200,000
HVAC plant costs	800,000
Total first costs	\$2,000,000

Annual operating costs

Figure L3-13

Maintenance, insurance, misc.	\$ 9,300
Fuel costs (\$0.60/gal)	467,000
Total annual operating costs	\$ 476,300

At 30.5% Btu input recovered from waste heat, the required Btu input to achieve 80% of Shenandoah's requirements would be:

Engine fuel: $(3.26 \times 10^{10} \text{ Btu/yr}) / .305 = 1.069 \times 10^{11} \text{ Btu/yr input}$

Back-up fuel: $(0.80 \times 10^{10} \text{ Btu/yr}) / 0.80 = 1.000 \times 10^{10} \text{ Btu/yr input}$

The total no. 2 fuel oil consumed = 780,000 gal/yr.

4. -- Wood Fired Cogeneration Plant

A. -- Description of Central Plant Scheme

(1) Components--

Figure L3-13 is a perspective view of a wood fired cogeneration plant. The following is a description of the components.

The wood stoker can handle any wood fuel or mixture of fuels (bark, sawdust, hogged wood, chips) fed from the storage area or mixing bins. The stoker spreader dispenses the wood fuel onto the grate in the boiler assembly. Several grating systems can be used efficiently for wood fuel, including simple fixed pinhole grates, vibrating grates, or continuous chain travelling grates. Dumping grates are not recommended.

The boiler itself is a water tube type to provide the most efficient heat transfer mechanism (radiative transfer as well as conduction and convection). The boiler is just inside the utility boiler class operating at 600 psi and 750 degrees F. Other boiler types, such as fire type boilers, are not applicable for steam turbine power production due to lower thermal efficiency, lower operating pressures, and limited size. Included with the boiler is a combustion air pre-heater and an economizer for boiler water preheating.

The air pollution control equipment is very simple for this system. The low sulfur content of wood (less than 0.1%) probably will not require scrubbers, and low exhaust temperatures minimize nitrogen oxides. The fly ash can be simply collected by multi-cyclone separators without going to costly electrostatic precipitators.

Various water treatments are required for the boiler makeup water to minimize scale formation within the system. These include fiber glass carbon prefilters, water softeners, and reverse osmosis procedures, as well as storage and pumping. The scale formation is also minimized by continuous and periodic blowdowns to drain the sediment water from the boiler. The de-aerator heater is required to reduce the oxygen content of the water since oxygen in hot water is an extremely corrosive agent.

The single stage, variable extraction turbines and packaged synchronous generators are capable of delivering 2000 KW of power.

The control room is sited for clear visibility of the entire installation. It allows fully automated system operation. The generator switchgear provides a safety link between the generator and the utility. The plant can be easily managed by a two-person staff including one person to supervise fuel unloading.

Plant siting can be in almost any location where wood fuel can be economically delivered. There are minimal water requirements which could be easily supplied by either a municipal supply or a well.

(2) Discussion of Similar Projects.

(a) Rocket Research Co., Richmond, Washington 98052. "Prefeasibility Study for 5MW, 10 MW and 25 MW Wastewood Burning Electric Power Generating Facilities."

The purpose of this report is the discussion of feasibility and the analysis of costs for construction and operation of 5 megawatt, 10 megawatt, and 25 megawatt wastewood burning electric power generating

plants near Estacada, Oregon.

(b) SNC Consultants Limited, Toronto, Ontario. "Wood Wastes to Energy - A Central Facility For a Town in Northern Ontario"

Wood waste in the area of Hearst, a small town in northern Ontario with five sawmills and a plywood plant located within a thirty-mile radius, is presently disposed of by burning in natural draft teepee burners, which emit smoke and odors. Municipal refuse is disposed of in an unacceptable landfill. A study has been carried out to determine the technical and economic feasibility of building a central facility to cleanly dispose of the wood and municipal waste in the Hearst area and by so doing, to produce energy. The various available technologies for a central facility (e.g. gasification, steam and electricity generation) are evaluated and described. The study indicates that available waste can generate 250,000 lbs/hr of medium pressure steam which could supply heat to several nearby industries and municipal buildings (churches, schools, hospitals, arenas, etc.), enough electricity (12MW) to serve the town of Hearst and excess energy which could be utilized elsewhere, e.g., indoor swimming pools, greenhouses and/or sold to Ontario Hydro. A back pressure turbine with a conventional boiler is recommended.

(3) General Advantages

1. Utilizes a non-depletable fuel source--wood ;
2. Minimum pollution and environmental problems;
3. Relatively low fuel costs;
4. Relatively low first costs;
5. Mechanically reliable
6. Ease of switching to back-up fuels;
7. Possible use of wastes (lumber or sawmill)

materials as fuels.

(4) General Disadvantages

1. System size (2 MW) is really too small to take

- advantage of economics of scale and modular
off-the-shelf equipment;
2. Successful grid connections are difficult and
require a great deal of added equipment expense;
 3. System efficiencies drop when operating at
lower ranges of rated load;
 4. Additional transportatin and material handling
costs for fuel;
 5. Solid waste-ash removal problem; and
 6. Moisture and heat content of fuel may vary.

B. -- General Operation of Plant

(1) Full Load - Part Load Operation-- When operating a full load, electrical output is 2,000 KW and thermal output is 7.4×10^7 BTU/hr. The thermal load is the driving function of the system. Different thermal loads can be accomodated by varying steam generation rates. For example, quarter load operation would provide 250 KW electrical and 2.0×10^7 BTU/hr thermal. Overall system efficiencies will drop when operating substantially below optimum capacity.

(2) Fuels Used-- The system calculations are based on the following biomass fuel (wood) characteristics:

- 50% moisture content
- Heat content 5,000 BTU/lb
- Consumption 10,250 tons annually
- Price \$10/ton

(3) Auxiliary Power and Back-Up Systems-- A fuel oil fired I. C. engine generator system could supply back-up in the event of total system failure.

An alternate fuel system should be considered if there is a requirement for continuous production through upsets affecting wood supply handling equipment, or the ability of the boiler to accept and burn the wood.

Natural gas would be the most desirable, requiring only supply piping, controls, and burner. Oil would require, in addition, equipment for sulfur dioxide abatement. Coal would not be feasible because of extensive boiler redesign and additional atmospheric pollution control equipment.

(4) Reliability-- Steam generation for the purpose of cogenerating electrical and thermal energy is not a new concept. The concept of burning wood as a fuel has also been proven feasible. Maximum downtime due to fuel supply problems is unlikely due to the adaptability of the tri-fuel boiler. Therefore, the wood fired cogeneration system should be at least as reliable and more flexible than coal or gas fired central plant cogeneration systems.

G. -- Grid Connection

Power will be delivered to the grid as 3 phase 60 HZ current. The primary concern is matching generator frequency to the frequency of the power grid. These frequencies must be exactly matched in order to prevent disruption of the power grid. The frequency of a conventional generator is completely dependent upon its RPM. Thus, it is essential that turbine generator RPM remain constant over the complete range of rated output. Accurate and precise speed controls would be necessary. Since the load of the boiler-turbine generator system is a function of Shenandoah's thermal requirements and grid connections require a constant RPM, at times the system may have to produce too much heat, necessitating its dissipation. Further research will have to be done into the equipment and added expense necessary for a successful grid connection.

D.-- Efficiency discussion

(1) Inputs--

- Air

- Fuel -- Wood (50% moisture content) 5.30 tons/hour
at peak load or 10,250 tons annually.

(2) Outputs--

- Heat to thermal system -- 4.09×10^{10} Btu/year

- Electrical output -- 3,000 megawatt hours/year(min.)

(3) Waste energy

% of Total Input Energy

Boiler losses (70% efficient)

30%

Turbine losses (80% efficient)	8.7%
Generator losses (97% efficient)	2%
(4) Overall efficiency	
Annual efficiency	= 50%
Peak efficiency	= 68%

E. -- Specific Applications at Shenandoah

(1) Size of plant--

Turbine generator size	2000 KW
Wood fired boiler	60,000 lb/hr

(2) Annual energy consumption

10,250 tons of wood annually (assume 50% moisture content)

F. -- Cost Data

(1) First costs

Turbine generator (single stage, back pressure, non-condensing)	\$240,000
Tri-fuel boiler (500 HP, 1725 lb/hr)	500,000
Fuel storage and conveying equipment	200,000
Switchgear	100,000
Misc. plant and electrical equipment	50,000
HVAC equipment	310,000
TOTAL	\$1,400,000

(2) Operating costs

Maintenance, insurance, misc.	\$50,000
Operating labor (3 shifts, 2 operators)	180,000
Fuel costs (10,250 tons/yr x \$10/ton)	102,500
TOTAL	\$332,500

G.-- Cost and Supply of Wood Fuel for the Shenandoah Project

Present plans are to utilize wood as fuel for power production of the Shenandoah Development Project. This plant is to be a cogeneration plant having a capacity of one to two megawatts. Long term expansion possibilities indicate that fuel supply on sufficient quantities for ten megawatts should be considered. Since purchased wood fuel for utility boilers in the geographical area under consideration represents essentially

a new market, several economic questions require consideration. Assuming the demand is created, the most basic of the economic questions would be those of cost and supply. It is the purpose of this section to give preliminary answers about potential fuel supply and cost. This will be addressed by three steps. The first step is to determine the amount of wood required to fire a boiler capable of producing two to ten megawatts of electricity. The second step is to determine from published sources the amount of available wood fuel in an area not to exceed 50 miles from the point of use. The third step, which is the most important, is to do an actual field study of potential fuel supply, probable cost, and related problems. Related problems will include such things as capital expenses, transportation, and continuity of supply.

(1) Bulk Wood Requirements-- The thermodynamic cycle for production of electricity could be expected to be on the order of 30% to 40% efficient. Individual steps would, of course, be of higher efficiency, but compounded efficiencies should reduce to about this estimate. The total amount of useful energy in a pound of wood is, of course, dependent upon the species, moisture content, and many other variables. An average figure used here is approximately 4,500 Btu per pound of 50% moisture content (wet basis) wood. Using the gross estimates of 50% moisture content, 4,500 Btu per pound, and overall cycle efficiency of 33%, to produce ten megawatts of continuous power, one would need 276 tons of green wood (50% moisture content) per day. For two megawatts, this number is 55 tons per day. Continuous operation would require this supply to be maintained 365 days per year. This rough figure is in fairly good agreement to actual figures from the electricity generator in Burlington, Vermont, using wood as a fuel.

The numbers reported here are not intended to reflect extreme accuracy, but rather to indicate a ballpark number of bulk wood requirements for electricity generation. The fact that the close agreement between calculated numbers and actual operating numbers exists is sufficient verification to continue with more essential details of the cost and supply analysis.

(2) Waste Wood Supply in Coweta and Surrounding Counties-- The initial assumption for the second step of the analysis is that the cheapest and easiest source of wood is wood waste from sawmills in the area. The basic intent of this phase is to look at wood supply and ownership published in the two following sources:

1. Forest Resources Information for Carroll, Clayton, Coweta, Fayette, Fulton, Heard, Meriwether, Spalding, and Troop Counties, Georgia. Prepared by the Georgia Forestry Commission, March 19, 1979.
2. 1978 Wood-Using Industries in Georgia: A Utilization Report and Directory, compiled by P. M. Butts and W. L. Wells, Jr., Georgia Forestry Commission.

In the counties of interest, there are 2,087,700 acres, of which 1,392,600 is commercial forest land. Of the commercial forest land, 35,700 acres are publicly owned, 365,800 acres are private farmland, 817,700 acres is categorized as other private, 164,800 acres is forest industry land, and 8,900 acres is forest industry leased. There is an estimated 10,475 cords of hardwood and 13,373 cords of softwood. The annual growth of softwoods is 1,422 cords. The annual removal rate of softwoods is 470 cords. The respective numbers for hardwoods are 501 cords and 217 cords. The above numbers indicate that a considerable wood industry does exist in Coweta and surrounding counties. Thus, the local area could very probably supply sufficient sawmill waste to fuel a two to ten megawatt electric utility boiler.

Reference 2 gets more specific as to the type of forest industry and specific ownership. This study will only consider primary wood user and further limit itself to sawmills. In that geographic area described earlier, there are at least 11 sawmills. One has an estimated capacity of over 20 million board feet per year, 2 have capacities of between 10 and 20

million, 3 have capacities of between 5 and 10 million, 1 between 3 and 5 million, and 4 have capacities of less than 3 million. Georgia Forestry Commission data indicates that in the 9-county area mentioned above, there are over 530,000 green tons of wood residue produced from primary wood-using plants. Of this total, approximately 20% should fire a 10 megawatt plant. Approximately 8% of this total is listed as unused (this should fire a 4 megawatt boiler). As indicated on the 3rd part of this section, there appears to be even more unused residue than reported.

From the published data, there appears to be at least enough unused residue on close proximity for Shenandoah to fuel a 4 megawatt boiler.

(3) Field Study of Fuel Supply and Cost-- In this step, actual contact was made with sawmill operations. Three larger operations were personally visited, several other (large and small) were contacted via telephone. Basically this part will relate what was actually learned at each of the three sites, then conclude with an average calculation of approximate cost per ton of wood waste.

The first site visited produced 90 to 100 tons of green waste per day. This operation ran 5 days per week, which gives us 450 to 500 tons per week or 23,400 to 26,000 tons per year. There were no slow times or seasonal variation, so this one supplier should be able to supply enough fuel for approximately 2.5 megawatts continuous generation. The moisture content was reported as approximately 30 to 50% wet basis. The composition of the waste was 50% bark and sawdust mixture and 50% chips. The shipping distance would be about 35 miles. Preference at this site was given to shipping by rail, which was estimated to be 30% cheaper than by truck. It was further estimated that for an efficient continuous collection of waste for sale would require the expenditure of \$50,000 for conveyer, silos, and related equipment. The basic financial and engineering study had supposedly been done.

When asked about increasing the amount of waste he could supply by utilizing logging residue, the answer was that field equipment required too much maintenance and suffered too much down time to consider that idea any

further.

This supplier was presently giving sawdust away to people who would come and collect it themselves. To make the operation feasible, a price of \$7/ton was estimated. This price was also considered to be the absolute minimum.

The second site visited produced about 35 tons per day of waste on a 5-day per week operation. Once again, there were no seasonal variations reported, so this would yield 175 tons per week or 9,100 tons per year. That should roughly supply 0.9 megawatts. It was indicated that the waste could be bought for \$4.75 per ton if the buyer did his own shipping. For the supplier to ship, the price would have to escalate to \$5.50 to \$6.00 per ton.

This potential supplier said he could increase his waste by chipping residue during logging. Unlike the first site, this supplier thought it would be feasible. He indicated a low price of about \$25,000 for a small chipper.

A conveyor system was already operational at this site for waste handling, so capital expense to collect and sell sawmill waste would be minimal.

The shipping distance in this case would be about 25 miles and the method to be used would be via trucks.

The third potential supplier had initially indicated via telephone that he had no waste. He supposedly burned all of his waste for plant energy. As it turned out, he meant that he burned his kiln dried waste. He did not burn his wet waste because of pollution. This supplier presently sells bark waste and gives what sawdust he can away. The waste production was 80 tons per day of bark and 30 tons per day of sawdust. This should yield about 28,600 tons total per year, which should fire a 2.75 megawatt boiler.

The sale price here was \$2/ton for the raw material plus shipping cost. Shipping was to be via trucks. An interesting point was learned here. According to this supplier, trucks cannot be loaded to their capacity with sawdust because they are then over their weight limit. He estimates that 1/2 to 2/3 capacity would be the maximum. Shipping about 30 to 40 miles should increase the total price to about 3.50 to \$4.50 per ton. This supplier was concerned about long term commitments because he had recently suffered some capital expense to supply waste only to lose the orders 2 months later. His indication was that at least 6-month commitments should be made.

(4) Conclusion--Using what is reported above and what was discussed via telephone conversations, an approximate average of \$6/ton should be expected.

The three suppliers contacted can supply enough waste to generate around 6 megawatts. This indicates there is more available waste than reported on references 2 and 3. Using trucks appears to be the prevailing method of shipping. Capital expenditure required in some cases seemed to be required to handle the waste efficiently.

In conclusion, there appears to be enough waste wood in a 40-mile radius to supply fuel for a 10 megawatt facility.

G.--Summary

It appears that the wood fired cogeneration system is the most suitable of the central plant schemes. The first costs and operating costs are relatively low when compared to other central plant options of this size.

One important favorable point of the wood fired cogeneration plan is the use of a non-depletable fuel. Present research and development work and funding is wary of systems based on scarce fuels, while much effort is being placed into alternate fuel utilization.

5.--SOLAR OPTIONS

While several solar alternatives were investigated, this section concentrates on the possibility of utilizing solar energy in a central plant configuration to meet expected loads. This section includes a brief description of the three following solar options: 1) converting solar energy into electricity by using photovoltaic cells and providing electricity to all-electric homes and businesses; 2) generating superheated steam by concentrating solar energy with tracking parabollic reflectors and expanding the steam through turbines to produce electricity; the waste steam from the turbines is then used to meet the demand for domestic hot water, space heating, and cooling; 3) generating hot water with the use of flat plate collectors to meet domestic hot water, space heating, and cooling loads only.

In all three options, backup conventional systems are provided to meet loads when solar energy is not available or when stored energy runs out. Boilers, mechanical chillers and water heaters are some of the pieces of equipment which can be used for heating and cooling purposes. Availability of electricity must be insured by purchasing power from the grid utility whenever the central plant is unable to satisfy demands.

Preliminary cost estimates for all three options are also included. It is apparent from these estimates that the Photovoltaic and Solar Total Energy Systems (first and second options, respectively), cannot compete with the Solar Thermal System utilizing current technology. A preliminary analysis of a solar Thermal System designed to meet the expected loads is also included. Enough information is included to allow an economical comparison between the Thermal System and other systems.

A.--Photovoltaic Electric Generation

Solar photovoltaic cells convert sunlight directly into electricity. This represents an obvious advantage over solar-thermal systems due to the very high reliability and low maintenance costs. However, the difficulty of storing large amounts of electricity and the high cost of the cells are major limitations. Mass production of cells and the use of concentrators to focus sunlight onto the cell could reduce first costs drastically in the near future.

Use of photovoltaic cells at Shenandoah requires installation of a central network of cells which converts solar energy into electricity and of power lines to distribute this electricity to energy homes and businesses in the community. Individual electric water heaters and strip heaters can be used to satisfy domestic hot water and space heating needs. Cooling can be accomplished by installing conventional air conditioning units in each residence. Electricity must be purchased from the utility company any time the solar plant is unable to generate enough for its own. Also, electricity can be sold to the utility during clear days when solar energy is plentiful and generation of electricity exceeds the needs of the community. This excess power would be available during periods of peak demands.

The cost of solar cells is currently \$10/peak watt. This cost does not include the cost of the land, the cost of additional equipment in the central plant, the cost of electrical distribution or the cost of the individual building systems.

The peak insolation in the Shenandoah area is 1,000 watts/m. The peak useful energy from the sun is then calculated as follows:

$$\begin{aligned} \text{Peak Useful Energy} &= \text{Peak insolation} \times \text{cell efficiency} \times \text{AC-DC inverter efficiency} \\ &= 1,000 \text{ watts/sq m} \times 0.12 \times 0.85 = 110 \text{ watts/sq m} \end{aligned}$$

In terms of cell area, the cost is:

$$\begin{aligned} \text{Cost/cell area} &= \$10/\text{peak watt} \times 110 \text{ peak watts/sq m} \\ &= \$1100/\text{sq m} \end{aligned}$$

The demand load from the community can be calculated from information found in the previous section using the equation below:

$$\begin{aligned} \text{Annual demand load} &= \text{heating load} \\ &\text{or} = \text{cooling load/air conditioning load} + \text{electric load} \\ &= 10.6 \times 10^6 \text{ watts} \end{aligned}$$

The number 2.5 represents the coefficient of performance (COP) of a typical air conditioning unit. Assuming that the cell network is to supply 65% of the annual load, the solar participation is:

$$10.6 \times 10^6 \text{ watts} \times 0.65 = 6.85 \times 10^6 \text{ watts}$$

The cell area required is calculated below:

$$\text{Cell area} = 6.88 \times 10^6 / 110 \text{ watts per sq.m} = 62,545 \text{ sq.m}$$

The first cost of the solar cells (no other costs included) can be estimated as follows:

$$\text{Cell cost} = \$1,100/\text{sq m} \times 62,545 = \$68.8 \text{ million.}$$

This figure will be used later in the report to show that photovoltaic electric generation is not a viable alternative when compared to other solar options.

B.--Solar Total Energy System

The idea behind a Solar Total Energy System at Shenandoah is to generate hot water, chilled water, and electricity at a central plant and to distribute the utilities to individual homes. An example of how this can be accomplished is given in Appendix B, which corresponds to the schematic of a system proposed by Westinghouse Electric Corporation to supply about 65% of the energy needs of a knitwear factory in the Shenandoah area. Solar energy is collected by concentrating the sun rays by a field of tracking parabolic collectors into a common focus through which a high temperature fluid is continuously circulated. The energy content of this fluid can either be stored in periods of low demand in a high temperature storage tank, or used directly in a boiler during periods of high demand to generate superheated steam at high pressure. The steam is continuously expanded through two successive turbines, which are connected to electric generators. A portion of the exhaust from the turbines is then used to power absorption chillers which provide chilled water to the plant and the remaining is used for process heating. A similar system was proposed by General Electric for the same knitwear factory.

The energy loads of the community can be met with a system which is almost an exact replica of the one described above. The main difference is that steam is not used for process heating, but for generating hot water. Underground pipe lines carry hot and chilled water to the community, where

individual heat exchangers adjust the temperature of the circulating air to provide for space heating or cooling. Other exchangers are used for producing domestic hot water. Electricity is distributed from the central plant generators using conventional power lines.

Backup systems located in the central plant or in each residential or commercial unit provide thermal and electric energy when the energy available from the storage tank is exhausted and the sun is not shining. The Solar Total Energy System also has the flexibility of purchasing and selling electricity from and to the utility company.

The approximate total cost of the systems proposed in references 4 and 5 (10) is \$12 million dollars; they were designed to supply 33% of the electrical energy demand, 62% of the process steam and 89% of the energy required to drive the absorption chillers for an overall solar annual participation of 65%. Other information available for the same knitwear factory is as follows:

Annual space heating load	=	6.82×10^8 Btu
Annual air conditioning electric consumption	=	504,450 Kwh
Annual electric load (lighting and power)	=	830,496 Kwh
Process steam	=	6.38×10^9 Btu of natural gas + 45,576 gallons of oil

A solar system capable of supplying 65% of the annual demand should then deliver 3.32×10^{10} Btu/year.

If the total cost of the system is roughly proportional to the solar energy delivered, a comparison can then be made between the knitwear factory and the community. Thus, the total expected cost for the central community concept at Shenandoah is:

Total expected first cost = \$12 million $\times (3.32 \times 10^{10} / 1.70 \times 10^{10}) = \23.43 million

This figure is probably somewhat conservative since energy losses will be higher for the community than for the factory. However, the number \$23 million will be used for comparing the different solar options.

C.-- Solar Thermal System

The purpose of a solar-thermal system is to meet domestic hot water and space heating and cooling requirements. No attempt is made to generate electricity, and all electric power must be purchased from the utility company. The possibility of selling excess power during periods of high insolation is therefore not available.

A proposal has been submitted by Dura-Built Construction Company to construct a central solar system providing heating and cooling to a group of fifteen homes in the Shenandoah area. The proposed system will deliver 51% of the annual heating and cooling loads (1.5×10^9 Btu/yr) at an initial cost of \$246,298. The energy is to be collected by 3,324 square feet of vacuum tube flat plate collectors.

The annual heating and cooling loads for the community under consideration are calculated from information given previously as follows:

$$\begin{aligned}\text{Annual load} &= 1.709 \times 10^{10} \text{ Btu/yr} + 1.668 \times 10^{10}/0.5 \text{ Btu/yr} \\ &= 5.045 \times 10^{10} \text{ Btu/yr}\end{aligned}$$

where 0.5 is the average coefficient of performance of the absorption unit.

The cost of a system similar to the one described above can then be approximated using the assumption of a linear relationship. Thus,

$$\begin{aligned}\text{Approximate cost} &= \$246,298 \times (5.045 \times 10^{10} / 1.5 \times 10^9) \\ &= \$8.28 \text{ million}\end{aligned}$$

This cost corresponds to a solar participation of 51%. In order to compare the thermal system with the other systems already described in this report, the cost must refer to a solar participation of 65%:

$$\begin{aligned}\text{Adjusted cost(65\% participation)} &= 8.284 \times (0.65/0.51) \\ &= \$10.6 \text{ million}\end{aligned}$$

D.--Comparison among Solar Options

The photovoltaic and the Solar Total System are obviously not attractive from the economic standpoint when compared with a thermal-only system. Therefore, only the latter will be considered in more detail in the Appendix of this report.

CHAPTER 5

ENERGY CONSERVATION PLANS

5.1-- Introduction

This chapter contains a description of the conventional development plan and brief descriptions of the three energy conservation plans developed in Chapter 4. Following the three levels of conservation approaches for the community is a section which depicts the energy usages for each of the plans as well as the estimated energy savings between each of the plans and the conventional plan. The final section examines the costs and savings involved with each plan and presents the overall savings/investment analysis for each.

5.2-- Site and Climate Characteristics

It should be noted that the energy conservation plans which are presented below are located on the same site as the original conventional plan. Therefore, the same site and climate descriptions which were presented in Chapter 2 above will hold for the three energy plans. The only difference which exists between the conventional plan and the energy plans is the number of units of the various building types. We felt that one energy conservation measure would be to place a higher density in some of the land uses shown in the conventional plan. Consequently, there are more building units shown in the energy conservation site plans. This difference is only shown for planning purposes. The energy and economic analyses are based on the equivalent numbers of buildings and/or square footage, whichever was easiest to work with. Therefore, the energy and economic analyses are consistent from one plan to the next.

5.3--Conventional Development Program

LEGEND

- A. JUNIOR HIGH SCHOOL
21.62 AC, 130,000 S.F. TOTAL FLOOR AREA
- B. CHURCH/DAY CARE CENTER
9.67 AC
- C. FIRE/POLICE STATION
2.6 AC, 2,400 S.F. TOTAL FLOOR AREA
- D. 75 SINGLE FAMILY UNITS
54.48 AC, 96,800 S.F. TOTAL FLOOR AREA
(1400-1800 S.F./UNIT)
- E. 50 TOWNHOUSE UNITS
6.35 AC, 101,000 S.F. TOTAL FLOOR AREA
(50 UNITS @ 1800 S.F., 20 UNITS @ 1200 S.F.)
- F. GOLF CLUB
5.7 AC, 20,000 S.F. TOTAL FLOOR AREA
- G. MAINTENANCE BUILDING (GOLF)
2.7 AC, 10,000 S.F. TOTAL FLOOR AREA
- H. 26 SINGLE FAMILY UNITS
12.73 AC, 51,200 S.F. TOTAL FLOOR AREA
(1800-2600 S.F./UNIT)
- I. 200 APARTMENTS
20.42 AC, 231,000 S.F. TOTAL FLOOR AREA
(50 2BR UNITS @ 950 S.F., 120 3BR UNITS @ 1200 S.F.)
- K. CONVENIENCE SHOPPING/GAS
5.85 AC
- L. GOLF COURSE
- M. RECREATION AREA / OPEN SPACE
12.20 AC

- APPROXIMATE LOCATION OF EXISTING SANITARY SEWER
- - - - - PROPOSED SANITARY SEWER
- ▬▬▬▬▬▬ PROJECT BOUNDARY

REV. 8/1/78

6/27/78

SHENANDOAH

COWETA COUNTY,

GEORGIA

**A CASE STUDY OF PROJECT PLANNING
AND DESIGN FOR ENERGY CONSERVATION**

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. DE-78-0-01-4318

TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY - ENGINEERING EXPERIMENT STATION
SHENANDOAH DEVELOPMENT, INC.
LAURANN REED AND ASSOCIATES - LANDSCAPE ARCHITECTS AND ENVIRONMENTAL PLANNERS
FINCH, ALEXANDER, BARNES, ROTHSCHILD, AND PASCHAL, INC. - ARCHITECTS
NEWCOMB AND BOYD - MECHANICAL ENGINEERS
WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

SHEET **1** OF

CONVENTIONAL
PLAN

FIGURE 5.3.2.1

5.3.1--Site plan.

The conventional site plan for the 235-acre study area is shown below. The conventional site plan has been designed from standard development practices and the buildings have been sized and oriented in accordance with standard practices.

5.3.2--Description of normal development process.

The development process followed at Shenandoah is a standard process. The developer either buys or gains control of a large area of contiguous parcels of land. The developer outlines a general guide to land use patterns over the total site. Since Shenandoah is a New Community, it offers industrial, commercial, and residential sites with different portions of the 7,400 acres planned for each.

The standard practice in community development is to attract jobs through sale of commercial and industrial sites; these jobs will attract new residents to the community. The developer will sell lots or larger parcels of land to builders to build homes, condominiums, and apartments within certain guidelines concerning appearance, size, set-back distances, etc.; these guidelines are contained in the covenant of the community.

The internal decision-making of Shenandoah Development can best be understood by examination of Figure 5.3.2.1, which shows the planning team. For an illustration of how this planning team works, we have used the decision-making process of formulating a five-year development plan under which the project is now proceeding. The five-year development plan was completed on May 20, 1977, to guide the project for years 1977-1981.

The following categories have been treated in the five-year plan:

1. Subdivision development schedule and costs (23 subdivisions in parts of three villages).
2. Village-wide development schedule and costs for infrastructure (water, sewer, roads, underpasses, railroad spurs, etc.) in parts of four villages.
3. Town-wide development schedules and costs for boulevards, road relocation, water and sewer facilities, etc.

4. Calculation of water and sewer needs for industrial, residential, and commercial uses.
5. Schedule and construction costs of community facilities (open space improvements, recreation facilities, fire and police stations, etc.)

The formulation of this five-year plan was directed primarily by Shenandoah's chief executive officer, guided by the chairman of the board, in close cooperation with the president and comptroller.

The plans, as drawn by Shenandoah, are submitted to the New Communities Development Corporation of the U.S. Department of Housing and Urban Development for analysis and feedback from HUD in areas of marketing, finance, housing, social planning, etc.

The plan began with marketing analyses based on industrial sales in Shenandoah and environs between January 1975 and May 1977, on sales in metro Atlanta and its sub-regions, and on future market projections for these respective areas during the next five years.

Once the market demand and anticipated revenues were established, the planning and engineering divisions were involved in the following decisions:

1. what areas are already developed to meet the anticipated demand;
2. which adjacent lands can be most easily and economically developed, with the least added infrastructure and the highest conformity to good land use and the 25-year development plan;
3. what are the estimated costs of these developments.

Consulting engineers, particularly in the area of water and sewer needs, are brought into these deliberations. Governmental agencies, such as the State Department of Natural Resources, and quasi-governmental agencies, such as the Newnan Water and Light Commission, are among those involved in these decisions.

When buildable areas have been selected, and lot sizes and densities determined, the planner lays out the preliminary drawings for the configuration of roads, lots, water and sewer lines, open spaces, tot lots, bikeways, etc. The Shenandoah planner interfaces with the Coweta county

planner. The Shenandoah project engineer consults with the Coweta County building superintendent, who must eventually accept the roads for county maintenance. And the engineer also consults with appropriate representatives of all utility companies.

Plans are also submitted to Shenandoah's Development Review Committee. Since the A-95 Review process was completed in 1973, there is no further requirement to submit routine plans to that process of state agencies. However, Shenandoah maintains a close liaison with the A-95 office in the State Office of Planning and Budget, and has several times voluntarily submitted development plans for review and comment. This is particularly applicable to the archaeological arm of A-95, which has examined Shenandoah sites on a number of occasions.

When approval has been gained from all interested parties, Shenandoah's engineering department engages a consulting engineering firm to prepare final plans for development, which are used to obtain a building permit from the office of the County building superintendent. The detailed final plat is filed with the Clerk of Superior Court, and the project is let out for bidding with the work ordinarily awarded to the lowest qualified bidder. That construction firm is provided with copies of Shenandoah's erosion and siltation guidelines, as well as the guidelines of the Development Review Committee (DRC). Construction proceeds accordingly, with close oversight by Shenandoah's engineers. Since all utility lines are buried underground inside Shenandoah, there must be coordination with utility companies during all the phases described here.

While the land is being developed, the sales and promotion divisions of Shenandoah are proceeding with marketing of the sites. Slightly different procedures are followed in the three main divisions of sales.

(1) Residential sales. Shenandoah Realty, Inc., a wholly-owned subsidiary of Shenandoah Development, Inc., sells land, not to individuals, but to builders. Builders submit architectural drawings and site development plans to the Development Review Committee for consultation and approval. Present DRC guidelines make no specific requirements for energy

conservation. But Coweta County operates under the Southern Standard Building Code. And the Special Projects division of Shenandoah has worked closely with builders and industrialists to encourage energy conservation practices and the use of alternate energy sources.

Approved builders may buy several lots for speculative or pre-sold houses--or they may buy from one to four lots for model homes, and place a number of additional lots under option. Homebuyers, looking at the model homes, may choose a particular model with certain added optional features (garage, basement, solar water heating system, etc.) and pick one of the lots under option to that particular builder. Electricity and natural gas are available without restrictions to homebuyers.

A building permit is secured from the office of the County building inspector and construction proceeds under the supervision of the Shenandoah engineering division. Coweta county also has building inspectors who visit the site. Shenandoah's governmental relations division, working with the engineering department, has secured approval for FHA and VA loans of each subdivision which has a recorded plat.

(2) Industrial sales. Approximately 450 acres in Shenandoah's 1,200-acre Industrial Park have already been developed (graded, with utilities, access roads, etc.). Industrial prospects are at present far more careful in examining energy availability and options for energy conservation and alternate energy sources. Industrial clients for developed or undeveloped lots must submit site and building plans to the DRC, and to the office of the county building inspector for a building permit. Water needs are especially sensitive and heavy water users are discouraged. Similarly, industrial wastes, sewerage, and air pollution are closely examined by the DRC in line with present and projected stringent requirements of EPA. The State Department of Natural Resources has been frequently consulted on these matters.

(3) Commercial sales. Ordinarily handled with the same processes as described in Industrial sales.

(4) Public buildings and amenities. Currently, these matters are under the direction of the staff of Shenandoah Development, and the DRC. Where government grants are involved, it is necessary for the Governmental Relations and Special Projects Divisions to work with federal, state, and local agencies such as HUD, DOE, EPA, DOT, HEW, State Department of Natural Resources, A-95 Clearinghouse, Chattahoochee-Flint APDC, Coweta County Commission, Coweta County Board of Education, and other official and quasi-official planning bodies.

5.3.3--Description of building types.

The conventional plan primarily contains residential units, including single-family detached, garden apartments, and townhouses, along with a high school, fire and police station, golf club, and a shopping/gas store.

-Single-family detached: 73 units @ 1,600 s.f. and 26 units @ 2,200 s.f.; 174,000 s.f. total or 26.5% of site total.

-Townhouses: 20 units @ 1,200 s.f. and 30 units @ 1,500 s.f.; 69,000 s.f. total or 10.6% of site total.

-Apartments: 80 units @ 950 s.f. and 120 units @ 1,300 s.f.; 232,000 s.f. total or 35.4% of site total.

-High school: 160,000 s.f. or 24.3% of site total.

-Fire and police station: 2,400 s.f. or 0.4% of site total.

-Golf clubhouse: 14,700 s.f. or 2.2% of site total.

-Shopping/gas: 4,000 s.f. or 0.6% of site total.

The total square footage for the site is 656,000.

The land use allocated for a church/day care center is within the study area; however, the team decided to omit the center from the study because there would essentially be no changes made on it throughout the study and the energy consumption was negligible. Likewise, the maintenance building is omitted from the analysis because it does not change throughout the analysis and is neither heated nor cooled.

5.3.4--Conventional plan building costs.

The cost per square foot for each building type is presented below. The costs include the energy end-use systems and represent the costs associated with the standard construction. Standard construction implies: (a) single-glazing in residential units, double-glazing in non-residential units (b) R-11 insulation in walls, R-19 insulation in ceilings (c) standard 2x4 frame construction in residential units, golf club, and convenience store (d) brick veneer with interior concrete block in the school and fire/police station.

Building	Units	\$/sf	\$/unit	Total \$
SFD-1600	73	23	36,800	2,686,400
SFD-2200	26	24	52,800	1,372,800
TH-1200	20	23	27,600	552,000
TH-1500	30	24	36,000	1,080,000
APT-950	80	20	19,000	1,520,000
APT-1300	120	20	26,000	3,120,000
SCHOOL	1	32	5,120,000	5,120,000
F/P	1	40	96,000	96,000
GOLF	1	48	705,600	705,600
COMMERCIAL	1	24	96,000	96,000
Total				\$16,348,800

In addition to the above construction costs, the site and lot development costs are allocated to each building type as follows:

Building	Lot Development	Site Development
SFD-1600	\$113,600	\$383,202
SFD-2200	39,910	186,806
TH-1200	20,039	79,446
TH-1500	37,711	148,157
APT-950	51,673	243,075
APT-1300	105,867	511,034
SCHOOL	152,588	521,770
FIRE-POLICE	34,367	8,589
GOLF CLUB	44,770	47,238
COMMERCIAL	40,980	12,883
TOTALS	\$641,505	\$2,141,200

5.3.5 -- Energy Consumption in Conventional Plan

The conventional plan as described above will use both electricity and natural gas. Natural gas will provide space heating, water heating, and cooling needs and electricity will supply cooling, lighting, and

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MWH)
1	SFO(1630)	42.400	17.61	0.00	0.00	0.00	1285.64
2	SFO(2200)	42.400	24.35	0.00	0.00	0.00	633.22
3	TH(1200)	45.000	15.12	0.00	0.00	0.00	302.47
4	TH(1500)	45.000	20.47	0.00	0.00	0.00	614.11
5-10	APT(950)	49.000	18.08	0.00	0.00	0.00	1446.36
6	APT(1300)	49.000	22.38	0.00	0.00	0.00	2686.10
7	MS	43.400	1532.70	0.00	0.00	0.00	1532.70
8	F/P	54.900	66.70	0.00	0.00	0.00	66.70
9	GOLF	54.900	287.10	0.00	0.00	0.00	287.10
10	COMM	54.900	78.10	0.00	0.00	0.00	78.10
							8,932.50

Table 5.3.4.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MMBtu)
1	SFD(1600)	2.796	113.07	0.00	0.00	0.00	8,253.86
2	SFD(2200)	2.796	156.36	0.00	0.00	0.00	4,065.34
3	TH(1200)	2.796	67.63	0.00	0.00	0.00	1,352.54
4	TH(1500)	2.796	91.53	0.00	0.00	0.00	2,746.06
5	APT(950)	2.796	56.54	0.00	0.00	0.00	4,522.84
6	APT(1300)	2.796	70.00	0.00	0.00	0.00	8,399.56
7	HS	2.912	220.30	0.00	0.00	0.00	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10
9	GOLF	2.912	156.10	0.00	0.00	0.00	156.10
10	COMM	2.912	42.50	0.00	0.00	0.00	42.50
							<u>29,790.20</u>

Table 5.3.4.2

miscellaneous needs except in the high school, where heating will be provided by electricity.

The total annual electrical energy consumption for the conventional plan is 8932.5 MWH. The electrical energy consumption in MWH per unit as well as the cost in \$/MWH is shown below in Table 5.3.4.1.

The total annual natural gas consumption for the conventional plan is 29,790.2 MMBtu. The per unit consumption (MMBtu) and costs (\$/MMBtu) are shown below in Table 5.3.4.2.

5.3.6 -- Cost Figures and Assumptions of Model

The costs of the conventional plans as well as the conservation plans which follow in this chapter are divided among the various elements of the plan and are analyzed in several ways. Basically, the total cost is comprised of the following parts: building construction, site and lot development, electrical energy, natural gas energy, and thermal energy. These cost figures and energy consumption figures are considered the "base" figures throughout the remaining analysis. All changes in costs and energy unless otherwise stated refer to these figures.

The incremental construction costs show any positive or negative changes in the construction costs of the base plan. Similarly, the incremental development costs show any changes in the site and lot development costs because of any modifications to the base plan. The incremental energy costs indicate the levels of dollar savings because of lesser amounts of energy consumed in the conservation plans relative to the conventional, or base, plan.

It should be noted that when "annual costs" are discussed below and in the tables, these numbers refer to non-discounted, current dollars. Only when reference is made to "net present value" or "present value" are the costs discounted, and in all cases dollars are discounted to 1981 dollars since that is the official starting date for the Shenandoah project.

An explanation of some of the notation and abbreviations will simplify the understanding of some of the tables and discussion. The notation "L"- "digit"- "letter" indicates which level plan is being discussed and the type of construction. A "0" indicates the conventional plan, a "1" indicates the Level 1 , or passive, site plan, a "2" indicates the Level 2, or decentralized options, site plan, and a "3" indicates the Level 3, or central utility, site plan. An "S" indicates standard construction with 2 x 4 studs, R-11 insulation in walls, R-19 insulation in ceilings, and single glazing. An "R" indicates the revised or improved construction techniques with 2 x 6 studs on 24 inch centers, R-19 insulation in the walls, R-26 insulation in the ceilings, and double glazing. Therefore, for example, the LOS plan refers to the conventional plan with standard construction (the "base" plan) and the L3R plan refers to the central utility plan with revised construction.

When referring to the primary LOS, L1R, L2R, and L3R plans, there are a standard set of assumptions which are implied. The total period of analysis is 25 years with all construction in the first 3 years and the balance of the analysis takes place over the next 22 years. Note, however, that as buildings are completed during the first 3 years, they begin consuming energy. By the end of the third year, all buildings are online and consuming energy. The construction financing is assumed to be a 5 % annual effective rate. The reason for this apparently low rate is that any one construction dollar is generally not loaned for an entire year. For example, a house will be built and the construction loan paid off in 2-3 months. Therefore, its annual effective rate is only 1/6 to 1/4 of the actual annual rate. We assumed construction loans would equal the prime rate plus 2-3 points; with a prime rate of 12% , we chose 15% as the actual annual rate. Although some buildings will take longer than 4 months, we chose this time period as the standard construction time period which gives us an annual effective rate of 5%. We feel this simplifying assumption will give an adequate estimate of interest charges during the construction period.

The standard discount rate of 10% is used. Although we feel this is unrealistically low at this time since the annual inflation rate is higher

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290822.	0.	585716.	0.	1879685.	0.	5756224.
SINGLE FAMILY (2200)	1616006.	0.	288488.	0.	925741.	0.	2830235.
TOWNHOUSE (1200)	691152.	0.	120855.	0.	396577.	0.	1208583.
TOWNHOUSE (1500)	1283566.	0.	224407.	0.	805276.	0.	2313251.
APARTMENT (950)	1852752.	0.	366388.	0.	1909334.	0.	4128474.
APARTMENT (1300)	3761696.	0.	744005.	0.	3545280.	0.	8050981.
SENIOR HIGH SCHOOL	6195200.	0.	815972.	0.	1395291.	0.	8406464.
FIRE-POLICE STATION	116160.	0.	51977.	0.	79793.	0.	247930.
GOLF CLUBHOUSE	853776.	0.	111330.	0.	336161.	0.	1301267.
COMMERCIAL SPACE	116160.	0.	65174.	0.	88952.	0.	270287.

Table 5.3.6.1

SHENANDOAH CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION LLS
CONVENTIONAL - STANDARD
ANALYSIS PERIOD 22 YEARS
CONSTRUCTION PERIOD 3 YEARS
CONSERVATION LEVEL 5-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING 5.00%
DISCOUNT RATE 10.00%
R O I CAPITAL 20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

PRESENT VALUE COST REPORT

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
5-15 DETACHED DWELLING UNITS	496828.	0.	674264.	0.	2865426.	0.
CLUSTER DWELLING UNITS	7589168.	0.	1455654.	0.	6656467.	0.
INSTITUTIONAL FACILITIES	6311360.	0.	867950.	0.	1475084.	0.
COMMUNITY FACILITIES	989936.	0.	176504.	0.	425114.	0.
TOTAL	19777293.	0.	3374312.	0.	11362091.	0.
INTEREST	988865.	0.	0.	0.	0.	0.

* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981

TOTAL NET PRESENT VALUE - \$ 35502501.

Table 5.3.6.2

SITE PLAN

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	5694799.	0.	1243913.	0.	229761.	0.	7465473.
1982 - 2	12204532.	0.	2627618.	0.	583715.	0.	14815865.
1983 - 3	3230831.	0.	472033.	0.	676638.	0.	4279503.
1984 - 4	0.	0.	0.	0.	730437.	0.	730437.
1985 - 5	0.	0.	0.	0.	788576.	0.	788576.
1986 - 6	0.	0.	0.	0.	851410.	0.	851410.
1987 - 7	0.	0.	0.	0.	919327.	0.	919327.
1988 - 8	0.	0.	0.	0.	992743.	0.	992743.
1989 - 9	0.	0.	0.	0.	1072112.	0.	1072112.
1990 - 10	0.	0.	0.	0.	1157925.	0.	1157925.
1991 - 11	0.	0.	0.	0.	1250714.	0.	1250714.
1992 - 12	0.	0.	0.	0.	1351057.	0.	1351057.
1993 - 13	0.	0.	0.	0.	1459580.	0.	1459580.
1994 - 14	0.	0.	0.	0.	1576961.	0.	1576961.
1995 - 15	0.	0.	0.	0.	1703938.	0.	1703938.
1996 - 16	0.	0.	0.	0.	1841308.	0.	1841308.
1997 - 17	0.	0.	0.	0.	1969938.	0.	1969938.
1998 - 18	0.	0.	0.	0.	2150768.	0.	2150768.
1999 - 19	0.	0.	0.	0.	2324820.	0.	2324820.
2000 - 20	0.	0.	0.	0.	2513199.	0.	2513199.
2001 - 21	0.	0.	0.	0.	2717109.	0.	2717109.
2002 - 22	0.	0.	0.	0.	2937354.	0.	2937354.
2003 - 23	0.	0.	0.	0.	3176852.	0.	3176852.
2004 - 24	0.	0.	0.	0.	3435639.	0.	3435639.
2005 - 25	0.	0.	0.	0.	3715889.	0.	3715889.

Table 5.3.6.3

than 10%, we assume that the inflation rate will not maintain this high level indefinitely. If this assumption proves to be wrong, the ramifications of long-term inflation at these high levels would render this (and all other) analysis ineffectual. A return on investment of capital figure is shown on some tables. This is used for an extension of this model which employs an opportunity cost option; this option is not used in this analysis and should be ignored.

There are four annual escalation rates used in the model: construction, electricity, natural gas, and thermal. These rates are assumed to be 10%, 7.5%, 10%, and 5%, respectively. The construction rate is effective only during the first 3 years, and the energy rates are effective throughout the analysis period. The escalation rates include general inflation and are not incremental rates.

Unless otherwise stated, the above assumptions are in use. When sensitivity analyses are run, the variable being examined will be stated and, in general, will be shown on tables and the computer print-outs. Unless otherwise noted, all other assumptions remain the same.

5.3.7 -- Costs of Conventional Plan

The total construction, development, and energy costs are summarized by each of the 10 elements, or building types, in Table 5.3.6.1.

Table 5.3.6.2 shows the present value of all costs by cost centers, including construction, development, energy, and interest on construction. The total present value of all costs of the LOS plan is \$35,502,561. The meaning of this figure is the construction of all buildings on the site and the consumption of energy in the buildings over the next 25 years would cost, in 1981 present value dollars, approximately \$35.5 million. The annual costs of construction and energy consumption are summarized in Table 5.3.6.3.

The figures below show the sensitivity which the LOS plan has to changes in the price escalation rates of electricity and natural gas and

FIGURE 5.3.1

FIGURE 5.3.2

Sensitivity: Natural Gas Fuel Escalation 5 - 16%

FIGURE 5.3.3

the discount rate. As can be seen, as the escalation rate of electricity moves from 5% per year to 16% per year, the total present value of the plan moves up rapidly from \$33.2 million to \$54.6 million. Because of the high cooling needs of the plan, the costs prove to be quite sensitive to changes in the price rise of electricity, showing a 64% increase in present value of costs.

On the other hand, as the price escalation rate of natural gas increases from 5% to 16% annually, the present value of the LOS plan increases from \$34.4 million to \$38.7 million, a 12.5% total increase.

As the discount rate changes in the range from 9% to 20% the present value falls 25.6% from \$37.0 million to \$27.5 million. This is, naturally, to be expected since the energy costs beyond a few years are greatly discounted as the discount rate compounds from year to year.

5.4 -- CONSERVATION PLAN PROGRAMS

5.4.1-- The Passive Site Plan

5.4.1.1-- Introduction.

The concept for the development of mixed land uses at Shenandoah as a passively sited, energy conserving community is based on a plan that uses the natural site characteristics, maximizes on passive energy siting requirements, and allows flexibility for the changing needs of the Shenandoah Development Corporation.

The northern portion of the site is developed primarily for public facilities. The high school, church/day care, and police/fire station are developed here since each facility requires direct accessibility and visibility from Georgia route 34 and each facility is centrally located to future development. The convenience store is also developed here since its location lends itself to quick stops, central location, and high visibility.

Apartments and townhouses are developed in the central portion of the site since slope, aspect, and soils are most favorable for this high

PASSIVE SITE PLAN

LEGEND

- 6 GARDEN APARTMENTS
- 2 TOWNHOUSE UNITS
- TYP SINGLE FAMILY DWELLING
- BICYCLE & PEDESTRIAN PATH
- TOT LOT or PLAY AREA

SHENANDOAH

COWITA COUNTY,

GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR DEPARTMENT OF ENERGY - CONTRACT NO. EM 78-G-01-4215

TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY ENGINEERING EXPERIMENT STATION
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 FINCH, ALEXANDER, BARNES, ROTHSCHILD, AND PASCHAL, INC. - ARCHITECTS
 NEWCOMB AND BOYD - MECHANICAL ENGINEERS
 WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

**PASSIVE
SITE PLAN**

intensity development. These land uses are serviced by a loop road from road "C". This site has close proximity to open space and goods and services. Single family development is also located in this area with adequate separation from the proposed high density residential by the loop road and an open space corridor.

The southern portion of the site is developed primarily for single family detached residential units. This area, in addition to having good soils and slope exposures, is removed from higher intensive residential areas and public services and is more suited for single family. This area is serviced by a loop road from road "C" which will connect with future residential development to the south.

The golf course occupies a major portion of the flood plain with the clubhouse and maintenance building on a north slope. The area developed for the clubhouse is most suited for this facility because of its location to the golf course. The recommendations for siting and building integration for each land use facility are discussed individually in the following section.

3.4.1.2 -- Passive Plan Facilities and Recommended Guidelines

1. 216 Garden Apartments.

This high density building type is located on the most favorable slope and exposure on site with good access to main thoroughfares, shopping, and services. With this location, car trips to these services will be a minimal distance. The buildings form a loose, open east-west layout which will provide maximum summer breeze cooling. The layout of the parking area will reduce direct solar heating of the pavement.

A linear green belt area will separate the apartment building clusters individually providing visual relief and pedestrian walkways. The impact of natural drainage courses is minimal since the building and parking follow the natural contour of the land reducing excess grading, preserving existing vegetation, and lowering grading and planting costs. The following sketch suggests the landscape treatment of apartment dwellings required for energy conservation. The two schemes presented show buildings both north and south of the parking lot and their suggested treatment.

The buildings north of the parking lot will contain the outdoor living patios toward the green belt area. A berm was not placed on the building in order to gain light and air circulation to the ground floor units. However, a berm and coniferous planting will be placed 10 to 15 feet from the patio area creating a wind protection for the building. A swale is developed around the building in order to allow cold air drainage to pass.

FIGURE 5.4.1.1

Apartments ————— Passive Site Guidelines

Plan north ↑
scale 1" = 40'

Single Family -
Two Development Strategies

Windows on the north side of the building should be minimal. However, light and natural ventilation will aid in preserving energy use in each building.

2. High School.

Since the school needed high visibility from Georgia Highway 34, it was generally locked into this site on the conventional plan. However, the school position is much better over the conventional

plan since it is located to the north side of the parcel, in turn allowing adequate area for parking and recreation. The 160,000 square feet area in the building and 500-car parking lot is located in old pasture areas, minimizing clearing and grubbing costs.

Other facilities include a 1/4-mile running track, a football field and regulation baseball field. The school building should be flexible in design in order to accommodate all required classroom facilities during the day, and college classes, plays, musical concerts and/or social gatherings during the night. Although building location is on south sloping terrain, it is recommended that the north, east and west walls are bermed. Maximum natural lighting and solar collection is recommended for the roof and south wall exposure.

3. 112 Single Family Units.

The single family dwellings are a mixture of large homes (2200 to 2600 s.f.) and average homes (1400 to 1800 s.f.) located in various areas throughout the site. The majority of single family units are located near the southern portion of the site which is best suited for such development. The majority of the streets are oriented east-west allowing optimum southern orientation for each lot. Many of the dwellings were staggered to allow for air circulation during the summer and wind protection during the winter. Side lot setbacks are minimal in order to allow protection on east and west wall exposures from direct solar gain. Also, many property lines will have a common planting of heavy shading deciduous trees reducing solar gain and planting costs to the home buyer. For dwellings on west and north slope exposures, stringent grading and berming standards should be enforced by the development review committee. The sketch below indicates suggested passive requirements for dwellings on north and west slope exposures.

4. Golf Course, Clubhouse and Maintenance Building.

Seven holes of the 18-hole golf course occupy the majority of the flood plain, with four holes across road "C" to the east and seven holes to the west of the west boundary line. The realignment of holes 2 and 3 from the conventional plan relieved some prime south sloping land for residential development. Holes 2 and 3 were placed on westerly sloping terrain, utilizing an area where housing should not be placed. The golf course, being on the lowest areas on site, will open up dense lowland vegetation, allowing better air movement and evaporation of soil moisture which will in turn lower humidity.

The clubhouse is situated on a knoll overlooking the golf course where a good terminus is created for holes 9 and 18. This area contains prime hardwoods that exist on site; therefore, care in grading and clearing is essential to the success of this facility. A parking lot of about 145 spaces services the clubhouse. This should be adequate for a facility of this nature.

FIGURE 5.4.1.3

Section
Scale: 1"=20'
North ←

Adjustable Reflection
Board - Winter Solar
Gain

heavy Coniferous
Planting

Air & Light Intake

Perm 1st Floor
West, East & North
Wall areas! Enter
Building on 2nd
Floor

Existing Grade

2nd Floor

1st Floor

Jan Sun-Noon

July Sun-Noon

Outdoor Patios

Horizontally louvered
divider for privacy &
controlled air movement
between units.

Louvered Canopy

Adjustable for
control of solar gain

Plan North ↑
Scale: 1"=60'

Berm & conifers
perpendicular to
wind. Entrances
are protected.

Place parking between
existing trees - assure
minimal impact to trunk
& roots.

Entrance Walk

850'
845'
840'
30' min.

Preserve
Existing Trees

Solar Access Area
Cleared

Solar Access Area

Outdoor Patios

Townhouse Units

Passive Site Guidelines

The maintenance building is tied into the entrance road of the clubhouse with direct access to the golf course.

5. 50 Townhouses.

The density of 6.0 dwellings per acre will provide ample area for living. This area is serviced by a single loaded loop parking lot in order to preserve as many pines and hardwoods as possible. A clubhouse with pool and parking is provided with the townhouse area, although four more units may be substituted in its place. Approximately 3/4 of the townhouse units have direct frontage on the golf course. Almost all the units attained optimum orientation except where restricted by grade.

The treatment of integrating the townhouse building with the landscape will permit berming the complete wall area of the ground floor. The following sketch recommends standards for townhouse development on site.

6. Police/Fire station.

Since the police/fire station will be responsible for the local area only, a single building is recommended in the passive siting plan. The location is adjacent to Road C and near Georgia route 34. Because of the necessary requirements of the physical structure and design of the police and fire station, there is little which can be done to the building itself. If possible, we recommend some partial berming and some planting on the north, east, and west exposures.

7. Convenience store/Gas.

Since this service is a quick shop facility, visibility and close access to Road "C" was imperative. This facility contains a total of 4,000 s.f. with ultimate parking capacity of 57 spaces. The building is optimally oriented and we recommend planting for the building.

8. Circulation.

As mentioned earlier, practically all streets in residential areas were aligned east-west in order to allow north-south oriented lots. Both the north and south residential areas are serviced by two loop roads. Road widths are planned for twenty feet providing many positive factors for the development of the area. Right of way widths have been reduced to forty feet allowing a ten foot area between the road.

A bicycle path and pedestrian walkway system are planned for the entire 235 acres and will connect future developments on all sides of the site. These trails are aligned to traverse each of the major use areas and link all residential units for the convenience of the residents. In most cases these paths will be in open space corridors away from roadways.

The above description of the Level 1 plan presents the overall layout of the plan and, along with the description given above in Chapter 4, presents the underlying rationale of the plan. This section will

delineate the various functional changes which will be required in the site and lot development, landscaping, and building construction.

There are two groups of changes in the building construction which will be necessary. In order to increase the overall thermal efficiency of the building and to reduce air infiltration certain changes are needed. The revised construction calls for increasing the R-values of the walls and roofs of most of the building types. The R-values of the walls and roofs are increased from R-11 and R-19 to R-19 and R-26, respectively. In addition, all windows are replaced with double-glazing. Finally, a tighter building is built by caulking around windows, doors, and any other part of the building where a structural break is made. These changes will reduce the overall U-value of each building and reduce air infiltration.

The second type of change necessary in the actual building design is to accomodate the passive siting of each building. When the townhouses and apartments were designed in the clusters shown above rather than the rectangular configuration shown in the conventional plan, the total perimeter of the buildings increased. This naturally adds to the cost of construction and is taken into account. Because of the southern exposure enjoyed by nearly all of the buildings and the increased glass areas on the southern walls, care must be taken to minimize the direct solar gain through these windows in the summer months. To accomplish this overhangs have been added to all buildings along the southern glass areas. The width of the overhangs has been established at approximately three-quarters the height of the glazing.

The changes which are necessary outside of the building include shading, berming, and shelterbelts. Shading will be provided by existing vegetation and additional planting. Note that care must be taken when grading and lot preparation is done to leave those trees which will enhance shading and act as shelterbelts. Planting of shade trees will be necessary on some single family, apartment, and townhouse units in addition to the school, fire/police, and convenience store buildings. With proper shading placement as much as 75% of direct solar radiation can be relieved.

Berming will be required on the townhouses and the school buildings. The townhouses will have their lower levels either partially or totally bermed depending on the particular slope on which they are placed. The school will have total protection on the north, east, and west walls.

The shelterbelts are primarily made, where possible, on existing earth berms or ridges and should be placed no more than twenty nor less than ten feet from the structures. By using the earth berms, existing vegetation, and additional planting, air infiltration can be reduced substantially. Previous research has indicated that a properly placed shelterbelt can reduce air infiltration 40%. Although we do not include fences in our study, the addition of a five foot wooden fence, when used with the above shelterbelt can reduce the air infiltration as much as 60%. (Mattingly and Peters, 1975). Other studies have shown that heating energy requirements have been reduced from 23-34% with the proper placement of shelterbelts (Olgyay, 1963 and Flemer, 1974). Shelterbelts in addition to existing berms and vegetation are provided for single family, apartment, and townhouse units.

5.4.2--The Passive Site Plan with Decentralized Systems

The Level 2 plan is identical with the Level 1 site plan plus a series of decentralized systems have been added to the residential units: the single-family detached, the apartments, and the townhouses.

As discussed in Chapter 4, four options were considered economically feasible, technically feasible, and marketable. The four options include solar water heating, direct gain systems, attached greenhouse, and Trombe walls. Since it is unlikely that both a direct gain system and a Trombe wall would be used in conjunction with one another, we have decided to use only the direct gain system in the Level 2 analysis. All descriptions, data, and cost information is given in Chapter 4. The site plan is identical to the passive, Level 1 site plan shown in Map 5.4.1.1 above.

5.4.3--The Central Utility Plan

CENTRAL UTILITY SITE PLAN

LEGEND

- 6 GARDEN APARTMENTS
- 2 TOWNHOUSE UNITS
- TYP SINGLE FAMILY DWELLING
- BICYCLE & PEDESTRIAN PATH
- TOT LOT or PLAY AREA

SHENANDOAH

COUNTY

GEORGIA

A CASE STUDY OF PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

PREPARED FOR: DEPARTMENT OF ENERGY - CONTRACT NO. ES-78-G-01-4215

TEAM MEMBERS: GEORGIA INSTITUTE OF TECHNOLOGY - ENGINEERING EXPERIMENT STATION
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WILLIAMS-RUSSELL AND ASSOCIATES - CIVIL ENGINEERS

CENTRAL UTILITY SITE PLAN

The central utility plan (L3) is shown below in Map 5.4.3.1. The location of the central plant is on the eastern side of the site in a central location to the study site. The basic site plan is similar to the Level 1 plan except that higher density dwellings have been moved to areas adjacent to central site. This will reduce the distribution costs these more dense, more energy intensive land uses. Other than these changes, the same principles which were discussed in the Level 1 plan hold and were used for development of the Level 3 plan.

The actual plant which is recommended for the site is the wood-fired cogeneration plant discussed above in Chapter 4. The economic analysis, projected energy savings, and total costs discussed in the remainder of this chapter are based on the figures and data presented in Chapter 4.

5.5 -- Estimated Energy Savings

This section presents the estimated energy savings of each of the three energy conservation plans: L1R, L2R, and L3R.

5.5.1 -- L1R

The total annual energy savings are shown for electricity and natural gas below in Tables 5.5.1.1 and 5.5.1.2. The total annual electrical savings is 496.25 MWH and the total annual natural gas savings is 8907.88 MMBtu. The electrical savings is 5.5% annually and the natural gas savings is 29.9% annually over the LOS plan.

The primary reason that the natural gas was impacted so greatly and not the electricity is that most of the features which the L1R plan incorporates enhance the heating of the buildings, rather than the cooling. The berms, shading, shelterbelts, southern glazing, overhangs, double glazing, and improved, tighter construction serve to allow more solar energy in and reduce air infiltration. The main effects of these features are to reduce the heating load; in some cases these features can have detrimental effects on the cooling loads. Because of the theoretical nature of these designs and the computer simulation used to estimate energy loads, the reduced infiltration and increased southern glazing can actually

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	BASE LOS TOTAL (MWH)	TOTAL ANNUAL SAVINGS (MWH)	NET LIR TOTAL (MWH)
1	SFD(1600)	42.400	17.61	-2.03	0.00	0.00	1,285.64	148.19	1,137.45
2	SFD(2200)	42.400	24.35	-2.81	0.00	0.00	633.22	73.06	560.16
3	TH(1200)	45.000	45.12	-1.38	0.00	0.00	302.47	7.6	294.87
4	TH(1500)	45.000	20.47	-0.52	0.00	0.00	614.11	15.6	598.51
5	APT(950)	49.000	18.08	-1.03	0.00	0.00	1,446.36	82.4	1,363.96
6	APT(1300)	49.000	22.38	-1.28	0.00	0.00	2,686.10	153.60	2,532.50
7	HS	43.400	1532.70	-7.60	0.00	0.00	1,532.70	7.60	1,525.10
8	F/P	54.900	56.70	0.00	0.00	0.00	66.70	0.00	66.70
9	GOLF	54.900	287.10	-4.00	0.00	0.00	287.1	4.00	283.10
10	CCMM	54.900	78.10	-4.20	0.00	0.00	78.10	4.20	73.90
							8,932.50	496.25	8,436.25

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Table 5.5.1.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	BASE LOS TOTAL (MMBtu)	TOTAL SAVINGS (MMBtu)	NET LIR TOTAL (MMBtu)
1	SFD(1600)	2.796	113.07	-33.58	0.00	0.00	8,253.86	2,451.34	5,802.52
2	SFD(2200)	2.796	156.36	-46.44	0.00	0.00	4,065.34	1,207.44	2,857.90
3	TH(1200)	2.796	67.63	-21.06	0.00	0.00	1,352.54	421.20	931.34
4	TH(1500)	2.796	91.53	-26.51	0.00	0.00	2,746.06	855.3	1,890.76
5	APT(950)	2.796	56.54	-17.36	0.00	0.00	4,522.84	1,388.80	3,134.04
6	APT(1300)	2.796	70.00	-21.49	0.00	0.00	8,399.56	2,578.80	5,820.76
7	HS	2.912	220.30	0.00	0.00	0.00	220.30	0.00	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10	0.00	31.10
9	GOLF	2.912	156.10	-3.90	0.00	0.00	156.10	3.90	152.20
10	CCMM	2.912	42.50	-1.10	0.00	0.00	<u>42.50</u>	<u>1.10</u>	<u>41.40</u>
							29,790.20	8,907.88	20,882.32

Table 5.5.1.2

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	L1R TOTAL (MMH)	L2R SAVINGS (LOSS) ANNUAL (MMH)	NET L2R TOTAL ANNUAL (MMH)
1	SFD(1500)	42.400	17.61	-2.03	.54	0.00	1,137.45	(39.42)	1,176.87
2	SFD(2200)	42.400	24.35	-2.81	.75	0.00	560.16	(19.50)	579.66
3	TH(1200)	45.000	15.12	-.38	.41	0.00	294.87	(8.20)	303.07
4	TH(1500)	45.000	20.47	-.52	.51	0.00	598.51	(15.30)	613.81
5	APT(950)	49.000	18.68	-1.03	.32	0.00	1,363.96	(25.60)	1,389.56
6	APT(1300)	49.000	22.38	-1.28	.44	0.00	2,532.50	(52.80)	2,585.30
7	HS	43.000	1532.70	-7.60	0.00	0.00	1,525.10	(0)	1,525.10
8	F/P	54.900	66.70	0.00	0.00	0.00	66.70	(0)	66.70
9	GOLF	54.900	287.10	-4.00	0.00	0.00	283.10	(0)	283.10
10	CCMH	54.900	78.10	-4.20	0.00	0.00	<u>73.90</u>	<u>(0)</u>	<u>73.90</u>
							8,436.25	(160.82)	8,597.07

Table 5.5.2.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	L1R TOTAL (MMBtu)	L2R SAVINGS (LOSS) ANNUAL (MMBtu)	NET L2R TOTAL ANNUAL (MMBtu)
1	SFD(12000)	2.796	112.07	-33.58	-41.00	0.00	5,802.52	2,993.00	2,809.52
2	SFD(22000)	2.796	156.36	-46.44	-56.50	0.00	2,857.90	1,469.00	1,388.90
3	TH(12000)	2.796	67.63	-21.06	-25.70	0.00	931.34	514.00	417.34
4	TH(15000)	2.796	91.53	-28.51	-32.40	0.00	1,890.76	960.00	930.76
5	APT(9500)	2.796	56.54	-17.36	-19.30	0.00	3,134.04	1,544.00	1,590.04
6	APT(13000)	2.796	76.00	-21.49	-26.40	0.00	5,820.76	3,168.00	2,652.76
7	HS	2.912	220.30	0.00	0.00	0.00	220.30	(0)	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10	(0)	31.10
9	GOLF	2.912	156.10	-3.90	0.00	0.00	152.20	(0)	152.20
10	CCMH	2.912	42.50	-1.16	0.00	0.00	41.40	(0)	41.40
							20,882.32	10,648.00	10,234.32

Table 5.5.2.2

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	LIR TOTAL ANNUAL (MWH)	L3R SAVINGS ANNUAL (MWH)	NET L3R TOTAL ANNUAL (MWH)
1	SFD(1600)	42.400	17.61	-2.03	0.00	-4.06	1,137.45	296.38	841.07
2	SFD(2200)	42.400	24.35	-2.81	0.00	-5.62	560.16	146.12	414.04
3	TH(1200)	45.000	15.12	-0.38	0.00	-3.99	294.87	79.80	215.07
4	TH(1500)	45.000	20.47	-0.52	0.00	-6.69	598.51	200.70	397.81
5	APT(950)	49.000	18.00	-1.03	0.00	-7.02	1,363.96	561.60	802.36
6	APT(1300)	49.000	22.38	-1.28	0.00	-7.41	2,532.50	889.20	1,643.30
5-37 7	MS	43.400	1532.70	-7.60	0.00	-262.70	1,525.10	262.70	1,262.40
8	F/P	54.900	66.70	0.00	0.00	-9.70	66.70	9.70	57.00
9	GCLF	54.900	287.10	-4.00	0.00	-41.10	283.10	41.10	242.00
10	CCMM	54.900	78.10	-4.20	0.00	-12.10	73.90	12.10	61.80
							8,436.25	2,499.40	5,936.85

Table 5.5.3.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	L1R TOTAL ANNUAL (MMBtu)	L1R SAVINGS ANNUAL (MMBtu)	NET L1R TOTAL ANNUAL (MMBtu)
1	SFD(1600)	2.796	213.67	-33.53	0.00	-79.49	5,802.52	5,802.52	0
2	SFD(2200)	2.796	256.36	-46.44	0.00	-109.92	2,857.90	2,857.90	0
3	TH(1200)	2.796	67.63	-21.06	0.00	-46.57	931.34	931.34	0
4	TH(1500)	2.796	91.53	-28.51	0.00	-71.02	1,890.76	1,890.76	0
5	APT(950)	2.796	56.54	-17.36	0.00	-39.18	3,134.04	3,134.04	0
6	APT(1300)	2.796	76.00	-21.49	0.00	-48.51	5,820.76	5,820.76	0
7	HS	2.912	220.30	0.00	0.00	-220.30	220.30	220.30	0
8	F/P	2.912	31.10	0.00	0.00	-31.10	31.10	31.10	0
9	GCLF	2.912	156.10	-3.93	0.00	-152.20	152.20	152.20	0
10	COMM	2.912	42.50	-1.10	0.00	-41.40	41.40	41.40	0
							<u>20,882.32</u>	<u>20,882.32</u>	<u>0</u>

Table 5.5.3.2

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TYPE	DESCRIPTION	THERMAL ENERGY UNIT COST	THERMAL ENERGY UNIT CONSUMPTION	TOTAL L3R THERMAL ANNUAL (MMBtu)
1	SFD(1600)	10.59	89.74	6,551.02
2	SFD(2200)	10.59	124.10	3,226.60
3	TH(1200)	10.59	78.66	1,573.20
4	TH(1500)	10.59	97.39	2,921.70
5	APT(950)	10.59	71.85	5,748.00
6	APT(1300)	10.59	97.25	11,670.00
7	HS	10.59	1508.00	1,508.00
8	F/P	10.59	89.00	89.00
9	GOLF	10.59	387.00	387.00
10	COMM	10.59	105.00	<u>105.00</u>
				33,779.52

Table 5.5.3.3

increase the cooling load in some summer months in some buildings. We did, however, attempt to correct for these occurrences.

5.5.2 -- L2R

The total annual energy consumption and savings are shown in Tables 5.5.2.1 and 5.5.2.2 for electricity and natural gas. The total annual electrical "savings" is actually an additional 160.82 MWH over the L1R plan. The annual natural gas savings, however, is 10,648 MMBtu when compared to L1R. The former represents an additional 1.9% electricity over the L1R plan; however, L2R still uses 335.43 MWH or 3.8% less electricity than does LOS. The L2R plan uses 51% less natural gas than does L1R and 19,555.88 MMBtu or 65.6% less natural gas than the base LOS plan.

The additional electrical requirements are for the pumps necessary to run the active solar water heating systems. Naturally, the largest, and quite substantial, gain is in natural gas savings. Because no decentralized cooling systems were economically feasible the three alternatives chosen, direct gain, attached greenhouse, and solar water heating, all supplement natural gas for water heating and space heating.

5.5.3 -- L3R

The total annual energy consumption and savings are shown in Tables 5.5.3.1, 5.5.3.2, and 5.5.3.3 for electricity, natural gas, and thermal. Because of the chilled water cooling, a substantial amount of the electricity load is reduced. The L3R plan uses 29.6% less electricity or 2499.4 MWH than the L1R plan and 2995.65 MWH or 33.5% less electrical energy than the LOS plan. Because of the hot water distribution, 100% of the natural gas used for space and water heating is replaced by the thermal energy generated at the central plant. Naturally, to offset these benefits, 33,779.52 MMBtu's of thermal energy are required for the heating and cooling of buildings on the site.

SHERANOGAN CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION L1F
PASSIVE REVISED
ANALYSIS PERIOD 22 YEARS
CONSTRUCTION PERIOD 1 YEARS
CONSERVATION LEVEL 1-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING 5.00%
DISCOUNT RATE 10.00%
R O I CAPITAL 20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

PRESENT VALUE COST REPORT

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4900829.	349527.	874204.	-19251.	2805426.	-510313.
CLUSTER DWELLING UNITS	7589168.	715345.	1455654.	-169303.	6656467.	-704871.
INSTITUTIONAL FACILITIES	6311360.	89815.	867950.	-90163.	1475084.	-6828.
COMMUNITY FACILITIES	969936.	28396.	170504.	-611.	425114.	-9514.
TOTAL	19777293.	1153083.	3374312.	-279329.	11362091.	-1231526.
INTEREST	988865.	57654.	0.	0.	0.	0.

* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981

TOTAL NET PRESENT VALUE = \$ 35202443.

Table 5.6.1.1

SITE PLAN

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ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	329622.	23463.	565710.	-12896.	1879685.	-341862.	5635628.
SINGLE FAMILY (2200)	1616006.	115364.	288488.	-6355.	925741.	-168451.	2770793.
TOWNHOUSE (1200)	691152.	74826.	120855.	-8819.	396577.	-41406.	1233195.
TOWNHOUSE (1500)	1283568.	138920.	224407.	-16468.	805276.	-84240.	2351524.
APARTMENT (950)	1852752.	162140.	366388.	-47529.	1909334.	-202528.	4840556.
APARTMENT (1300)	3721696.	329459.	744005.	-96558.	3545280.	-376697.	7907189.
SENIOR HIGH SCHOOL	6195200.	65434.	815973.	-86739.	1395291.	-6828.	8378332.
FIRE-POLICE STATION	116160.	4380.	51977.	-3424.	79733.	0.	248886.
GOLF CLUBHOUSE	853776.	19747.	111330.	3570.	336161.	-4826.	1319757.
COMMERCIAL SPACE	116160.	8649.	65174.	-4181.	88953.	-4688.	270068.

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Table 5.6.1.2

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6074799.	479982.	1140913.	-84342.	229761.	-28950.	7831564.
1982 - 2	12204532.	696281.	2027618.	-179704.	583715.	-60867.	19271577.
1983 - 3	3131331.	40540.	472033.	-37534.	676638.	-66874.	4223636.
1984 - 4	0.	0.	0.	0.	730437.	-72801.	657636.
1985 - 5	0.	0.	0.	0.	788576.	-79264.	789312.
1986 - 6	0.	0.	0.	0.	851410.	-86312.	765099.
1987 - 7	0.	0.	0.	0.	919327.	-93998.	825328.
1988 - 8	0.	0.	0.	0.	992743.	-102381.	890360.
1989 - 9	0.	0.	0.	0.	1072112.	-111538.	960582.
1990 - 10	0.	0.	0.	0.	1157925.	-121510.	1036415.
1991 - 11	0.	0.	0.	0.	1250714.	-132400.	1118314.
1992 - 12	0.	0.	0.	0.	1351057.	-144284.	1286773.
1993 - 13	0.	0.	0.	0.	1459580.	-157255.	1302325.
1994 - 14	0.	0.	0.	0.	1576961.	-171414.	1485548.
1995 - 15	0.	0.	0.	0.	1703938.	-186871.	1517067.
1996 - 16	0.	0.	0.	0.	1841308.	-203747.	1637561.
1997 - 17	0.	0.	0.	0.	1989938.	-222175.	1767762.
1998 - 18	0.	0.	0.	0.	2150768.	-242301.	1908468.
1999 - 19	0.	0.	0.	0.	2324820.	-264281.	2060538.
2000 - 20	0.	0.	0.	0.	2513199.	-288291.	2224908.
2001 - 21	0.	0.	0.	0.	2717119.	-314521.	2402588.
2002 - 22	0.	0.	0.	0.	2937854.	-343179.	2594675.
2003 - 23	0.	0.	0.	0.	3176852.	-374493.	2802358.
2004 - 24	0.	0.	0.	0.	3435639.	-408713.	3026926.
2005 - 25	0.	0.	0.	0.	3715899.	-446113.	3269775.

Table 5.6.1.3

Figure 5.6.1
Sensitivity: Electric Fuel Escalation 5 - 16%

Figure 5.6.2
Sensitivity: Natural Gas Fuel Escalation 5 - 16%

Figure 5.6.3
Sensitivity: Discount Rate 9 - 20%

5.6 -- Sensitivity and Savings/Investment Analysis

5.6.1. -- L1R

The total present value of the L1R plan is \$35,202,443 over the 25 year life of the project study period. The present value summary report is shown in Table 5.6.1.1. The total cost for each building element and the annual costs are shown in Tables 5.6.1.2 and 5.6.1.3.

The sensitivity analyses produced results similar in magnitudes to those of LOS. As electricity escalation per year varied from 5% to 16%, the total present value of costs moved from \$33.0 to \$53.3 million, a 61.5% increase. Natural gas proved to be less sensitive; as the rate varied from 5% to 16% the present value figures increased from \$34.4 to \$37.4 million, only an 8.7% increase. Again, as the discount rate changed from 9% to 20%, the present value figures fell from \$36.5 to \$27.9 million, a 23.6% decline.

The savings/investment ratio for the base L1R plan is calculated by dividing the savings in present value of the energy costs by the change in investment (over the LOS plan) necessary to bring about the energy savings. The energy savings in present value 1981 dollars taken from Table 5.6.1.1 is \$1,231,526. To calculate the change in investment, add the incremental interest, incremental construction, and incremental development costs. This figure is \$931,408. Since less money was invested than was returned in energy savings, the savings/investment ratio is greater than 1. It is equal to 1.32.

When making investment decisions, both the present value method and the S/I ratio method will give the same answer as to whether the investment should be made or not. However, the only true (and accepted) method to decide between two investments is the present value method. In this case the present value of costs of the L1R plan are less than the present value of costs of the LOS plan, \$35,202,443 versus \$35,502,561. Thus, between the two scenarios, the L1R plan is superior.

5.6.2 -- L2R

The total present value of costs of the L2R plan is \$35,344,603. The summary report is shown in Table 5.6.2.1. The costs for each building

SHERANJOAH CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION L2R
DECENTRALI - REVISED
ANALYSIS PERIOD 22 YEARS
CONSTRUCTION PERIOD 3 YEARS
CONSERVATION LEVEL 2-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING 5.00%
DISCOUNT RATE 10.00%
R O I CAPITAL 20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

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COST CENTER	PRESENT VALUE COST REPORT					
	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	906828.	670329.	874204.	-19251.	2805426.	-828146.
CLUSTER DWELLING UNITS	7589168.	1208173.	1455654.	-169303.	6056467.	-1109665.
INSTITUTIONAL FACILITIES	6311360.	69798.	867950.	-98163.	1475084.	-6828.
COMMUNITY FACILITIES	969936.	18396.	176514.	-611.	425114.	-9514.
TOTAL	19777293.	1976689.	3374312.	-279329.	11362091.	-1954152.
INTEREST	988865.	98834.	0.	0.	0.	0.
* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981						
TOTAL NET PRESENT VALUE - \$	35344633.					

Table 5.6.2.1

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290822.	451868.	585716.	-12896.	1879685.	-555151.	5639984.
SINGLE FAMILY (2200)	1616106.	218521.	289488.	-6355.	925741.	-272995.	2769406.
TOWNHOUSE (1200)	691152.	113621.	120855.	-8809.	396577.	-75365.	1244030.
TOWNHOUSE (1500)	1283568.	120595.	224407.	-16408.	805276.	-147679.	2369759.
APARTMENT (350)	1852752.	287302.	366388.	-47529.	1909334.	-303349.	4064899.
APARTMENT (1300)	3761696.	580655.	744065.	-96558.	3545280.	-583271.	7951807.
SENIOR HIGH SCHOOL	6195200.	65434.	815973.	-86739.	1395291.	-6828.	8378332.
FIRE-POLICE STATION	116160.	4356.	51977.	-3424.	79793.	0.	248861.
GOLF CLUBHOUSE	853776.	19747.	111330.	3578.	336161.	-4826.	1319757.
COMMERCIAL SPACE	116160.	8649.	65174.	-4181.	88953.	-4688.	270068.

Table 5.6.2.2

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6194799.	881199.	1140910.	-84942.	229761.	-42881.	8220750.
1982 - 2	12204532.	1158821.	2027618.	-179704.	583715.	-91304.	15783678.
1983 - 3	3100811.	48540.	472033.	-37534.	676638.	-100584.	4189926.
1984 - 4	0.	0.	0.	0.	730437.	-110129.	620308.
1985 - 5	0.	0.	0.	0.	788576.	-120596.	667986.
1986 - 6	0.	0.	0.	0.	851410.	-112058.	719354.
1987 - 7	0.	0.	0.	0.	919327.	-144624.	774703.
1988 - 8	0.	0.	0.	0.	992743.	-158481.	834362.
1989 - 9	0.	0.	0.	0.	1072112.	-173504.	898607.
1990 - 10	0.	0.	0.	0.	1157925.	-190063.	967862.
1991 - 11	0.	0.	0.	0.	1250714.	-248218.	1042497.
1992 - 12	0.	0.	0.	0.	1351057.	-228124.	1122933.
1993 - 13	0.	0.	0.	0.	1459580.	-249953.	1209628.
1994 - 14	0.	0.	0.	0.	1576961.	-273890.	1303071.
1995 - 15	0.	0.	0.	0.	1702938.	-300142.	1403796.
1996 - 16	0.	0.	0.	0.	1841308.	-328934.	1512374.
1997 - 17	0.	0.	0.	0.	1969938.	-360513.	1629425.
1998 - 18	0.	0.	0.	0.	2150768.	-395152.	1755616.
1999 - 19	0.	0.	0.	0.	2324820.	-433149.	1891671.
2000 - 20	0.	0.	0.	0.	2513199.	-474831.	2038368.
2001 - 21	0.	0.	0.	0.	2717109.	-520559.	2196550.
2002 - 22	0.	0.	0.	0.	2937854.	-570729.	2367126.
2003 - 23	0.	0.	0.	0.	3176852.	-625774.	2551078.
2004 - 24	0.	0.	0.	0.	3435639.	-686171.	2749469.
2005 - 25	0.	0.	0.	0.	3715889.	-752444.	2963444.

Table 5.6.2.3

Figure 5.6.4
Sensitivity: Electric Fuel Escalation 5 - 16%

Figure 5.6.5

Sensitivity: Natural Gas Fuel Escalation 5 - 16%

Figure 5.6.6
Sensitivity: Discount Rate 9 - 20%

SHEMANDOAH CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION L3F
CENTRAL UTILITIES - REVISED
ANALYSIS PERIOD 22 YEARS
CONSTRUCTION PERIOD 3 YEARS
CONSERVATION LEVEL 3-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING 5.00%
DISCOUNT RATE 10.00%
R O I CAPITAL 20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

COST CENTER	PRESENT VALUE COST REPORT					
	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4900828.	389000.	874204.	-19251.	2805426.	45814.
CLUSTER DWELLING UNITS	7503168.	756807.	1455654.	-169303.	6656467.	214338.
INSTITUTIONAL FACILITIES	6311360.	-266683.	867950.	-90163.	1475084.	-17246.
COMMUNITY FACILITIES	969936.	38842.	176514.	-611.	425114.	-7186.
TOTAL	19777493.	917966.	3374312.	-279329.	11362091.	235719.
INTEREST	980865.	45098.	0.	0.	0.	0.
* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981						
TOTAL NET PRESENT VALUE - \$	36422816.					

Table 5.6.3.1

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290622.	256334.	585716.	-12896.	1879685.	30825.	6030486.
SINGLE FAMILY (2200)	1616006.	132687.	288488.	-6355.	925741.	14990.	2971536.
TOWNHOUSE (1200)	691152.	82183.	120855.	-8809.	396577.	66724.	1348682.
TOWNHOUSE (1500)	1283568.	152678.	224407.	-16408.	805276.	34251.	2483772.
APARTMENT (950)	1852752.	175248.	366388.	-47529.	1909334.	-76682.	4179471.
APARTMENT (1300)	3761696.	346738.	744005.	-96558.	3545280.	190045.	8491206.
SENIOR HIGH SCHOOL	6195100.	-269434.	815973.	-86739.	1395231.	-18071.	8032220.
FIRE-POLICE STATION	116160.	2752.	51977.	-3424.	79793.	825.	248082.
GOLF CLUBHOUSE	853776.	19278.	111330.	3570.	336161.	-2041.	1332074.
COMMERCIAL SPACE	116160.	9364.	65174.	-4181.	88953.	-5146.	270525.

Table 5.6.3.2

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6394759.	521603.	1140913.	-84942.	229761.	58834.	7960969.
1982 - 2	12264532.	567181.	2627619.	-179704.	583715.	126687.	15270030.
1983 - 3	5130831.	-78299.	472033.	-37534.	676638.	124709.	4288379.
1984 - 4	0.	0.	0.	0.	730437.	120116.	850554.
1985 - 5	0.	0.	0.	0.	788576.	114328.	902904.
1986 - 6	0.	0.	0.	0.	851410.	107197.	958608.
1987 - 7	0.	0.	0.	0.	919327.	98560.	1017887.
1988 - 8	0.	0.	0.	0.	992743.	88236.	1080979.
1989 - 9	0.	0.	0.	0.	1072112.	76027.	1148139.
1990 - 10	0.	0.	0.	0.	1157925.	61714.	1219639.
1991 - 11	0.	0.	0.	0.	1250714.	45054.	1295768.
1992 - 12	0.	0.	0.	0.	1351057.	25780.	1376837.
1993 - 13	0.	0.	0.	0.	1459580.	3598.	1463179.
1994 - 14	0.	0.	0.	0.	1576961.	-21815.	1555146.
1995 - 15	0.	0.	0.	0.	1703938.	-50818.	1653120.
1996 - 16	0.	0.	0.	0.	1841308.	-83802.	1757505.
1997 - 17	0.	0.	0.	0.	1989938.	-121202.	1868736.
1998 - 18	0.	0.	0.	0.	2150768.	-163493.	1987275.
1999 - 19	0.	0.	0.	0.	2324820.	-211201.	2113619.
2000 - 20	0.	0.	0.	0.	2513199.	-264900.	2248299.
2001 - 21	0.	0.	0.	0.	2717109.	-325227.	2391882.
2002 - 22	0.	0.	0.	0.	2937654.	-392879.	2544975.
2003 - 23	0.	0.	0.	0.	3176852.	-468622.	2708229.
2004 - 24	0.	0.	0.	0.	3435679.	-553301.	2882339.
2005 - 25	0.	0.	0.	0.	3715889.	-647841.	3068048.

Table 5.6.3.3

Figure 5.6.7
Sensitivity: Electric Fuel Escalation 5 - 16%

Figure 5.6.8
Sensitivity: Natural Gas Fuel Escalation 5 - 16%

Figure 5.6.9
Sensitivity: Thermal Fuel Escalation 1 - 12%

Figure 5.6.10
Sensitivity: Discount Rate 9 - 20%

element and the annual costs are shown in Tables 5.6.2.2 and 5.6.2.3.

The sensitivity analysis on electrical escalation rates again showed the greatest swing. As rates moved from 5% to 16% the present value of costs increased from \$33.1 to \$53.8 million, a 62.5% increase. As the natural gas rates increased annually from 5% to 16%, the present value of costs increased only 4.0%, from \$35.0 to \$36.4 million. Since the use of natural gas has been reduced so drastically in this plan, these results are expected. Finally, as the discount rate increases from 9% to 20%, the present value of total costs fall by 22.4% from \$36.6 to \$28.4 million.

The savings/investment ratio for the L2R plan versus the LOS plan is 1.1. Since this is greater than 1 and since the present value of costs is less than the LOS plan, the L2R plan is superior to the LOS plan.

5.6.3 -- L3R

The total present value of the L3R plan is \$36,422,816. The summary report, the costs of each building element, and annual cost summary report are presented in Tables 5.6.3.1, 5.6.3.2, and 5.6.3.3.

The sensitivity analysis was run on electricity, natural gas, thermal energy, and the discount rate. Naturally, the natural gas sensitivity run showed no change in the \$36.4 million present value figure since the L3R plan utilizes no natural gas. The sensitivity of L3R to electrical escalation rates was significant. As the escalation rate varied from 5% to 16% per year, the total present value of costs increased from \$34.9 to \$49.1 million, a \$14.2 million or 41% increase. The plan proved to be less sensitive to the rate of increase in thermal energy costs. As the annual escalation rate moved from 1% to 12%, the total present value figure increased from \$34.4 million to \$44.5 million, a 29% increase. As on the other plans, the total present value of costs fell as the discount rate was increased. In this case the total fell from \$37.8 to \$28.6 million as the rate increased from 9% to 20%. The graphs are shown in the following tables.

The savings/investment analysis produces some interesting results. The present value of costs of the LOS plan is \$35,502,561, while the present value for the L3R plan is \$36,422,816. It may seem surprising that the L3R present value is greater than that of the LOS plan; upon examination, however, these results are understandable.

This analysis priced the thermal energy at \$10.59 per MMBtu's. This rate should cover the construction of the central plant and all debt service. This price is higher relatively than the prices of electricity and natural gas. Therefore, the electricity which is displaced by L3R, approximately 33% of LOS electricity consumption, and the natural gas which is totally displaced by L3R are both cheaper than the thermal energy which replaces them. When examined from an overall conservation view, however, the L3R plan is extremely efficient in replacing scarce, non-renewable energy sources with renewable, abundant sources. If this conservation goal is, indeed, considered to be in the public good, then there should be some additional "price" or benefit assigned to the conservation qualities of the L3R plan. The most obvious "price" to be assigned to this public benefit would be some form of subsidy or other monetary incentive which would defray the additional costs invoked by this plan. Therefore, with government assistance in the form of construction subsidies, tax incentives, or rate subsidization, the effective rates and effective present value of costs would be lowered. The converse of this system, of course, is to add an extra "cost" to the natural gas and electricity rates which would indicate the cost of additional use of these energy sources with respect to a national conservation policy. This would have the effect of raising the present value of costs of the other plans relative to the L3R plan. Without some form of government assistance (tax on normal energy sources or some subsidy technique for this cogeneration plan) this energy conservation plan would not qualify in terms of the present value analysis, given the assumptions within the model.

CHAPTER 6

IMPEDIMENTS AND SOLUTIONS TO IMPLEMENTATION

The criteria for evaluating different energy-conserving options were technical feasibility, economic feasibility, and marketability. Although an option may meet the criteria, other factors could constrain its development. Impediments could include regulations and opposition from decision-making institutions (utilities, bankers, zoning boards, builders, developers, etc.). This chapter discusses the most pertinent impediments to the development of energy-conserving communities.

The impediments are quite different for the Level 2 plan, which uses dispersed energy devices, than for the Level 3 plan, which uses a central utility with thermal energy distribution. Impediments for the Level 1 passive plan would be similar to those for Level 2. The following categories of impediments may constrain implementation of energy-conserving designs in the community:

- Utility attitudes,
- Regulatory constraints,
- Environmental impacts,
- Incidence of costs and benefits,
- Marketing,
- Developer's attitudes, and
- Builder's attitudes.

6.1--Impediments to Level 1 and Level 2 Plans

6.1.1.--Utility attitudes.

In the Level 1 and Level 2 plans, the major utility requirement is for natural gas on either a primary or back-up thermal energy source and

electricity as a power source for lights, cooling and appliances.

Georgia law requires that the utility companies provide service in their service area except in unusual circumstances that would probably not be applicable to the Case Study area. Atlanta Gas Light Company has indicated that they would provide service to energy-conserving customers. Coweta-Fayette Electric Membership Corporation (EMC) stated that they are currently providing "back-up" service to a few "solar customers" and, therefore, would be willing to provide some or all of the type of service required by these plans.

The Georgia Public Service Commission (PSC) has jurisdiction over Atlanta Gas Light Company policies and rates but not over Coweta-Fayette EMC. Atlanta Gas Light Company expressed a willingness to cooperate with energy-conserving developments to establish equitable rates; however, the rates would be subject to the load characteristics of the development, and Atlanta Gas Light Company has the approved right to add a surcharge to certain customers who have minimal energy requirements. A key provision for the Case Study area is that the annual load factor be less than 5%. The PSC will not allow the use of this surcharge in most cases when the load factor is greater than 5%. This is invariably true when gas is the sole source of thermal energy. The surcharge that may be added is \$8/therm/year. The National Energy Act (NEA) may have an effect on the PSC's approval of this practice, but this is not likely to occur prior to implementation of the project. In all likelihood, the utilities would not constrain development of energy-conserving features in any way.

Utilities can also help promote installation of more energy efficient options. For example, the Tennessee Valley Authority is hoping to bypass the construction of 2,000 megawatts of electric power plants through programs in energy conservation, solar energy and wood energy. However, the capital investment for new capacity needed by gas utilities is substantially lower than electric utilities. Thus, it is unlikely that Atlanta Gas Light will be inspired to strongly support programs that decrease natural gas demand. New legislation may alter the gas company's willingness to support energy-conserving measures. The President's Import

Reduction Program proposed that electric and gas utilities be required to offer long-term financing to their residential and commercial customers for conservation improvements. These loans would be included in the utility rate bases, just as investments for new generating capacity would be, and the principal would be repaid when the house or building is sold. President Carter requested two billion dollars for the program over ten years.

6.1.2.--Regulatory and Legal Constraints.

Regulatory measures can constrain or encourage implementation of energy-conserving designs. The most severe constraints occur in existing communities, where a variety of regulations govern additions to houses, and in communities having strict development plans that include no provision for energy conservation.

6.1.2.1.--Land-use regulations. The only land use regulation which is currently in effect for the Case Study development is the Coweta County Zoning Resolution; however, county approval of a proposed plan requires consideration by local county officials since the infrastructure will ultimately be dedicated to the county. Preliminary review indicates some potential impediments due to maintenance considerations for open drainage channels. This review-approval process may require the elimination of some or all of the open drainage channels in order to implement the plan. There may be additional requirements imposed by subsequent reviews.

The Case Study development area is a part of a New Community (NC) district described in Article 9-A of the zoning resolution. This type of district was established for innovative developments of large tracts of land in Coweta County and allows significant design and planning flexibility. Therefore, there are no zoning regulations in direct conflict with any of the proposed site plans. The major drawback to the resolution is that it provides no impetus for implementing any energy-conserving plan.

Several options for incorporating energy conservation with land-use planning exist. For example, the Newnan-Coweta Planning Commission could develop and adopt a comprehensive development plan accompanied with

refinement of the zoning resolution which would eliminate the remote potential for substandard or haphazard development, would insure solar access for new development, and would promote energy-conserving development throughout the county. Enabling legislation at the state level is a desirable and appropriate prerequisite to support the legal validity of this approach. The enabling legislation would constitute an amendment to the state zoning enabling act, which states that energy conservation is within the scope of land use regulations. This conclusion regarding the desirability of legislative actions is evidenced by Kenneth A. Rubin's testimony to the New York State Legislative Commission on Energy Systems in which he gives a legal background for land use controls in general and points to the need to establish "public use" and that the means bear a direct and rational relationship to the documented purpose.

The major problems associated with the use of these controls in the Case Study development area would be delays in achieving the required legislation, resolution of conflicts between governmental entities involved, and development of a final product that was politically palatable and would withstand judicial scrutiny. The advantages are the enhancement of market acceptance of this innovative approach to development, consequentially improving marketability.

6.1.2.2.--Building codes. The Southern Standard Building Code is applicable, with minor modification, to the Case Study development area. In January, 1978, the Southern Standard Building Code Association completed a contract with the National Bureau of Standards to determine if the code contains any conflicts which would deter the use of solar energy. Although none were found, it was recommended that the codes be modified to include some additional provisions which would require energy efficient building design. These provisions are embedded in the Georgia State Energy Code for Buildings, effective July 16, 1978. In the absence of this or proven market experience, it is unlikely that builders could be induced to construct energy efficient buildings. The code does not require the inclusion of solar energy systems, and many builders may be unwilling to consider solar as an option. All energy conservation plans will require adequate enforcement of the Georgia State Energy Code for Buildings, in its

entirety, by local officials to insure successful implementation of the building design features. The active systems integral to the Level 2 plan will require a favorable builders' attitude or appropriate development guidelines for their implementation.

6.1.2.3.--Solar access provisions. One major problem with implementation of devices or designs dependent on solar radiation is how to guarantee that nearby objects will not block the path of the sun's rays. Georgia has adopted legislation, the Solar Easement Act of 1978, which validates the creation of voluntary solar easements. The easements must be privately negotiated and it is likely that circumstances involved in some cases will make it difficult, if not impossible, for an agreement to be reached. However, in many instances solar easements should provide an effective means to insure continued solar access. Within the Case Study development area, a property owner could negotiate with his neighbor for solar easements. The negotiated easements would guarantee access to solar radiation even if either or both pieces of property were sold. Potential problems with this approach may be an adverse effect on marketability and the legal limitation of 20 years duration on these easements.

Solar rights could be established according to the Doctrine of Prior Appropriation, analogous to water rights. This approach has been adopted by the New Mexico State Legislature. However, legal remedies to water rights disputes are often unsure and frequently expensive as these cases are often subject to lengthy litigation. The potential for achieving legislative action on such a proposal is probably limited to the western states which have legal precedent in this area.

California has adopted a shade control act declaring a shadow on a collector to be a "public nuisance." The California law is limited to trees and shrubs; however, in residential areas, trees and shrubs are likely to be the major obstruction to solar access. A public nuisance law could be extended to include the shadows of structures, but this would decrease the possibility of the law withstanding court test because "American Jurisprudence generally holds that a building or structure cannot be complained of as a nuisance merely because it interferes with the

passage of light and air to adjoining premises." (Kraemer, 1978). A law similar to California's for Georgia with no inherent problems in enforcement could be passed by either state or local government.

The following drawbacks to the use of public nuisance law as a guarantee of solar access are evident:

1. Lawsuits are necessary in every case;
2. There may be no provision to compensate those actually impaired;
3. Injunctive relief would not be available in many jurisdictions;
4. There would be no security for solar energy system owners until after they had installed the system and won the suit; and
5. Because public nuisance is a crime, the homeowner may have to wait for the state to sue. (Miller, 1977)

In light of these disadvantages, public nuisance laws were not considered a viable route to guarantee solar access.

Covenants may be established which restrict the obstruction of insolation. As Sandy F. Kraemer states in Solar Law, "properly prepared solar access covenants should become the most effective method of providing sunlight to new residential developments." (Kraemer, 1978) Solar covenants should have wide applicability to new communities such as the Case Study development area; however, substantive law in Georgia limits their duration to 20 years. Thus, other measures may be required to support the covenants and/or take their place should they not be reestablished at expiration. The covenants should delineate quantifiable standards with individual cases subject to evaluation by the Development Review Committee (DRC). Since covenants exist for the Case Study development area, adoption of solar access covenant(s) would be accomplished by amendment as per Section 9.02 of the existing covenants. With careful drafting of the covenants, no foreseeable legal problems other than duration exist.

An ordinance may be enacted by local government which would establish the shading of a collector as a private nuisance. Court treatment of similar ordinances indicates that such an ordinance would not be valid in cases where burden of compliance was too great in relation to the benefit of compliance; however, it would appear that judicial decision

may support application of such an ordinance to trees, shrubs, and fences. In spite of this, with regard for the other available alternatives, the value of this type of ordinance seems limited. The public nuisance ordinance appears to be a better approach.

Under the Eminent Domain Doctrine, the State is granted the power to condemn property for public use and benefit with just compensation. This right, in specific circumstances, may be passed to local governments for their jurisdiction under State authority. Solar access could be shown to constitute a valid public use in terms of "The broader view (which) finds anything that yields a public advantage to be a public use. Under this interpretation, which continues to gain acceptance, neither the entire community nor a considerable portion of it need benefit directly from the taking. The amount of compensation to be paid under the suggested statute is the difference between the fair-market values of the land before and after creation of the solar-skyspace easement. Market value commonly is defined as the price that would be agreed upon by an informed seller who is willing but not obligated to sell and an informed buyer who is willing but not obligated to buy. It should be possible to develop a formula that incorporates all pertinent factors in estimating these values." (Thomas, et. al., 1978). Use of this alternative will require the State of Georgia to adopt solar access as a valid public use that could be acquired with compensation under the Eminent Domain Doctrine and to establish a formula for determining compensation value. Use of Eminent Domain to guarantee solar access is feasible, although a lag time will certainly be required to move through the process.

In summary, the most feasible solar access provisions appear to be the voluntary solar easements bill, which already exists, and the developer's use of covenants in the community. The covenants must be effective in guaranteeing solar access and, at the same time, acceptable to potential builders and homeowners. An example of a general covenant is shown in the appendices.

6.1.2.4.--Other regulatory and legal considerations. Federal, state, and local regulations provide design standards for water, sanitary sewer and

storm drainage systems and require site grading and construction practices which minimize soil erosion. There are no apparent conflicts in complying with these regulations and concurrently minimizing life-cycle energy use for the infrastructure; therefore, compliance should be routine for all the energy-conserving plans. No type of environmental impact statement is required for the Level 1 or Level 2 plans:

The National Energy Act (NEA) passed in October, 1978 contains several incentives for energy-conserving design. The NEA promulgated rate design standards requiring their consideration by state regulatory agencies and non-regulated utilities. This regulation is intended to expedite the establishment of equitable rates for low or infrequent users of energy.

The NEA also contains numerous provisions for financing and tax incentives for energy conservation which should enhance marketability and expedite the implementation process. Tax credits for active solar equipment provide a 20% direct credit for purchases up to \$2,000 and 15% for purchases from \$2,000 to \$10,000. New provisions that President Carter requested on July 16, 1979, include a tax credit of \$20 per million Btu estimated design savings per year for a thermal performance at a specified level above the Building Energy Performance Standard (BEPS) baseline established pursuant to the Energy Conservation and Production Act. The maximum amount of this tax credit is \$10,000 per building. For example, a 1,600 square foot Level 1 home (passive with revised construction) will consume 33.7 million Btu's less than a conventional home that should meet the BEPS baseline. The home's owner is eligible for a maximum tax credit of \$674. The owner of a home with a Trombe wall qualifies for a maximum additional \$346 credit. The President also proposed a 20% tax credit for builders of new passive solar residences. The maximum credit is \$2,000 per unit.

Since these proposals have not been enacted, they were not incorporated into the study. However, they demonstrate the favor shown to energy-conserving strategies by the federal government. Whatever future legislation is passed will almost certainly give added incentive for the Level 1 plan and Level 2 plan.

6.1.3.--Environmental Concerns.

Many of the features of the energy-conserving plans contain factors which are intrinsically related to the natural environment. Any design of these features may inadvertantly affect these factors in a manner that would promote the ultimate degradation of the natural environment. Coincidentally, many of the considerations for energy efficient design correlate with environmental planning to minimize potential impact on the natural environment.

The factors indigenous to any community plan which unavoidably affect the natural environment are:

1. Point Source Pollution--Manifest in inadequately treated waste discharges.
2. Non-Point Pollution--Due to increased impervious area which increases run-off volume and the introduction of man-made materials of a potentially low biodegradation rate.
3. Soil Erosion and Downstream Deposition--resulting from grading and modifications to the existing drainage patterns.
4. Changes to the Ecosystem--due to removal of natural flora, and consequentially, fauna, for structures, landscaping and the installation of infrastructure.

The energy-conserving plans have been compared to the conventional plan as their features relate to these factors.

6.1.3.1.--Point source pollution. The only possible point source waste discharge in any of the plans may originate from the cogeneration facility; thus, it is included in the discussion of the Level 3 Plan.

6.1.3.2.--Non-point pollution. The reduction in pavement surface area and the utilization of natural drainage channels are energy-conserving design consideration for all three plans and should both reduce run-off volumes and improve the quality of the run-off resulting in a net reduction in non-point pollution.

6.1.3.3.--Soil erosion and downstream deposition. The planning criteria for energy conservation provide for reduced grading and increased adherence to natural drainage patterns which combined with the required construction provisions will minimize soil erosion and downstream deposition and should

reduce it from the conventional plan. Where man-made drainage channels are installed, proper design will prevent any significant soil transport.

6.1.3.4.--Changes to the ecosystem. Larger amounts of open space, landscaping which utilizes native species and existing flora as much as possible, minimal grading activities and a reduction in the quantity of infrastructure installed are all features of the energy-conserving plans and should reduce the overall impact on the natural ecology.

6.1.4.--Incidence of costs and benefits.

A major concern of the organizations that will have a role in the ecology-conserving communities is who will pay the additional costs. Obviously, the costs will eventually be passed on to the owners of the community's buildings or will be supported by government agencies through tax incentives, direct grants or loan guarantees.

Because the builder buys land from the developer and includes those costs in the final purchase price, the developer's costs should be passed on to the builder. Thus, the initial development costs will be paid by the developer. Upon sale of land, the builder assumes the development costs which he includes as part of the total cost of the building to its eventual owner. Government incentives could be applied throughout this process.

For example, if the developer felt he could not pay for shelter belts around the community, the government could provide a loan payable upon sale to the builder. If the builder was not willing to pay the extra costs of shelter belts, the government could extend the loan to him as well. If the homeowner did not consider reduced infiltration sufficient reason to pay \$150 extra for a house, the government could offer a tax credit or other measure as an incentive. Without government incentive, both the developer and builder must assume the risk that the eventual buyer will be willing to pay extra for energy-conserving features.

6.1.5. -- Availability of Financing

The investor's (includes developer, builder, and buyer) willingness to pay for energy-conserving features depends on the availability of favorable financing for the additional costs. Banks in the Shenandoah area have given loans for solar homes so the Level 1 and Level 2 plans should not be constrained by the availability of financing.

6.1.6.--Marketing

Marketing attempts to create a demand for a given product. In the Level 1 and Level 2 plans, marketable features for potential homeowners include reduced annual fuel costs, aesthetically designed community, privacy due to large number of trees, accessibility to the nearby commercial/industrial area, modern building designs and the novelty of living in a new town. Individuals would balance these features against the life cycle costs and future selling value as compared to conventional homes.

The Level 1 and Level 2 plans were selected because the life cycle costs were comparatively low. Nevertheless, the future selling prices of the homes are very uncertain.

Individuals may perceive that due to rising fuel prices, the value of energy-conserving homes must increase; however, an appraiser may put a lower future price than the current buyer feels is warranted. The appraiser's view is critical as it determines the amount of financing available; the future buyer may be willing to pay the seller's price, but only if financing is available. The uncertainty of the future value may cloud the perceived attractiveness of the investment to the potential homebuyer.

The investor in apartments and townhouses is concerned about two major factors--how much rent can be charged and what price will the units be sold for in the future. An after-tax cash flow analysis can be used to determine the rent needed to earn a 20% internal rate of return on investment. Apartment investors typically own buildings from five to ten years and then sell them. Assuming the apartment buildings appreciate at the rate of inflation, the owner could earn a 20% rate of return by

charging \$200 per month for an apartment in the Level 1 plan. An apartment renter would save \$103 in fuel costs in 1982 by renting a Level 1 plan apartment instead of a conventional apartment. Thus, the investor should be able to earn a high rate of return and provide tenants with lower annual costs.

6.1.7.--Builder's Attitudes

Builders typically try to minimize the costs of a house and virtually disregard annual energy costs required for heating and cooling. This tendency should change as fuel costs increase in the future. Nevertheless, builders remain extremely risk averse to designs that increase construction costs. The main reason for their conservative nature is an uncertainty whether a buyer will pay higher costs now in order to gain cost savings over the life of the house.

Several approaches mentioned in the section on regulations can help overcome builder's reluctance. Building codes can be instituted in special zones (e.g., solar energy utilization zones) that require specific styles of construction. Shenandoah Development, Inc. could establish covenants that govern building designs or it could prescribe designs in the sales contract signed with the builder.

6.1.8.--Developer's Attitudes.

Shenandoah Development, Inc. has set a goal of establishing an energy-conserving community. However, it will not jeopardize its own existence by imposing too idealistic or impractical conditions on use of the land. For Shenandoah to continue to exist, builders must buy land and construct houses, apartments and townhouses. The developer will be very cautious about devising covenants or contractual agreements that may discourage builders.

The developer, as well as the builder, is risk averse to additional development costs. Likewise, the developer welcomes cost savings for modifications that will not affect the eventual sale of property; thus, the Level 1 and Level 2 plans, which have lower site development costs than the

conventional plan, should be attractive options.

6.1.9.--Recommended Incentives.

In light of the impediments discussed above, we recommend the following actions for encouraging development of the Level 1 and Level 2 plans:

1. Investigate the use of energy-conserving and solar utilization zoning categories in the community.
2. Urge the state to rigorously enforce the Georgia State Energy Code for Buildings in the community.
3. Encourage residents of the community to negotiate solar easements with their neighbors.
4. Establish solar access covenants which restrict the obstruction of insolation on buildings in Shenandoah.
5. Publicize the incentives passed in the National Energy Act and in response to President Carter's proposed Import Reduction Program.
6. Work to educate local builders, bankers, and appraisers about the economic savings of the energy-conserving plans.
7. Perform market research studies to estimate the demand (and acceptable cost) for energy-conserving structures.
8. Help market homes, apartments and townhouses in the community.
9. Consult with builders about the acceptability of different covenants and contractual agreements. Work out compromises that preserve the energy-conserving nature of the community.

6.2--Impediments and Solutions to the Level 3 Plan

Many of the same impediments exist for the Level 3 plan that were discussed for Level 1 and Level 2. The central utility plant and thermal distribution system may present additional problems, which are discussed in this section.

6.2.1.--Utility Attitudes.

The Coweta-Fayette Electric Membership Corporation will supply electricity to the energy-conserving community. The EMC and its owner, Oglethorpe Power Corporation, agreed to consider ownership and operation of the central utility plant. The Georgia Power Company also expressed interest, but felt that since an EMC would supply the community's electricity, Ogelthorpe was the most appropriate candidate for ownership.

Among the other potential owners and/or operators of the central utility plant, there are no viable alternates. Coweta-Fayette EMC's relationship with Oglethorpe would not allow them to own any sort of generating facility. Atlanta Gas stated that ownership was beyond the scope of their corporate purpose and policy which is to sell natural gas. Shenandoah views their role as a land developer to include such activities as planning, land acquisition and the installation of infrastructure to be deeded to the public. Ownership and operation of facilities, where necessary, is a transient activity for the developer; therefore, they do not wish to own and/or operate a central utility plant. In addition, they do not have the technical expertise required to operate a utility plant. Coweta County has limited financial and labor resources (it took 6 years before Coweta County accepted infrastructure at Shenandoah and assumed ownership and maintenance responsibilities) to apply to such a project; therefore, it is doubtful that they would pursue this undertaking. The only remaining alternative would be some form of private ownership of the plant and/or thermal distribution system.

Oglethorpe Power Corporation's decision to build rests primarily on several questions--Can the necessary capital be raised? Can Oglethorpe own a thermal plant and distribution system? Do they want to? Is the system indeed economical? Will the government support the system with incentives? Oglethorpe has made two commitments for proceeding with the Central Utility Plan: (1) they will finance to some extent, a feasibility study to investigate the above questions and (2) they will go ahead with the project subsequent to favorable determinations in the feasibility study.

6.2.2.--Environmental impacts

The Central Utility Plant is controlled by Point Source Pollution regulations and is subject to numerous environmental regulations. The design of the plant meets all required pollution standards and no additional environmental problems are anticipated.

Regulations of the Environmental Protection Agency require that an environmental impact statement be filed and approved for the proposed cogeneration facility prior to implementation of the plan. Although it is anticipated that the statement will be routine and not significantly impede the implementation process, the preparation, review and approval process is often subject to unexpected delays.

6.2.3.--Incidence of Costs and Benefits

There are three major components of the Central Utility Plan--the cogenerating facility, the thermal distribution system, and the individual buildings. The costs for the plant and distribution lines will be borne by the utility, presumably Oglethorpe Power Corporation. Revenues for steam and electricity sales will cover the utility's costs. The owners of the buildings will purchase the equipment used to transfer the heat in the thermal distribution lines to the rooms. The equipment will replace conventional gas furnaces, and the hot and chilled water will substitute for natural gas heating and electric cooling. However, the owners will also have to install electric heat pumps for back-up systems.

The time factor will influence the attractiveness of the central utility plan. The major costs fall before the system is even operational. The benefits accrue every year.

6.2.4.--Financing.

Oglethorpe Power Corporation raises capital through internal sources and external sources, bonds. The majority of OPC's long-term financing is guaranteed by the Rural Electrification Administration (REA).

Banks in the Shenandoah area would probably provide financing for buildings up to the appraised value; however, appraisers may question the sense of investing in two heating systems. Thus, the appraised value of the thermal heating system with heat pump back-up may be less than its total cost. The economics of the system would have to be quite favorable for the system to be valued at true cost. Of course, salesmanship can help convince the appraiser of the virtues of the thermal heating system.

6.2.5.--Marketing.

The same marketing considerations exist for the Level 3 community as for Level 1 and Level 2.

6.2.6.--Builder's attitudes.

The builders will consider the Level 3 plan much as Level 1 and Level 2.

6.2.7.--Developer's attitudes.

The developer will consider the Level 3 plan much as Level 1 and Level 2. In order to insure that the thermal distribution system is used, Shenandoah Development could use covenants or provisions in sales agreements to encourage builders to install thermal heating/cooling systems. However, Shenandoah has said they will not force builders to put in one type of system. Therefore, builders must be willing to cooperate for the Level 3 plan to succeed.

6.2.8.--Recommendations.

Specific recommendations for overcoming impediments to the Central Utility Plan are as follows:

1. Investigate in a detailed feasibility study, the specific institutional arrangements for the plan.
2. Provide loans for cogenerating facilities through federal, state, or private agencies.
3. Make provisions for incorporating cogenerating systems with thermal distribution lines into the rate base.
4. Provide tax credits for helping building owners purchase systems that use thermal energy from cogenerating power plants.

- (1) If shutters are used on every window all winter hours except from 10:00 a.m. to 5:00 p.m., the energy savings are as follows:

$$\begin{aligned}\Delta U \text{ value} &= U \text{ windows} - U \text{ shutters} \\ &= .64 - .0975 = .5425 \text{ Btu/hr} - \text{°F} - \text{ft}^2\end{aligned}$$

Annual reduction in heat loss if shutters are in place all winter:

$$\begin{aligned}&= \Delta U \text{ value} \times \text{°days} \times 24 \text{ Hr/day} \\ &= .5425 \times 2681 \times 24 \\ &= 34,907 \text{ Btu/sq. ft. of covered glass}\end{aligned}$$

Annual reduction in heat loss for house with 330 sq. ft. of glass with shutters in place from 10:00 a.m. until 5:00 p.m. (only about 23% of heat loss occurs during this time according to the U.S. Department of Energy's BIN Analysis Technique):

$$\begin{aligned}&= 34,907 \text{ Btu/ft.}^2 \times 330 \text{ ft.}^2 \times (1-.23) \\ &= 8.87 \text{ million Btu., or 26.9\% of annual heat loss of 33 million Btu.}\end{aligned}$$

- (2) The direct gain system design used in the analysis was generic, as we devised no house plans. The design includes 240 sq. ft. of glass and 180 sq. ft. of storage in the floor, which serves as thermal mass. For more discussion see Chapter 4.
- (3) In a typical 2000 sq. ft. house, a 240 sq. ft. greenhouse can contribute between 5% and 10% of space heating needs according to the Passive Solar Energy Book written by Edward Mazria.
- (4) The 60% contribution of the active solar system for heating water was derived using the F-Chart method described in The Solar Decision Book written by Richard Montgomery.

(5)

Rationale on interest and escalation rates:

- Construction financing - 5% -- We assumed a four-month start/completion period for most of the residential units. Since interest is paid only during construction period, a 5% interest rate for four months is approximately equal to 15% annually, which is a close approximation of current rates which are running at prime plus 2-3 points.

- Discount rate - 10% -- We assumed 10% because this is the customary rate used in this type of analysis. Of course, a sensitivity analysis was run on this factor.

- ROI Capital -- This factor was not used in the analysis. It is shown because earlier in the study we thought it may be useful; as it turned out, it was superfluous.

- Construction - 10% -- This rate was chosen as an approximation of the general inflation rate over the next several years.

- Electricity - 7.5% --

Gas - 10.0% --

These rates were chosen as realistic long-run escalation rates by reviewing trade journals and primarily by conversations with utilities.

- Thermal - 5% -- This rate was chosen because we felt the thermal energy costs would be a function primarily of wood costs and our approximation was 5% annually. If wood and wood "wastes" become ever more popular, I suspect this figure may be low.

- (1) A "cost center" is a group of building types. For example, the "Detached Dwelling Units" cost center is the sum of the single-family dwellings, large and small. The "cluster" cost center is the sum of the multi-family units, townhouses and apartments. We decided not to aggregate the analysis in this way, but nonetheless thought it might be useful information. The various cost figures of the cost center should in every case be the sum of the corresponding figures from the "Elemental Report" where the "elements" are the specific building types.
- (2) Stein, Richard G. Architecture and Energy. Garden City, New York: Anchor Press/Doubleday, 1977. pp. 201-206.
- (3) See Olgyay, p. 99.
- (4) See Landscape Planning for Energy Conservation. Environmental Design Press, 1977, page 3.
- (5) Options for Passive Energy Conservation in Site Design, p. 89.
- (6) The space demands of the 1600 sq. ft., passive house built with revised construction were about 15,367 Btu/sq. ft.-° days. Cooling requirements were determined through a complex procedure that is not reducible to a degree day estimate.

- (7) In analysis of direct gain systems, we computed the heating load with no solar gain at 47.4. Such a load would require 63.1 MMBtu's of natural gas; however, due to solar gain in the conventional home's windows, natural gas consumed for heating was 41.2 million Btu's.

In Balcomb's analysis in the Passive Solar Associates Workbook, the fraction of heating supplied by solar is approximately 60% of the solar load ratio, except when the ratio is greater than .8, when the fraction of solar heating declines from 60% of the ratio. Taking into account the generic design of our model house and the general uncertainty of passive performance, we simplified the computation so that the solar heating fraction was 60% of the solar load ratio. In only three months -- Oct., Nov., and April -- did this estimate depart from Balcomb's analysis. Therefore, our estimates were a bit optimistic compared to Balcomb's original approach.

However, in subsequent work reported in the 3rd National Passive Conference held in San Jose, California, Balcomb reports much more optimistic direct gain performance. This work was published after the Level 2 plan was completed; therefore, it could not be used in our analysis here. However, the numbers reported above are in between the two Balcomb estimates and are thus good estimates. In our analysis, the remaining heating load is 25 million Btu's, while in Balcomb's first estimate, it is 26 million Btu's and in his revised estimate, it is 20 million Btu's.

- (8) See Appendix 5.

- (9) The work referenced is: "Heat Pump Centered Integrated Community Energy Systems - System Development Georgia Institute of Technology Interim Report," February 1979, Argonne Contract number 31-109-38-4551.

- (10) 4. Westinghouse Electric Corporation, "Conceptual Design Proposal in Connection with Solar Total Energy-Large Scale Experiment", submitted to ERDA in response to Request for Proposal EG-77-R-04-0026, March 1977.
5. General Electric Space Division, "Solar Total Energy Large Scale Experiment at Shenandoah, Georgia", Department of Energy Contract Number EG-77-C-04-3985, July 1978.

See Bibliographies in next section for any further references.

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Includes:

- **Passive Siting and Design**
- **Decentralized Options**
- **Central Utility**
- **Annotated Additional Bibliography**
- **Additional References**

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2 ANNOTATED ADDITIONAL BIBLIOGRAPHY

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Farahan, Ebrahim, "Residential Electric and Gas Water Heaters," ANL/CES/TE 77-2 (August 1977).

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Discusses the possibility of providing central heating for a community by electric or fossil-fired central boilers. Two types of electrical, immersion heater and electrode and two types of fossil fired, fire tube and water tube are considered. Characteristics, available sizes, cost considerations, and performance data are provided. Fuel oil, natural gas, and coal are considered as fuels for fossil-fired package boilers. Different arrangements (conveyor stoker, over and underfeed stoker) for coal-fired boilers are described. Pollution effects in fossil-fired boilers including emission factors for the various fuels as well as water treatment requirements are given.

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Discusses the use of waste heat from electric generators to run $\text{LiBr-H}_2\text{O}$ absorption machines that would provide cooling to the entire community. Single effect machines, using 12 psig steam, give COP's ranging from .6 to .65. Double effect machines, using 144 psig steam give COP's ranging from 1 to 1.15, but at considerable incremental cost. Manufacturers suggested operating conditions and available sizes, ranging from 3 to 1,660-ton capacity, are given. Capital and operating and maintenance costs are given as a function of capacity. Some considerations for integration into ICES are thermal storage (hot and cold), solar assisting, heat exchange between hot and cold portions of buildings, integration with compressive chillers, and auxiliary power requirements. Ammonia, water absorption chillers are not considered readily available technology at this time.

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"Site Energy Handbook, Vol. 1 - Methodology for Energy Survey and Appraisal," ERDA Project No. E(49-1)-3853 (October 1976).

Provides guidelines and forms for performing a site energy baseline survey including acquisition, manipulation, tabulation, and analysis of data, and also identifies possible site energy conservation opportunities with guidelines for their selection, analysis, and interpretation. It does not include building insides or transportation. Energy entering, generated, distributed, consumed, and recovered are quantified. Flow charts describing methodology are provided. Limited or comprehensive surveys are possible with the given guidelines. It is assumed that a system (community) already exists that needs to be modified. A three-phase approach to the survey is used: (1) identification of each site energy and utility system, (2) analysis of overall site energy configuration, and (3) identification and evaluation of sites energy conservation options, including cost and energy savings comparisons. Appendix B provides a good readable description of ICES.

"Alternative Energy Systems Feasibility Study for the Mendocino Community College District," Sunbelt Technology, Inc., and Collaborative Interface Design (1977).

Develops and evaluates methods for designing an energy efficient college campus. Designs, conclusions, and recommendations are specific to the Ukiah, California climate. Two typical campus buildings, a base model and energy conserving model are analyzed. Information concerning the availability and cost of conventional and alternative energy sources is provided. As background information, the seriousness of the energy crisis and technology and policy alternatives are discussed. The influence of building and system design and operation on energy consumption is discussed. Building skin, thermal mass, heating, cooling, ventilation, water use, solar energy utilization and rejection, orientation, vegetation, and site integration are all considered in the energy analysis. The energy conserving building design is recommended and shown to be lower in capital and operating costs.

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Provides a framework within which a community can determine its energy objectives, select energy management and conservation actions, and prepare time phased implementation plans. Comprehensive or partial energy plans are developed supposedly for communities larger than 25,000, although smaller communities could be analyzed. Energy audit is by land use sectors, energy using activities, and fuel types. The report is divided into three volumes, a workbook, appendices, and worksheets, Volume I, the workbook is divided into four parts, community energy audit, objectives formulation, identification of alternatives and strategies, and implementation. Such alternatives as site and structural characteristics, equipment energy use and operation are addressed. Directions for using the worksheets in Volume III are provided. Rules of thumb for estimating energy use in future additions, as well as descriptions of alternatives, impact assessment, and federal assistance programs are provided in Volume II. Worksheets in Volume III include parcels tabulation, master energy worksheet, objectives formulation, alternatives selection, implementation strategy selection, community and physical impact analysis, and final selection. The methodology is highly comprehensive, but can be applied to a portion of the community and at any population level.

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Discusses combined electric power with district heating systems in existence in Europe and USSR. Various systems are described with mechanical schematics. Equations for heat storage capacity and predicted indoor temperatures of buildings are provided. Thermal storage, scaling and corrosion problems are examined. A new cogeneration system employing large volume thermal storage is presented. The information is generally for large communities (>40,000) although it is applicable to smaller ones.

"Passive Design Ideas for the Energy Conscious Builder," National Solar Heating and Cooling Information Center.

Uses a standard practice house as a base and modifies it for energy conservation using various passive ideas including one-story configuration, greenhouses, orientation, atriums, window placement, air collectors, etc. The percent energy savings is quantified for each idea. Conceptual drawings and references are provided.

"Total Integrated Energy System (TIES) Feasibility Analysis for the Downtown Redevelopment Project, Pasadena, California," ERDA Contract No. EY-76-C-03-1151 (April 1977).

The purpose of this document is to determine the best way of serving energy needs of a commercial development in Pasadena. The criteria are economic benefit, minimum energy use and minimum pollution. Three alternatives are considered: a conventional, utility connected system, a total energy system in which the plant is near the user supplying waste heat for heating and cooling and a TIES system that operates on thermal demand with power output to the utility grid. The TIES system is directly operated by the utility and offers 20% of the minimum demand for electricity. Descriptions of the different energy systems with cost comparisons are given. The Electrical Energy Associations AXCESS computer program is used to analyze each system and provides annual energy consumption by end use. Diesel, gas turbine and steam turbine systems are considered for TIES, with the diesel engine consuming the least energy. However, the TIES scheme is shown to be financially infeasible and the conventional alternative is recommended. Appendices with quantitative data are provided.

Romanos, Michael C., "Community Planning for Energy Conservation - A Scenario for ERDA's Community Design RD&D," ERDA Contract No. 31-109-38-3701 (June 1977).

This report defines the goals and objectives of research activities in conservation in the community, with particular emphasis on the community design element. Communities are categorized and analyzed with respect to energy conservation. Special developments are included. Flow charts assist in developing an analysis of a land use/transportation system. The state-of-the-art in community energy consumption patterns is examined. RD&D needs are prioritized quantitatively in terms of these criteria: timing of impacts, energy conservation potential, degree of public acceptance, and institutional changes. A summary of the energy research plan by high, medium, and low priority in terms of planning levels evolves into a research framework. Note that ICES is given high priority.

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Co-op City is a cooperative housing project in New York City that has a central heating and cooling plant with emergency electric power generation. This report is an assessment of on-site electric power generation through upgrading of the plant. The assessment methodology, as well as the current status of equipment, is discussed. Candidate technical options and fuels are discussed with schematics and cost breakdowns. Appendix B provides a framework for determining the future economic feasibility of technical options.

"Grid Connected ICES: Preliminary Feasibility Analysis and Evaluation," Vol. 1 - Executive Summary, Vol. 2 - Final Report, Vol. 3 - Appendices, ERDA Contract No. EC-77-C-02-4214 (June 1977).

Alternative energy systems for the Health Education Authority of Louisiana (HEAL) demonstration community are discussed. Four systems are evaluated: (1) conventional central heating and cooling plant without electric generation, (2) the existing system of individual steam turbine plants driven by gas, (3) coal fired, high pressure, temperature steam plant in which by-product electric power is fed into the grid, and (4) similar to (3), but also provides community cooling by centrifugal compressors and chilled water distribution. A description of the entire community with flow diagrams and schematics for each alternative is provided (Volume II). Total estimated costs for each system are given (Volume I). System (4) is recommended and shown to be economically feasible. Volume II gives an in-depth description of five tasks leading to completion of the system. These include preliminary energy analysis and institutional assessment, conceptual design, firming up commitments, and a detailed work management plan. The Appendices in Volume III provide maps of the demonstration community, demand profiles, environmental assessment, financing, and personnel qualifications.

"Technology Assessment of Modular Integrated Utility Systems," Vol. 1 - Summary Report, ORNL/HUD/MIUS - 24 (December 1976).

A description of general MIUS systems and their impact on resources, economics, environment, social, institutional, and demographic areas. The stress is on societal impact and not energy. The technology assessment methodology is discussed. A discussion of what population levels MIUS is best suited for is provided. Conceptual drawings describe various MIUS systems. Seven model systems ranging from MIUS to all electric homes are compared in terms of energy use, economic and environmental impact, and social effects. Cause-effect relationships of MIUS are illustrated by contingency diagrams.

"Solar Energy in America's Future - A Preliminary Assessment," DSE-115/2 (March 1977).

This report documents a Stanford Research Institute study of potential roles that solar energy technologies could have for meeting U. S. energy needs over the next 45 years. Computer simulations are used in analysis. Three scenarios -- low demand, solar emphasis, and reference -- are developed. A national view comparing the three scenarios by three perceptions is discussed. These are industrial growth, reordering of values and priorities, and a fundamental transformation to decentralization and soft technologies.

"Grid Connected Integrated Community Energy Systems," Executive Summary, ERDA Contract No. EC-77-C-02-4210 (June 1977).

A 54% increase in fuel utilization is projected with this ICES system installed at the University of Minnesota. Schematics and process diagrams, heat balances, project schedule, and a cost summary are provided. Oil and gas using plants are decommissioned and a coal pyrolysis system is installed. Steam instead of hot water distribution is integrated with thermal storage to lower peak demand. Also, coal is obtained at a cheaper price through rail renovation.

"Trenton ICES," Vol. 1, Phase 1, Final Report, ERDA Contract No. EC-77-C-02-4212 (July 1977).

A preliminary energy assessment indicates a 32-43% fuel reduction for this system which would serve 18 existing buildings in the Trenton, New Jersey area. Thermal gain profiles of buildings are developed. The steam turbine power plant allows a 25% load increase with space for an additional turbine/boiler. Thermal storage tanks store hot water in the winter and cold water in summer. The ICES and conventional systems are evaluated. An institutional assessment includes legal and regulatory considerations controlling the plant regardless of ownership.

Hilsen, N. B., "Environmental, Economic, and Conservation Aspects of Integrated Energy Systems," Georgia Tech EES, U. S. EPA Contract No. 68-03-2394 (April 1978).

Reports methodology and results of an analysis of environmental, economic, and energy consumption aspects of cogeneration principles to form an IES. The subject is considered from the general, comprehensive perspective and is difficult to apply to specific sites. Pros and cons of IES are developed through cost and energy considerations. The analysis methodology is comparative treatment of a base case and alternates. Appendices provide computer program description, social impact analyses, and a discussion on liquid waste.

"The Planners Energy Workbook," Sponsored by the Office of Conservation and Environment, FEA (October 1976).

A contribution to the lack of information and methods for planners to bring energy into the set of goals and criteria. Straightforward calculational procedures and worksheets that use energy intensity factors (EIFs) to carry out an evaluation of alternative land use planning and design. Local data and information (building construction practices, industry and transportation mix, etc.) are used to quantify EIFs. The interdependence between land use and energy consumption is well discussed.

"Energy and Land Use: Analysis of Alternative Development Patterns," Environmental Comment (September 1975).

Presents quantified information illustrating the possible variations in energy consumption that are likely with alternative forms of development. The energy consumption that is attributable to various patterns is measured with the implications for future development. The present energy balance of Washington, D. C., by source and end use is presented.

"Energy Conservation and Land Development," Environmental Comment (July 1977).

Presents a round table discussion of the qualitative relationship between energy conservation and land development. Provides a good list of references on energy conservation and land use planning.

"Solar Energy and Land Use," Environmental Comment (May 1978).

Various articles describing the land use implications of solar utilization and adoption of solar into new building design. A good discussion of the solar access issue is presented.

Mills, Madolia, Massey, "Energy Conscious Design Techniques: Associated Economic, Environmental, Legal, and Social Considerations., Council of Planning Librarians Exchange Bibliography No. 1456 (February 1978).

A bibliography siting books concerned with energy consumption in building design and retrofit. Directed at architects, builders, developers, researchers, planners, lawyers, homeowners, students, and others. Sections on economics, environment, legal and social issues, books, periodicals, articles, and general information.

Lehrfield, D., "System Design and Proof of Concept Experiment of a Total Energy System," ERDA Contract No. EY-76-C-02-2947 (December 1976).

A quarterly progress report on a central plant total energy system utilizing a Stirling engine as the prime mover. Comparative first costs (to conventional and other TES) and part load curves of various equipment are presented. Plans for development, conceptualized systems, and site location options are discussed.

"Methodology for the Development of Energy Management Plans in Small Communities," Sizemore & Associates, ERDA Contract No. EA-77-X-01-1834 (February 1978).

A series of 35 steps which a community can take to identify its motivations for creating an energy management plan with specific goals. The methodology is developed in conjunction with an energy management study of LaGrange, Georgia. Similar efforts, climate, utility data, economics, and different users are discussed. Information sources, energy survey forms, fuel data, and economic and environmental acceptance information are presented along with an example problem.

"The Impact of Energy Costs and Supply Prospects on Land Development Practices," Urban Land Institute (April 1978).

An assessment of Urban Land Institute members perceptions regarding the impact of energy economics on land development practices by survey. The emphasis is on building design, materials, alternative energy, and R&D, with less on site design and location. A great deal of quantitative data related to community energy consumption, such as effects of size and climate, transportation, and use of alternative resources. The questionnaire that was used for the survey is presented.

"Energy Management in Municipal Buildings," Massachusetts Department of Community Affairs Energy Conservation Project.

This document was prepared to convey to town managers and officials proven approaches to energy conservation. A plan to cut energy use by 30% in existing buildings and more in new buildings based on three management techniques: management, budgeting, and building audits. The work is done with 112 buildings in six cities with a potential annual savings of \$500,000. An annual energy index is developed for each building in million Btu/sq. ft. A technical appendix includes worksheets, general principles, and economic data.

"Energy Conservation in Residential and Commercial Buildings," Congressional Research Service, Library of Congress, Issue Brief No. IB75020.

A short document presenting background and policy analysis on the issue of government commitment to achieve energy conservation in building design and operation. Related national legislation is presented.

"Factors that Influence the Acceptance of Integrated Community Energy Systems," Argonne National Laboratories, Energy and Environmental Systems Division (January 1978).

How will affected individuals and organizations respond to ICES projects? This document identifies some potentially troublesome non technical factors such as interface with construction and real estate companies and the residents themselves. Potential communities, institutional flowcharts, economics, an overview of the development process, and effects of zoning, regulations, and ownership are presented. Major barriers to implementation are identified. Appendices provide a feasibility assessment, preconstruction planning details, leasing, sales and occupancy information, and management and operation principles. Appendix B has good illustrations of site location, building orientation, streets and vegetation effects on energy consumption.

"Financial Overview of Integrated Community Energy Systems," Argonne National Laboratories, Energy and Environmental Systems Division (January 1978).

Provides an overview of utilities and municipalities decision making processes and compares the cost of ICES with alternate energy sources. Social costs and benefits are not discussed. Recommendations for DOE and state activities in aiding ICES development are presented, including alteration of the regulatory framework (e.g. off peak electric rate-structures and natural gas curtailment). Financing strategies for ICES projects are discussed. Promising market areas for ICES are identified.

"An Overview and Critical Evaluation of the Relationship between Land Use and Energy Conservation," Volumes 1 and 2, Technology and Economics Inc., Cambridge, Mass. (March 1976).

This study investigates the relationship between land use, the pattern of activities and objects on the land, and their associated energy use. A conceptual framework for considering land/energy interactions is presented. Gaps in existing knowledge of the subject are identified with recommended, prioritized, additional research and government action to fill the gaps. Volume II presents four technical supplements that support the procedures and findings of Volume I. The history of energy development and its affect on land use patterns with alternative scenarios for the future is presented. The state-of-the-art in energy/land use policy practice including MIUS program headlights is discussed.

"Mixed Strategies for Energy Conservation and Alternative Energy Utilization in Buildings," Volumes II and III, Energy Resources Center, Honeywell, Inc., DOE Contract No. EY-76-C-03-1234 (November 1977).

The results of a project to provide information to assist home and building owners select different strategies for energy conservation. Measures

applicable to heating, cooling, lighting, and water heating are emphasized. Different cities in each region are chosen for analysis (Atlanta in Southeast). The computer programs DYNsim, SUNsim, AND ECON 1 are used for comparison. Solar hardware is considered, but the use of passive solar is neglected. The savings and payback period of various energy conservation techniques is presented. Volume III provides appendices to support conclusions.

Rubin, Arthur I., "Energy Conservation in Buildings - A Human Factors/ Systems Viewpoint," U.S. Dept. of Commerce/NBS (November 1976).

The author of this document feels that human comfort is taking a back-seat to energy conservation in buildings. He sites that reduced lighting and ventilation and increased temperature variations will cause unnecessary human discomfort and calls for experimental testing of these modifications. Criteria to select among alternative design options and various approaches to energy conservation are presented. Systems combining men and machines are considered to have high conservation potential. Current programs in this field are discussed.

Roberts, Deborah D., "Energy Recovery from Monroe County's Solid Waste: The Complexities of being an Innovate among Local Government," DOE Contract No. EY-76-C-02-4044 (December 1977).

A 200 ton per day MSW plant producing fuel suitable to burn with coal was presented as the solution to a landfill, not energy crisis in Monroe County, New York. Local politics and publicity inhibited development of the plant. Overcoming these obstacles is discussed in this report. The decision making process from conception to completion is presented.

"District Heating and Cooling Utilizing Temperature Differences of Local Waters," Water Resources Research Program, Argonne National Laboratories - ANL/WR-77-1 (May 1977).

This report examines the feasibility of cooling and heating buildings in Chicago's South Loop New Town by using cool Lake Michigan water and warm water from nearby electric generating station as heat pump reservoirs. Three systems are considered: Conventional, lake water cooling only, and modular heat pump systems. The modular heat pump system is shown to be lowest in capital and operating costs. Systems marketability, dependability and utilization are considered, as well as recommendations for future work. Economics is more fully discussed than technology. The system is only applicable to major U.S. urban centers located near lakes and oceans.

"Options for Passive Energy Conservation in Site Design," U.S. D.O.E.
Contract No. EC-77-C-01-5037 (June 1978).

A state-of-the-art study examining existing research and applications of land planning and design for energy conservation. The report is organized around the basic natural heating and cooling principles and the impact of site elements on human comfort. Methods for modifying sun and wind patterns to provide natural ventilation are discussed. Four climatic regions in the U.S. are considered: temperate, hot-humid, hot-arid, and cool. The document is divided into three sections: general guidelines for site design, regional variations, and appendices. Excellent illustrations of site design principles are provided. The underlying premise of this report, that recognition of existing site conditions, processes and factors will result in optimum and less expensive energy conservation measures, is well illustrated. Appendices summarize pertinent data collected during the project.

"Planning Program to Accelerate Energy Conservation in Municipalities,"
Interim Report, U.S. D.O.E. Contract No. EC-77-C-01-5017 (July 1978).

Development and testing of a structure to make available energy technologies that provide a solution to local government identified energy conservation needs. These needs are prioritized, and brief problem statements and solution considerations are presented. The appendix provides a discussion of some alternate energy sources.

"Integrated Community Energy Systems Commercialization Case Studies," Argonne
National Laboratories, Draft Only (May 1978).

Documents a case analysis of alternative ICES concepts applied to a major metropolitan development complex (Fox Valley, Near Chicago, Illinois). Procedures of conceptual design, economy and energy impact assessment and financial strategy development are illustrated as parts of the process leading to implementation of an ICES. Three quantitative measures are given for each technology option presented: Net energy conserved, net scarce fuels conserved and economic viability. The suitability of ICES to developer strategy and case study methodology are also discussed.

"Buildings Energy Use Data Book," 1st Edition, ORNL-5363 (April 1978).

Characterizes current and past energy end use activities in the residential/commercial sector with statistical data. Each chapter discusses a variable that is important to determining energy use on the national level, but can be applied locally. Demographic, economic, climatological, sociological, and the use of appliances effect on energy consumption. The energy use and efficiencies of major appliances is addressed. Building structure, insulation effectiveness, and climatological data are included to determine heating and cooling demands in structures. A review and comparison of selected energy studies is also included. Appendices and bibliography.

"Energy/Environment Fact Book," U.S. DOE/EPA Decision series (March 1978).

Provides the latest data in summary form emphasizing the pollution effects from the use of coal. These include emissions, air quality standards, trends in air pollutin, allowable discharge from power

plants, pollution from coal and other fuels, cost of pollution control equipment, and regional issues in coal mining. Information is quantified in easy to read tables.

"Energy Use for Building Construction," Supplement, DOE Contract No. EY-76-S-02-2791 (October 1977).

This document discusses the energy used per unit of component in manufacturing various building materials, useful information for conducting a total energy analysis on a community system. Included are metal doors, windows, plastics, plumbing fixtures and fittings, heating and electrical equipment, pipes, wire and asphalt (most energy intensive building material). Labor intensity for various building designs is also discussed. Alternative construction materials and methods are compared in BTU's/unit of production. An extensive breakdown of the energy distribution in a typical one family residence is included.

"Waste Flow Characteristics and Resource Recovery," ERDA Contract No. EY-76-C-02-4011 (October 1976).

A Comprehensive survey of local waste flow studies dealing with waste generation and composition, including geographic, climatic, and socio-economic factors. Waste flow data, the effects of waste flow on resource recovery, and recommendations for government action in this area are provided. Also included are the effects of operational characteristics of resource recovery systems and waste composition estimates for different areas of the country. References and contacts are provided.

"Adoption of Energy Conservation Technology by the Syracuse and Rochester City School Districts," Syracuse Research Corp., DOE Contract No. EY-76-02-4044 (December 1977).

Information that may be useful in developing an energy conservation plan for a public school system, or a single school within a community system. Included are a discussion of processes that bring the energy conservation issues into local schools, interface with the board of education, energy budget analysis, technologies and materials employed, and system factors. Appendices provide the meat of the energy conservation programs and guidelines.

"An Assessment of Thermal Insulation Materials and Systems for Building Applications," Brookhaven National Laboratory, DOE Contract No. EY-76-C-02-0016 (June 1978).

Seven types of insulation are identified and evaluated in terms of thermal performance, fire safety, water vapor transmission, and mechanical properties. Different insulation assemblies (with diagrams) are also reviewed for performance. Areas of insufficient data are identified. Heat loss distribution for various insulation - assembly combinations are discussed. The influence of building codes and standards is addressed.

"Environmental Development Plan (EDP) - Buildings and Community Systems
Fy 1977," D.O.E., DOE/EDP-0020 (March 1978).

Identifies environmental concerns associated with R,D&D of Buildings and community Energy Systems and a strategy for resolving these. A framework for including environmental considerations in early planning stages and resolving environmental effects concurrently with energy technology development. Results are grouped into four areas: A & E systems, consumer products, urban waste, and ICES. Technology descriptions of each of these are provided. Scheduled RD&D for the near future is included with a list of current (1977) projects and milestones. Various technological options and strategies for environmental control are assessed. Appendices provide detailed information research strategies and references.

"Barriers Connected with Certifying or Listing of Energy Conserving Products Used in Buildings," Hittman Associates, Inc., ERDA Contract No E(04-3)-1211.

A discussion of the overcoming disparity between technological progress and slow rate of implementation in regard to energy conservation devices. The survey of various products (only fully developed products are considered) is useful and includes fluegas dampers, heat pumps, instantaneous water heaters, infrared spaceheaters, and foam insulation with a brief description of each. The energy losses for various conventional air conditioning systems and major appliances, and options for reduction are discussed. Barriers to development mentioned include due process, testing, standards, economics, and legal. These are discussed with respect to each product.

"The California Residential Energy Standards," State of California, ERDA Contract No. EY-76-C-03-1178 (August 1977).

An evaluation of problems of implementation, enforcement, and design aspects of California Energy Conservation Standards. Legislation and standards discussion are not applicable, but information on energy and building design is useful. The design conditions are for California, but applicable in other areas. Appendix A is an energy design manual for residential buildings that provides information on calculating required degree of insulation, installation of insulation, properties of heat (in laymen's language), the use of glazing, pipes and ducts, and weatherstripping.

"Minimum Energy Dwelling (MED) Workbook," D.O.E. Contract No. EY-76-C-03-1198 (December 1977).

This document is based on information gathered during the design of two MED's at Mission Viejo, a planned community in Southern California. The use of many different types of energy conservation techniques in building and community design is discussed with an emphasis on minimizing mechanical systems through passive design. The design and construction of the homes is well detailed with blueprints, diagrams, and description. Thermal mass insulation, sun and windows, internally generated heat, ventilation and infiltration, solar collectors (evacuated tube type are

used, but others are discussed), mechanical systems (absorption machine, controls) and plumbing (minimizing cold and hot water usage) are all considered in building design. Land use planning, transportation, administration programs, home environment, community service, and human interaction considered in community design. The use of psychrometrics in determining human comfort is well discussed.

The following publications are available from the Georgia Office of Energy Resources and are cataloged under the indicated number.

"Design, Development and Utilization of Local Energy Resources at NWC, China Lake, to Demonstrate a Functioning Total Energy Community," Naval Weapons Center, China Lake, California (September 1973). OER-E-450-14

Documentation of a program to demonstrate the utilization of locally available energy resources to replace conventional energy. Waste treatment, wind power, insulation, geothermal energy, solar energy, and economic aspects are considered. A detailed cost analysis of the whole project is included. Integrated systems are considered where possible.

Coraman, Ron, "Outline of Low-Cost Solar Energy Systems," OER-E-460-10, September 1976).

A shopping list of low-cost solar systems that are proven and available ranging from \$10 to \$800. Passive and active water heaters and passive spaceheaters are considered. Many of the systems are available in Georgia.

"The Feasibility of Generating Steam in West Alabama Using Wood as a Fuel," OER-E-485-5, Vol 1-4 (All volumes essentially the same with different applications), ECON Energy Conservation Co. (September 1976).

A collection and interpretation of information relevant to the feasibility of using wood as a fuel for existing steam plants at various institutions in West Alabama. Forestry, engineering, and ecological aspects are addressed. Illustrations of various steam generating and pollution control equipment are provided. Economic and energy analysis for various wood fuels and applications are provided.

"Silvicultural Biomass Farms," Vol. 1-6, Mitre Corp, ERDA Contract No. E(49-18) 2081. OER-E-485-9.

- Volume 1) Summary
- 2) The Biomass Potential of Short Rotation Farms
 - 3) Land Suitability and Availability
 - 4) Site Specific Production Studies and Cost Analyses
 - 5) Conversion Processes and Costs
 - 6) Forest and Mill Residues as Potential Sources of Biomass

Analyzes the potential of extending the use of wood biomass as an energy feedstock. Potential sources, species, productivity, derivatives, and research are discussed. The major parameters in the design of an energy farm are addressed with estimated production costs. The ability of wood to meet future energy needs is discussed in general.

"Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating," Phase III Progress Reports, Univ. of Pa., NSF Grant No. GI27976 (March 1973) OER-e-600-27.

An interim report of a study to use thermal energy storage and solar energy to provide comfort conditioning by methods which consume less fuel and require less peak power. Included are the design of an off peak air conditioner, solar heating of residential buildings, and the investigation of materials for storing thermal energy.

"Cogeneration and Integrated Energy/Utility Systems," Proceedings of a Conference, National Consumer Research Institute (June 1977) OER-E-650-6.

Mostly qualitative information, in the form of speeches from government and industry as well as consumer groups. The conference was held to establish a workable basis for using cogeneration for industrial applications and in population centers. Some diagrams of various systems described are included.

"The Marketability of Integrated Energy/Utility Systems," NBS and HEW (December 1976). OER-E-650-3.

A guide to the potential of Integrated Energy/Utility Systems for campuses, medical complexes and communities. Example system proposals at the University of Florida, and Central Michigan University are provided. Compatibility with future planning, economic viability, and correlation of electrical and thermal loads are discussed. Availability of fuels and technology are considered.

"1976 Energy Cost Study - Single Family Housing," Atlanta Gas Light Co. (1976) OER-E-740-3.

Establishes the loads and compares the costs of operating gas and electricity for energy needs of single family houses in various areas of Georgia. The gas-electric and all electric house are considered. Various tables provide energy consumption by add-on and costs.

"The Builders Guide to Energy Conservation," National Association of Home Builders. OER-E-740-43.

Building site and design considerations for energy conservation. Includes orientation, glazing, insulation, shading, thermal mass, lighting, and heating and air conditioning systems. Material and appliances selection are also addressed. Various construction techniques are illustrated.

Fischer, H.C., "The Annual Cycle Energy System," ORNL. OER-E-750-10.

An annual cycle energy system (ACES) is one that provides year round space conditioning and water heating by using a heat pump with a water source that is frozen during the winter heating season to provide air conditioning in the summer. This paper gives detailed information with schematics for residential and commercial ACES. Large central systems and single home units are considered. Graphs provide information for local use. Economic payback and utility load factor are discussed.

"Vanpool Implementation Handbook," Partofa Workshop Kit, Commuter Van Workshops, sponsored by FEA. OER-E-780-15.

All aspects of implementing van pooling into a community including organization, identifying routes, drivers, vehicles, fares, assembly, and legal questions. Also included in the kit is general information and supplemental information for Georgia.

"ASHRAE Standard 90-75-Energy Conservation in New Building Design," ASHRAE Inc. OER-E-751-6.

Provides design requirements to improve the energy utilization in new buildings. In particular, design of building envelope with adequate R values and low infiltration and selection of mechanical, service and lighting systems and equipment. Graphs and quantitative information are very useful for low energy building design.

"The Costs of Sprawl," Vol 1-2, Real Estate Research Corporation (April 1974).

These two volumes that were prepared for HUD, EPA, and CEQ provide a comprehensive and consistent set of quantitative and qualitative estimates of the economic, environmental, resource psychic, personal, and community cost associated with alternative patterns of residential land development on the "urban fringe" at the neighborhood and community levels. Information is based on six neighborhood prototype developments ranging from single family dwellings to high rise apartments. Maps represent various neighborhood prototypes. Energy analysis is at the community level. Results are provided in tables. This report is not site specific in that it makes quantitative estimates based on national averages. The second volume provides an extensive literature search and an essay on the effects of alternative development plans.

ADDITIONAL REFERENCES

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- Handbook of Energy Policy for Local Government. Edward H. Allen, Utah State University, Lexington Books, 1975.
- The American Energy Consumer. Dorothy K. Newman and Dawn Day, Ballinger Publishing Co., Cambridge, Massachusetts, 1975.
- Solar Heating and Cooling of Residential Buildings: Sizing, Installation and Operation of System. Prepared by the Solar Energy Applications Laboratory of Colorado State University for the U.S. Department of Commerce, October 1977. NTIS No. 003-011-00085-2.
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- "Impact of Energy Crisis on Land Use" by Edmund N. Bacon in Urban Land, July-August 1973.
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- Alternatives in Energy Conservation: The Use of Earth Covered Buildings. Proceedings and notes of a conference held in Ft. Worth, Texas, July, 1975. Prepared for National Science Foundation, Division of Advanced Energy and Resources.
- Passive Design Ideas for the Energy Conscious Architect. Prepared for the National Solar Heating and Cooling Information Center by Rensselaer Polytechnic Institute. NSHCIC operated under HUD contract, no date.
- Terraset Elementary School, Reston, Virginia. Prepared by Douglas Carter, architect. Design approach for an underground school.

The Davis Experiment: One City's Plan to Save Energy. Prepared by The Elements. A Case Study. 1977.

Using Land to Save Energy. Corbin Harwood, Ballinger Publishing Co., 1977.

Solar Heating and Cooling: An Economic Assessment. Prepared for National Science Foundation by Arthur E. McGarity.

Life Cycle Costing Emphasizing Energy Conservation, Guidelines for Investment Analysis. Prepared for ERDA, Division of Construction, Planning, and Support, September 1976, revised May 1977. E (49-1)-3850. Prepared by Reynolds, Smith & Hills.

Methodology for Energy Management Plans for Small Communities. Prepared for DOE/Community Systems Branch by Sizemore & Associates under contract EA-77-x-01-1834. February 1978.

The Impact of Energy Costs and Supply Prospects on Land Development Practices. Prepared for DOE by Urban Land Institute. April 1978.

The Fiscal Impact Handbook by Robert Burchell and David Listokin, Center for Urban Policy Research, New Brunswick, New Jersey. 1978.

Year-End Report, National Energy Peak Leveling Program. Prepared for ERDA by Engineering Supervision Co. November 1976.

Community Planning for Energy Conservation, A Scenario for ERDA's Community Design Research Development and Demonstration. Prepared for ERDA by Argonne Laboratories. June 1977.

Survey of Passive Solar Buildings. Prepared by AIA Research Corp. for HUD, Office of Policy Development and Research, HUD-PDR-287.

Appendix 1

Building Data and Dimensions

Building Type	# units	Total area - ft ²	Exterior wall area -ft ² conventional	Exterior wall area - ft ² conservation
HIGH SCHOOL	1	160,000	17,620	18,500
CHURCH/DAY CARE	1	12,000	7,900	-
FIRE/POLICE STATION	1	2,400	1,764	-
SINGLE FAMILY--1600 sf	73	116,800	107,748	-
SINGLE FAMILY--2200 sf	26	57,200	44,460	-
TOWNHOUSE UNITS--1200 sf	20	24,000	44,100	55,980
TOWNHOUSE UNITS--1500 sf	30	45,000	included above	included above
APARTMENT UNITS--950 sf	80	76,000	138,931	148,068
APARTMENT UNITS--1300 sf	120	156,000	included above	included above
MAINTENANCE BLDG.	1	10,000	-	-
SHOPPING/GAS	1	4,000	2,340	-
GOLF CLUB	1	14,700	5,600	-

Building Type	Total glass area	Overhang - lineal feet	Total roof area - ft ²
HIGH SCHOOL	2,112	630	
CHURCH/DAY CARE	1,185	-	
FIRE/POLICE STATION	90	-	
SINGLE FAMILY--1600 sf	19,272	2,570	116,800
SINGLE FAMILY--2200 sf	9,438	1,258	57,200
TOWNHOUSE UNITS--1200 sf	6,345	625	69,000
TOWNHOUSE UNITS--1500 sf	included above	included above	included above
APARTMENT UNITS--950 sf	13,893	2,773	232,000
APARTMENT UNITS--1300 sf	included above	included above	included above
MAINTENANCE BLDG.	-	-	-
SHOPPING/GAS	468	36	4,000
GOLF CLUB	1,120	70	14,700

BUILDING DIMENSIONS

High school

conventional	256 x 625 = 160,000 sf	perimeter = 1,762 ft
conservation	same	" = 1,850 ft

Church/Day care

conventional	80 x 150 = 12,000 sf	perimeter = 460 ft
conservation	"	"

Fire/Police

conventional	48 x 50 = 2,400 sf	perimeter = 196 ft
conservation	"	"

Single family - 1600

conventional	32 x 50 = 1,600 sf	perimeter = 164 ft
conservation	"	"

Single family - 2200

conventional	40 x 55 = 2,200 sf	perimeter = 190 ft
conservation	"	"

Townhouse units

conventional	35 x 20 per unit	perimeter = 2,450 ft
conservation	35 x 40 per two units with 15 ft. jogs	perimeter = 3,110 ft

Apartment units

conventional	24 bldgs. @ 121 x 40	perimeter = 7,720 ft
conservation	36 bldgs. @ 80 x 40 with 15 ft. jogs	perimeter = 8,245 ft

BUILDING DIMENSIONS - continued

Shopping/gas

conventional	50 x 80 = 4,000 sf	perimeter = 260 ft
conservation	"	"

Golf club

conventional	see above	perimeter = 560 ft
conservation	"	"

Appendix 2

Insulation and Infiltration

The minimum FHA standards referenced in the text and the other envelope changes in the conservation plans are outlined below:

Conventional Construction: walls -- R-11
 roof -- R-19
 single glazing
 infiltration -- 1.5 A.C./hr.

Improved construction
and passive siting with
berms, wind shelters, etc.: walls -- R-19
 roof -- R-26
 double glazing
 infiltration -- 0.6 A.C./hr.

We assumed that going from conventional to improved construction techniques would reduce air infiltration from 1.5 changes per hour to 1.0 changes per hour. According to the 1977 Fundamentals Handbook of ASHRAE, page 21.5, Table 1, the number of air changes per hour under average conditions for rooms with windows or exterior doors on two sides equals 1.5. According to the footnote, the number of air changes when using weatherstripping or storm sash would be reduced to 1.0 air change per hour. Therefore, we assumed going from standard to improved construction would reduce air changes from 1.5 to 1.0 per hour.

An additional decrease in infiltration would be realized if the pressure difference were reduced from 0.10 inches of water to 0.05 (Table 3 on page 21.6). According to the mechanical engineering consultants and the landscape architect, this reduction is realistic in this area using berms, shelter belts, plantings, and natural terrain. Using the frame wall figures, this indicates a 40% reduction. Therefore, we assumed that the "passive siting" would reduce the infiltration from 1.0 air change per hour to 0.6 air changes per hour.

See also: "Wind and Trees: Air Infiltration Effects on
Energy in Housing," G.E. Mattingly and E. F. Peters.
Journal of Industrial Aerodynamics, 2 (1977) 1-19.

The appropriate U-values for wall, roof, and glass follow.

REGULAR CONSTRUCTION VS. IMPROVED CONSTRUCTION
U-VALUES COMPARED

BUILDINGS	U-VALUES, REGULAR CONSTRUCTION			U-VALUES, IMPROVED CONSTRUCTION			REMARKS
	WALLS	ROOF	GLASS	WALLS	ROOF	GLASS	
HIGH SCHOOL	.12	.08	.64	N.C.	N.C.	N.C.	NO CHANGE IN CONSTRUCTION TYPE.
CHURCH/DAY CARE	.55	.07	.64	—	—	—	
FIRE-ENGINE	.12	.08	.64	N.C.	N.C.	N.C.	NO CHANGE IN CONSTRUCTION TYPE.
SINGLE FAMILY UNITS - A	.07	.04	1.13	.04	.03	.64	
SINGLE FAMILY UNITS - B	.07	.04	1.13	.04	.03	.64	
TOWNHOUSE UNITS - A	.07	.04	1.13	.04	.03	.64	
TOWNHOUSE UNITS - B	.07	.04	1.13	.04	.03	.64	
APARTMENTS - A	.07	.04	1.13	.04	.03	.64	
APARTMENTS - B	.07	.04	1.13	.04	.03	.64	
MAINT. BUILDING	—	—	—	—	—	—	
SHOPPING/GAS	.07	.04	.64	.04	.03	.64	
GOLF CLUB	.07	.04	.64	.04	.03	.64	

Appendix 3

Sample Life-Cycle Cost Model Runs

- . Conventional Plan -- Standard Construction
- . Passive Plan -- L1
- . Central Utility Plan -- L3

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290822.	0.	585716.	0.	1879685.	0.	5756224.
SINGLE FAMILY (2200)	1616006.	0.	288488.	0.	925741.	0.	2830235.
TOWNHOUSE (1200)	691152.	0.	120855.	0.	396577.	0.	1208583.
TOWNHOUSE (1500)	1283568.	0.	224407.	0.	805276.	0.	2313251.
APARTMENT (950)	1852752.	0.	366388.	0.	1909334.	0.	4128474.
APARTMENT (1300)	3761896.	0.	744005.	0.	3545280.	0.	8050981.
SENIOR HIGH SCHOOL	6195200.	0.	815973.	0.	1395291.	0.	8406464.
FIRE-POLICE STATION	116160.	0.	51977.	0.	79793.	0.	247930.
GOLF CLUBHOUSE	853776.	0.	111330.	0.	336161.	0.	1301267.
COMMERCIAL SPACE	116160.	0.	65274.	0.	88953.	0.	270287.

Table 5.3.6.1

SHENANDOAH CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION - STANDARD
ANALYSIS PERIOD 22 YEARS
CONSTRUCTION PERIOD 3 YEARS
CONSERVATION LEVEL 0-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING 5.00%
DISCOUNT RATE 10.00%
R O I CAPITAL 20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

PRESENT VALUE COST REPORT

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4966828.	0.	874264.	0.	2805426.	0.
CLUSTER DWELLING UNITS	7589168.	0.	1455654.	0.	6656467.	0.
INSTITUTIONAL FACILITIES	6311360.	0.	867950.	0.	1475084.	0.
COMMUNITY FACILITIES	969936.	0.	176504.	0.	425114.	0.
TOTAL	19777293.	0.	3374312.	0.	11362091.	0.
INTEREST	988865.	0.	0.	0.	0.	0.

* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981

TOTAL NET PRESENT VALUE - \$ 35502561.

Conventional Plan

Table 5.3.6.2

SITE PLAN

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  33      000000  *****
  32      00  00  **
  31      00  00  **
  30      00  00  **
  29      00  00  *****
  28      00  00  **
  27      00  00  **
  26      00  00  **
  25      00  00  **
  24      00  00  **
  23      00  00  **
  22      00  00  **
  21      00  00  **
  20      00  00  **
  19      00  00  **
  18      00  00  **
  17      00  00  **
  16      00  00  **
  15      00  00  **
  14      00  00  **
  13      00  00  **
  12      00  00  **
  11      00  00  **
  10      00  00  **
  09      00  00  **
  08      00  00  **
  07      00  00  **
  06      00  00  **
  05      00  00  **
  04      00  00  **
  03      00  00  **
  02      00  00  **
  01      00  00  **
  00      00  00  **
  31358888  000000  *****

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YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6094799.	0.	1149913.	0.	229761.	0.	7465473.
1982 - 2	12244532.	0.	2027618.	0.	583715.	0.	14815865.
1983 - 3	3130831.	0.	472033.	0.	676638.	0.	4279503.
1984 - 4	0.	0.	0.	0.	730437.	0.	730437.
1985 - 5	0.	0.	0.	0.	788576.	0.	788576.
1986 - 6	0.	0.	0.	0.	851410.	0.	851410.
1987 - 7	0.	0.	0.	0.	919327.	0.	919327.
1988 - 8	0.	0.	0.	0.	992743.	0.	992743.
1989 - 9	0.	0.	0.	0.	1072112.	0.	1072112.
1990 - 10	0.	0.	0.	0.	1157925.	0.	1157925.
1991 - 11	0.	0.	0.	0.	1250714.	0.	1250714.
1992 - 12	0.	0.	0.	0.	1351057.	0.	1351057.
1993 - 13	0.	0.	0.	0.	1459580.	0.	1459580.
1994 - 14	0.	0.	0.	0.	1576961.	0.	1576961.
1995 - 15	0.	0.	0.	0.	1703938.	0.	1703938.
1996 - 16	0.	0.	0.	0.	1841308.	0.	1841308.
1997 - 17	0.	0.	0.	0.	1989938.	0.	1989938.
1998 - 18	0.	0.	0.	0.	2150768.	0.	2150768.
1999 - 19	0.	0.	0.	0.	2324820.	0.	2324820.
2000 - 20	0.	0.	0.	0.	2513199.	0.	2513199.
2001 - 21	0.	0.	0.	0.	2717109.	0.	2717109.
2002 - 22	0.	0.	0.	0.	2937854.	0.	2937854.
2003 - 23	0.	0.	0.	0.	3176852.	0.	3176852.
2004 - 24	0.	0.	0.	0.	3435639.	0.	3435639.
2005 - 25	0.	0.	0.	0.	3715889.	0.	3715889.

Table 5.3.6.3

TYPE	DESCRIPTION	QUANTITY	DEVELOPMENT PERCENTAGE	BASE CONSTRUCTION UNIT COST	INCREMENTAL CONSTRUCTION UNIT COST	DECENTRAL ELEMENT UNIT COST	CONSTRUCTION PERCENTAGES BY YEAR			TOTAL CONSTRUCTION COST
							1	2	3	
1	SFD(1600)	75	17.80%	37256.	0.	0.	67.2	33.2	0.2	2719688.
2	SFD(2200)	2E	8.70%	51367.	0.	0.	67.2	33.2	0.2	1335542.
3	TH(1200)	23	3.70%	28568.	0.	0.	0.2	100.2	0.2	571200.
4	TH(1500)	30	6.90%	35360.	0.	0.	0.2	100.2	0.2	1060800.
5	APT(950)	80	11.60%	19140.	0.	0.	50.2	50.2	0.2	1531200.
6	APT(1300)	120	23.80%	25907.	0.	0.	50.2	50.2	0.2	3108840.
7	HS	1	24.30%	5120000.	0.	0.	0.2	67.2	33.2	5120000.
8	F/P	1	.40%	96000.	0.	0.	0.2	100.2	0.2	96000.
9	GOLF	1	2.20%	705600.	0.	0.	0.2	50.2	50.2	705600.
10	COMM	1	.60%	96000.	0.	0.	0.2	0.2	100.2	96000.

TYPE DESCRIPTION	BASE SITE DEVELOPMENT UNIT COST	INCREMENTAL SITE DEVELOPMENT UNIT COST	BASE LOT DEVELOPMENT UNIT COST	INCREMENTAL LOT DEVELOPMENT UNIT COST	TOTAL DEVELOPMENT COST
1 SFD(1600)	5222.	0.	1409.	0.	484063.
2 SFD(2200)	7222.	0.	1948.	0.	238420.
3 TH(1200)	3983.	0.	1011.	0.	99880.
4 TH(1500)	4931.	0.	1251.	0.	185460.
5 APT(950)	3135.	0.	650.	0.	362800.
6 APT(1300)	4244.	0.	880.	0.	614880.
7 HS	521770.	0.	152588.	0.	674358.
8 F/P	8589.	0.	34367.	0.	42956.
9 GOLF	47238.	0.	44770.	0.	92008.
10 COMM	12883.	0.	40980.	0.	53863.

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MWH)
1	SFD(1600)	42.400	17.61	0.00	0.00	0.00	1285.64
2	SFD(2200)	42.400	24.35	0.00	0.00	0.00	633.22
3	TH(1200)	45.000	15.12	0.00	0.00	0.00	302.47
4	TH(1500)	45.000	20.47	0.00	0.00	0.00	614.11
5	APT(950)	49.000	18.08	0.00	0.00	0.00	1446.36
6	APT(1300)	49.000	22.38	0.00	0.00	0.00	2686.10
7	HS	43.400	1532.70	0.00	0.00	0.00	1532.70
8	F/P	54.900	66.70	0.00	0.00	0.00	66.70
9	GOLF	54.900	287.10	0.00	0.00	0.00	287.10
10	COMM	54.900	78.10	0.00	0.00	0.00	78.10
							<hr/> 8,932.50

Table 5.3.4.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	TOTAL (MMBtu)
1	SFO(1600)	2.796	113.07	0.00	0.00	0.00	8,253.86
2	SFO(2200)	2.796	156.36	0.00	0.00	0.00	4,065.34
3	TH(1200)	2.796	67.63	0.00	0.00	0.00	1,352.54
4	TH(1500)	2.796	91.53	0.00	0.00	0.00	2,746.06
5	APT(950)	2.796	56.54	0.00	0.00	0.00	4,522.84
6	APT(1300)	2.796	70.00	0.00	0.00	0.00	8,399.56
7	HS	2.912	220.30	0.00	0.00	0.00	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10
9	GOLF	2.912	156.10	0.00	0.00	0.00	156.10
10	COMM	2.912	42.50	0.00	0.00	0.00	42.50
							29,790.20

Table 5.3.4.2

TYPE	DESCRIPTION	THERMAL ENERGY UNIT COST	THERMAL ENERGY UNIT CONSUMPTION
1	SFD(1600)	0.00	0.00
2	SFD(2200)	0.00	0.00
3	TH(1200)	0.00	0.00
4	TH(1500)	0.00	0.00
5	APT(950)	0.00	0.00
6	APT(1300)	0.00	0.00
7	HS	0.00	0.00
8	F/P	0.00	0.00
9	GOLF	0.00	0.00
10	CCHM	0.00	0.00

ANALYSIS INFORMATION	
SITE PLANNING OPTION	L1R
PASSIVE	REVISED
ANALYSIS PERIOD	22 YEARS
CONSTRUCTION PERIOD	3 YEARS
CONSERVATION LEVEL	4-10 ELEMENTS

ANNUAL INTEREST RATES	
CONST FINANCING	5.00%
DISCOUNT RATE	10.00%
R O I CAPITAL	20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION 10.00%
ENERGY
ELECTRICITY 7.50%
GAS 10.00%
THERMAL 5.00%

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4906829.	349527.	874204.	-19251.	2805426.	-510313.
CLUSTER DWELLING UNITS	7589160.	705345.	1455654.	-169303.	6656467.	-704871.
INSTITUTIONAL FACILITIES	6311360.	69815.	867950.	-90163.	1475084.	-6828.
COMMUNITY FACILITIES	969936.	28396.	176504.	-611.	425114.	-9514.
TOTAL	19777293.	1153083.	3374312.	-279329.	11362091.	-1231526.
INTEREST	988865.	57654.	0.	0.	0.	0.

TOTAL NET PRESENT VALUE - \$ 35202443.

Passive Plan

Table 5.6.1.1

SITE PLAN

A 10x10 grid of dots forming the number 1234567890. The digits are arranged in a single row, with each digit occupying a 2x2 block of dots. The digits are: 1, 2, 3, 4, 5, 6, 7, 8, 9, 0.

ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3296822.	234163.	565710.	-12896.	1879685.	-341862.	5635628.
SINGLE FAMILY (2200)	1616606.	115364.	288488.	-6355.	925741.	-168451.	2770793.
TOWNHOUSE (1200)	691152.	74826.	120855.	-8809.	396577.	-41406.	1233195.
TOWNHOUSE (1500)	1283568.	138920.	224407.	-16408.	805276.	-84240.	2351524.
APARTMENT (950)	1852752.	162140.	366388.	-47529.	1909334.	-202528.	4040556.
APARTMENT (1300)	3761696.	329459.	744005.	-96558.	3545280.	-376697.	7907185.
SENIOR HIGH SCHOOL	6195200.	65434.	815973.	-86739.	1395291.	-6828.	8378332.
FIRE-POLICE STATION	116160.	4380.	51977.	-3424.	79793.	0.	248886.
GOLF CLUBHOUSE	853776.	19747.	111330.	3570.	336161.	-4826.	1319757.
COMMERCIAL SPACE	116160.	8649.	65174.	-4181.	88953.	-4688.	270068.

Table 5.6.1.2

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6094759.	479982.	1140913.	-84942.	229761.	-23950.	7831564.
1982 - 2	12264532.	696283.	2027618.	-179794.	583715.	-68867.	15271577.
1983 - 3	3130831.	46540.	472033.	-37534.	676638.	-66874.	4223636.
1984 - 4	0.	0.	0.	0.	730437.	-72801.	657636.
1985 - 5	0.	0.	0.	0.	788576.	-79264.	709312.
1986 - 6	0.	0.	0.	0.	851410.	-86312.	765099.
1987 - 7	0.	0.	0.	0.	919327.	-93998.	825328.
1988 - 8	0.	0.	0.	0.	992743.	-102383.	890360.
1989 - 9	0.	0.	0.	0.	1072112.	-111530.	960582.
1990 - 10	0.	0.	0.	0.	1157925.	-121510.	1036415.
1991 - 11	0.	0.	0.	0.	1250714.	-132400.	1118314.
1992 - 12	0.	0.	0.	0.	1351057.	-144284.	1206773.
1993 - 13	0.	0.	0.	0.	1459580.	-157255.	1302325.
1994 - 14	0.	0.	0.	0.	1576961.	-171414.	1405548.
1995 - 15	0.	0.	0.	0.	1703938.	-186871.	1517067.
1996 - 16	0.	0.	0.	0.	1841308.	-203747.	1637561.
1997 - 17	0.	0.	0.	0.	1989938.	-222175.	1767762.
1998 - 18	0.	0.	0.	0.	2150768.	-242301.	1908468.
1999 - 19	0.	0.	0.	0.	2324820.	-264281.	2060538.
2000 - 20	0.	0.	0.	0.	2513199.	-288291.	2224908.
2001 - 21	0.	0.	0.	0.	2717109.	-314521.	2402588.
2002 - 22	0.	0.	0.	0.	2937854.	-343179.	2594675.
2003 - 23	0.	0.	0.	0.	3176852.	-374493.	2802358.
2004 - 24	0.	0.	0.	0.	3435639.	-408713.	3026926.
2005 - 25	0.	0.	0.	0.	3715899.	-446113.	3269775.

TYPE	DESCRIPTION	QUANTITY	DEVELOPMENT PERCENTAGE	BASE CONSTRUCTION UNIT COST	INCREMENTAL CONSTRUCTION UNIT COST	DECENTRAL ELEMENT UNIT COST	CONSTRUCTION PERCENTAGES BY YEAR			TOTAL CONSTRUCTION COST
							1	2	3	
1	SFD(1600)	73	17.86%	37256.	2651.	0.	67.2	33.2	0.2	2913211.
2	SFD(2200)	26	8.70%	51367.	3667.	0.	67.2	33.2	0.2	1430884.
3	TH(1200)	20	3.70%	28560.	3092.	0.	0.2	100.2	0.2	633040.
4	TH(1500)	30	6.90%	35360.	3627.	0.	0.2	100.2	0.2	1175610.
5	APT(950)	80	11.60%	19140.	1675.	0.	50.2	50.2	0.2	1665200.
6	APT(1300)	120	23.80%	25907.	2269.	0.	50.2	50.2	0.2	3381120.
7	HS	1	24.30%	512000.	54878.	0.	0.2	67.2	33.2	5174078.
8	F/P	1	.40%	96000.	3620.	0.	0.2	100.2	0.2	99620.
9	GOLF	1	2.25%	705600.	16320.	0.	0.2	50.2	50.2	721920.
10	COMM	1	.60%	96000.	7148.	0.	0.2	0.2	100.2	103148.

TYPE DESCRIPTION	BASE SITE DEVELOPMENT UNIT COST	INCREMENTAL SITE DEVELOPMENT UNIT COST	BASE LOT DEVELOPMENT UNIT COST	INCREMENTAL LOT DEVELOPMENT UNIT COST	TOTAL DEVELOPMENT COST
1 SFD(1600)	5222.	-717.	1409.	571.	4734.05.
2 SFD(2200)	7222.	-992.	1948.	790.	233168.
3 TH(1200)	3983.	-547.	1011.	183.	92600.
4 TH(1500)	4931.	-678.	1251.	226.	171900.
5 APT(950)	3135.	-430.	650.	-61.	263520.
6 APT(1300)	4244.	-583.	880.	-82.	535080.
7 HS	521770.	-71685.	152588.	0.	682673.
8 F/P	8589.	-1180.	34367.	-1650.	40126.
9 GOLF	47238.	-6490.	44770.	9440.	94958.
10 COMM	12883.	-1770.	40986.	-1685.	50408.

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	BASE LOS TOTAL (MWH)	TOTAL ANNUAL SAVINGS (MWH)	NET LIR TOTAL (MWH)
1	SFD(1600)	42.400	17.61	-2.03	0.00	0.00	285.64	148.19	1,137.45
2	SFD(2200)	42.400	24.35	-2.81	0.00	0.00	633.22	73.06	560.16
3	TH(1200)	45.000	15.12	-3.38	0.00	0.00	302.47	7.6	294.87
4	TH(1500)	45.000	20.47	-5.52	0.00	0.00	614.11	15.6	598.51
5	APF(950)	49.000	18.08	-1.03	0.00	0.00	1,446.36	82.4	1,363.96
6	APF(1300)	49.000	22.38	-1.28	0.00	0.00	2,686.10	153.60	2,532.50
7	HS	43.400	1532.70	-7.60	0.00	0.00	1,532.70	7.60	1,525.10
8	F/P	54.900	66.70	0.00	0.00	0.00	66.70	0.00	66.70
9	GOLF	54.900	287.10	-4.00	0.00	0.00	287.1	4.00	283.10
10	COMM	54.900	78.10	-4.20	0.00	0.00	78.10	4.20	73.90
							8,932.50	496.25	8,436.25

Table 5.5.1.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	BASE LOS TOTAL (MMBtu)	TOTAL SAVINGS (MMBtu)	NET LIR TOTAL (MMBtu)
1	SFD(1600)	2.796	113.07	-33.58	0.00	0.00	8,253.86	2,451.34	5,802.52
2	SFD(2200)	2.796	156.36	-46.44	0.00	0.00	4,065.34	1,207.44	2,857.90
3	TH(1200)	2.796	67.63	-21.06	0.00	0.00	1,352.54	421.20	931.34
4	TH(1500)	2.796	91.53	-28.51	0.00	0.00	2,746.06	855.3	1,890.76
5	APT(950)	2.796	56.54	-17.36	0.00	0.00	4,522.84	1,388.80	3,134.04
6	APT(1300)	2.796	70.00	-21.49	0.00	0.00	8,399.56	2,578.80	5,820.76
7	HS	2.912	220.30	0.00	0.00	0.00	220.30	0.00	220.30
8	F/P	2.912	31.10	0.00	0.00	0.00	31.10	0.00	31.10
9	GOLF	2.912	156.10	-3.90	0.00	0.00	156.10	3.90	152.20
10	CCMH	2.912	42.50	-1.10	0.00	0.00	<u>42.50</u>	<u>1.10</u>	<u>41.40</u>
							29,790.20	8,907.88	20,882.32

Table 5.5.1.2

TYPE	DESCRIPTION	THERMAL ENERGY UNIT COST	THERMAL ENERGY UNIT CONSUMPTION
1	SFD(1600)	0.00	0.00
2	SFD(2200)	0.00	0.00
3	TH(1200)	0.00	0.00
4	TH(1500)	0.00	0.00
5	APT(950)	0.00	0.00
6	APT(1300)	0.00	0.00
7	HS	0.00	0.00
8	F/P	0.00	0.00
9	GOLF	0.00	0.00
10	COMM	0.00	0.00

SHENANDOAH CASE STUDY
PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION

ANALYSIS INFORMATION
SITE PLANNING OPTION
CENTRAL UTILITIES
ANALYSIS PERIOD
CONSTRUCTION PERIOD
CONSERVATION LEVEL

REVIS
22 YEARS
3 YEARS
3-10 ELEMENTS

ANNUAL INTEREST RATES
CONST FINANCING
DISCOUNT RATE
R O I CAPITAL

5.00%
10.00%
20.00%

ANNUAL ESCALATION RATES
CONSTRUCTION
ENERGY
ELECTRICITY
GAS
THERMAL

10.00%
7.50%
10.00%
5.00%

PRESENT VALUE COST REPORT

COST CENTER	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST
DETACHED DWELLING UNITS	4906828.	389000.	874204.	-19251.	2605426.	45814.
CLUSTER DWELLING UNITS	7569168.	756807.	1455654.	-169303.	6656467.	214338.
INSTITUTIONAL FACILITIES	6311360.	-266683.	867950.	-90163.	1475084.	-17246.
COMMUNITY FACILITIES	969936.	38842.	176514.	-611.	425114.	-7186.
TOTAL	19777293.	917966.	3374312.	-279329.	11362091.	235719.
INTEREST	984865.	45498.	0.	0.	0.	0.

* ALL COSTS ARE PRESENT VALUE DOLLARS, JAN. 1, 1981

TOTAL NET PRESENT VALUE - \$ 36422016.

Central Utility Plan

Table 5.6.3.1

SITE PLAN

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ELEMENT	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ELEMENTAL COST
SINGLE FAMILY (1600)	3290822.	256334.	585716.	-12896.	1879685.	30825.	6030486.
SINGLE FAMILY (2200)	1618006.	132667.	288488.	-6355.	925741.	14990.	2971536.
TOWNHOUSE (1200)	691152.	82183.	120855.	-8809.	396577.	68724.	1348682.
TOWNHOUSE (1500)	1283588.	152678.	224407.	-16408.	805276.	34251.	2483772.
APARTMENT (950)	1852752.	175208.	366388.	-47529.	1909334.	-76682.	4179471.
APARTMENT (1300)	3761696.	346738.	744005.	-96558.	3545280.	190045.	8431206.
SENIOR HIGH SCHOOL	6195100.	-269434.	815973.	-86739.	1395231.	-18071.	8032220.
FIRE-POLICE STATION	116160.	2752.	51977.	-3424.	79793.	825.	248082.
GOLF CLUBHOUSE	853776.	19278.	111330.	3570.	336161.	-2041.	1332074.
COMMERCIAL SPACE	116160.	9564.	65174.	-4181.	88953.	-5146.	270525.

Table 5.6.3.2

YEAR	BASE CONSTRUCTION COST	INCREMENTAL CONSTRUCTION COST	BASE DEVELOPMENT COST	INCREMENTAL DEVELOPMENT COST	BASE ENERGY COST	INCREMENTAL ENERGY COST	TOTAL ANNUAL COST
1981 - 1	6994799.	521603.	1140913.	-84942.	229761.	58834.	7960969.
1982 - 2	12264532.	567181.	2627619.	-179704.	583715.	126687.	15270030.
1983 - 3	3130831.	-78299.	472033.	-37534.	676638.	124709.	4288379.
1984 - 4	0.	0.	0.	0.	730437.	120116.	850554.
1985 - 5	0.	0.	0.	0.	788576.	114328.	902904.
1986 - 6	0.	0.	0.	0.	851410.	107197.	958608.
1987 - 7	0.	0.	0.	0.	919327.	98560.	1017887.
1988 - 8	0.	0.	0.	0.	992743.	68236.	1080979.
1989 - 9	0.	0.	0.	0.	1072112.	76027.	1148139.
1990 - 10	0.	0.	0.	0.	1157925.	61714.	1219639.
1991 - 11	0.	0.	0.	0.	1250714.	45054.	1295768.
1992 - 12	0.	0.	0.	0.	1351057.	25780.	1376837.
1993 - 13	0.	0.	0.	0.	1459580.	3598.	1463179.
1994 - 14	0.	0.	0.	0.	1576961.	-21815.	1555146.
1995 - 15	0.	0.	0.	0.	1703938.	-50818.	1653120.
1996 - 16	0.	0.	0.	0.	1841308.	-83802.	1757505.
1997 - 17	0.	0.	0.	0.	1989938.	-121202.	1868736.
1998 - 18	0.	0.	0.	0.	2150768.	-163493.	1987275.
1999 - 19	0.	0.	0.	0.	2324820.	-211201.	2113619.
2000 - 20	0.	0.	0.	0.	2513199.	-264900.	2248299.
2001 - 21	0.	0.	0.	0.	2717109.	-325227.	2391882.
2002 - 22	0.	0.	0.	0.	2937854.	-392879.	2544975.
2003 - 23	0.	0.	0.	0.	3176852.	-68622.	2708229.
2004 - 24	0.	0.	0.	0.	3435679.	-553301.	2882339.
2005 - 25	0.	0.	0.	0.	3715889.	-647841.	3068048.

Table 5.6.3.3

TYPE	DESCRIPTION	QUANTITY	DEVELOPMENT PERCENTAGE	BASE CONSTRUCTION UNIT COST	INCREMENTAL CONSTRUCTION UNIT COST	DECENTRAL ELEMENT UNIT COST	CONSTRUCTION PERCENTAGES BY YEAR			TOTAL CONSTRUCTION COST
							1	2	3	
1	SFD(1600)	73	17.81%	37256.	2902.	0.	67.2	33.2	0.2	2931534.
2	SFD(2200)	26	8.70%	51367.	4217.	0.	67.2	33.2	0.2	1445184.
3	TH(1200)	20	3.70%	28560.	3396.	0.	0.2	100.2	0.2	639120.
4	TH(1500)	30	6.93%	35360.	4206.	0.	0.2	100.2	0.2	1186980.
5	APT(950)	80	11.60%	19140.	1810.	0.	50.2	50.2	0.2	1676000.
6	APT(1300)	120	23.80%	25907.	2388.	0.	50.2	50.2	0.2	3395400.
7	HS	1	24.30%	512000.	-222673.	0.	0.2	67.2	33.2	4897327.
8	F/P	1	.40%	96000.	2274.	0.	0.2	100.2	0.2	98274.
9	GOLF	1	2.20%	705500.	24197.	0.	0.2	50.2	50.2	729797.
10	COMM	1	.60%	96000.	7934.	0.	0.2	0.2	100.2	103904.

TYPE DESCRIPTION	BASE SITE DEVELOPMENT UNIT COST	INCREMENTAL SITE DEVELOPMENT UNIT COST	BASE LOT DEVELOPMENT UNIT COST	INCREMENTAL LOT DEVELOPMENT UNIT COST	TOTAL DEVELOPMENT COST
1 SFD(1600)	5222.	-717.	1409.	571.	473405.
2 SFD(2200)	7222.	-992.	1940.	790.	233168.
3 TH(1200)	3983.	-547.	1011.	183.	92600.
4 TH(1500)	4931.	-670.	1251.	226.	171900.
5 APT(950)	3135.	-430.	650.	-61.	263520.
6 APT(1300)	4244.	-563.	880.	-82.	535080.
7 HS	521776.	-71685.	152588.	0.	602673.
8 F/P	8589.	-1180.	34367.	-1650.	40126.
9 GOLF	47238.	-6490.	44770.	9440.	94958.
10 COMM	12883.	-1770.	40980.	-1685.	50408.

TYPE	DESCRIPTION	ELECTRICAL ENERGY UNIT COST	ELECTRICAL ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	L1R TOTAL ANNUAL (MWH)	L3R SAVINGS ANNUAL (MWH)	NET L3R TOTAL ANNUAL (MWH)
1	SFD(1600)	42.400	17.61	-2.03	0.00	-4.06	1,137.45	296.38	841.07
2	SFD(2200)	42.400	24.35	-2.81	0.00	-5.62	560.16	146.12	414.04
3	TH(1200)	45.000	15.12	-3.38	0.00	-3.99	294.87	79.80	215.07
4	TH(1500)	45.000	20.47	-5.52	0.00	-6.69	598.51	200.70	397.81
5	APT(950)	49.000	18.00	-1.03	0.00	-7.02	1,363.96	561.60	802.36
6	APT(1300)	49.000	22.38	-1.28	0.00	-7.41	2,532.50	889.20	1,643.30
7	HS	43.400	1532.70	-7.60	0.00	-262.70	1,525.10	262.70	1,262.40
8	F/P	54.900	66.70	0.00	0.00	-9.70	66.70	9.70	57.00
9	GCLF	54.900	287.10	-4.00	0.00	-41.10	283.10	41.10	242.00
10	CGMM	54.900	78.10	-4.20	0.00	-12.10	73.90	12.10	61.80
							8,436.25	2,499.40	5,936.85

Table 5.5.3.1

TYPE	DESCRIPTION	NAT GAS ENERGY UNIT COST	NAT GAS ENERGY UNIT CONSUMPTION	CONSERVATION UNIT SAVINGS	DECENTRAL UNIT SAVINGS	THERMAL UNIT OFFSET	L3R TOTAL ANNUAL (MMBtu)	L3R SAVINGS ANNUAL (MMBtu)	NET L3R TOTAL ANNUAL (MMBtu)
1	SFD(1600)	2.796	113.67	-33.58	0.00	-79.49	5,802.52	5,802.52	0
2	SFD(2200)	2.796	156.36	-46.44	0.00	-109.92	2,857.90	2,857.90	0
3	TH(1200)	2.796	67.63	-21.06	0.00	-46.57	931.34	931.34	0
4	TH(1500)	2.796	91.53	-28.51	0.00	-71.02	1,890.76	1,890.76	0
5	APT(950)	2.796	56.54	-17.36	0.00	-39.18	3,134.04	3,134.04	0
6	APT(1300)	2.796	70.00	-21.49	0.00	-48.51	5,820.76	5,820.76	0
7	HS	2.912	220.30	0.00	0.00	-220.30	220.30	220.30	0
8	F/P	2.912	31.10	0.00	0.00	-31.10	31.10	31.10	0
9	GCLF	2.912	156.10	-3.90	0.00	-152.20	152.20	152.20	0
10	COMM	2.912	42.50	-1.10	0.00	-41.40	41.40	41.40	0
							<u>20,882.32</u>	<u>20,882.32</u>	<u>0</u>

Table 5.5.3.2

TYPE	DESCRIPTION	THERMAL ENERGY UNIT COST	THERMAL ENERGY UNIT CONSUMPTION	TOTAL L3R THERMAL ANNUAL (MMBtu)
1	SFD(1600)	10.59	89.74	6,551.02
2	SFD(2200)	10.59	124.10	3,226.60
3	TH(1200)	10.59	78.66	1,573.20
4	TH(1500)	10.59	97.39	2,921.70
5	APT(950)	10.59	71.85	5,748.00
6	APT(1300)	10.59	97.25	11,670.00
7	HS	10.59	1508.00	1,508.00
8	F/P	10.59	89.00	89.00
9	GOLF	10.59	387.00	387.00
10	COMM	10.59	105.00	<u>105.00</u>
				33,779.52

Table 5.5.3.3

Appendix 4

Infrastructure Cost Data

COST COMPARISON OF THE CONVENTIONAL, PASSIVE ENERGY AND CENTRAL UTILITY PLANS

To help determine if energy-efficient land development is economically feasible, a cost comparison of conventional and energy-efficient land development was made. Three alternative plans--the Conventional Plan, the Passive Energy Plan and the Central Utility Plan--were compared in terms of their infrastructure costs. Because the cost comparison will serve only as a planning tool, it is more a product of engineering judgment than of engineering design. To insure a reasonably valid cost comparison, the infrastructure layouts in the plans were made as consistent as possible.

Conventional Plan

To make the Conventional Plan more consistent with the energy-efficient plans, it was revised as follows: sidewalks were eliminated, the length of the main sanitary sewer line shortened, and a section of Road 'C' reduced from four lanes to two. Estimated costs of the Conventional Plan were based on the following assumed infrastructure:

1. Roads - The main road, Road 'C', begins with four 12 foot lanes, two emergency 10 foot lanes, a median, and curb and gutter, then eventually narrows into two 12 foot lanes with curb and gutter. All other roads have two 14 foot lanes with curb and gutter.
2. Storm Drainage - The drainage system, which collects and conveys storm runoff to White Oak Creek, consists of underground pipes, catch basins, headwalls, and drainage channels. In addition, a bridge or bridge culvert about 300 feet in length spans White Oak Creek.
3. Utilities - Water is brought to the site by a water main connecting into an existing 24" water main on Shenandoah Boulevard. The sanitary sewer system ties into an existing 36" sewer outfall running parallel to White Oak Creek. Other utilities such as power and gas were not considered for they are installed by the utility companies and are paid for by consumers over the period of use.

Passive Energy Plan

The Passive Plan differs from the Conventional Plan in that it conserves energy by taking advantage of natural site features. Its energy saving measures include orientation of streets and buildings to conserve energy and reduction in pavement width of collector roads to decrease solar radiation. Other measures, which aim primarily at minimizing energy intensive activity, include the use of ditches instead of curb and gutter along Road 'C', the placement of water and sewer in the same trench whenever possible, and the preferred use of drainage channels over under ground pipes.

Estimated costs of the Passive Energy Plan were based on the following assumed infrastructure:

- 2-
1. Roads - Road 'C' is the same as in the Conventional Plan except that it has ditches instead of curb and gutter. All other roads have a reduced pavement width of 20 feet and curb and gutter.
 2. Storm Drainage - As in the Conventional Plan, storm runoff is collected and discharged into White Oak Creek. However, greater use is made of drainage channels.
 3. Utilities - As in the Conventional Plan, the utilities comprise a water distribution system and a sanitary sewer system.

Central Utility Plan

Besides using natural site features to conserve energy, the Central Utility Plan provides an energy-saving heating and cooling system. Because the Central Utility Plan basically resembles the Passive Energy Plan, its infrastructure differs only slightly from that of the Passive Plan.

SUMMARY

Land Development Costs

Each plan contains two basic types of costs--a land development cost and a lot development cost. The land development cost consists of town and village costs. Costs associated with Road 'C', the golf course, and the infrastructure serving the fire station, police station, church, high school, and convenience store are town costs; costs associated with the infrastructure serving the single-family and multi-family tracts are village costs.

As shown in the table, the energy-efficient plans have a lower land development cost. This is due in part to the absence of curb and gutter along Road 'C' and the reduced pavement width of the other roads.

Lot Development Costs

Lot development costs are the costs of the infrastructure located within the single-family and multi-family tracts. The table indicates that the average cost of a single family unit is higher in the energy-efficient plans than in the conventional plan; whereas the cost of a multi-family unit is not significantly different.

In the energy-efficient plans, single-family residences have a staggered pattern of set-back distances resulting in a lack of uniformity in their infrastructure costs. According to the table, the difference in infrastructure cost of two single family residences could be as much as \$2,300.

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 1
OF 4 SHEETS

CONVENTIONAL PLAN INFRASTRUCTURE COST

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LAND DEVELOPMENT COSTS								
	TOWN COSTS (1979)								
	WATER LINE TO RD 'C'	2200	LF	25	55,000				
	RD 'C' - 4 LANE SECTION	1600	LF	155	248,000				
	RD 'C' - 2 LANE SECTION	3750	LF	55	206,250				
	BRIDGE		LS		200,000				
	STORM DRAINAGE		LS		128,150				
	WATER SYSTEM		LS		74,250				
	SANITARY SEWERS		LS		66,800				
	TOTAL				978,450				
	VILLAGE COSTS (1980)								
	ROADS	8250	LF	60	495,000				
	PEP & BICYCLE PATH	31,400	LF	5	157,000				
	STORM DRAINAGE				145,850				
	WATER SYSTEM				105,000				
	SANITARY SEWERS				117,400				
	TOTAL				1,020,250				

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 2
OF 4 SHEETS

CONVENTIONAL PLAN INFRASTRUCTURE COST

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LAND DEVELOPMENT COSTS								
	TOWN COSTS (1981)								
	GOLF COURSE		LS		1,000,000				
	CLUBHOUSE		LS		44,770				
	MAINTENANCE BLDG.		LS		18,040				
	HIGH SCHOOL		LS		152,538				
	CHURCH		LS		64,235				
	FIRE/POLICE		LS		34,367				
	COMMERCIAL		LS		40,980				
	WATER		LS		31,500				
	RD	1950	LF	60	117,000				
	TOTAL				1,503,480				
	LAND DEVELOPMENT TOTAL				3,502,180				

only for holes on the site

SHEET 3
OF 4 SHEETS

[illegible]

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 4
OF 4 SHEETS

CONVENTIONAL PLAN INFRASTRUCTURE COSTS

[illegible]

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 1
OF 4 SHEETS

PASSIVE PLAN INFRASTRUCTURE COST

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LAND DEVELOPMENT COSTS								
	TOWN COSTS (1979)								
	WATER LINE TO RD "C"	2200	LF	25	55,000				
	RD "C" - 4 LANE SECTION	1600	LF	120	192,000				
	RD "C" - 2 LANE SECTION	3750	LF	40	150,000				
	BRIDGE		LS		200,000				
	STORM DRAINAGE		LS		35,770				
	WATER SYSTEM		LS		30,750				
	SANITARY SEWERS		LS		75,100				
	TOTAL				738,620				
	VILLAGE COSTS (1980)								
	ROADS	8750	LF	55	481,250				
	FED. & BICYCLE PATH	31,400	LF	5	157,000				
	STORM DRAINAGE		LS		161,230				
	WATER SYSTEM		LS		134,720				
	SANITARY SEWERS		LS		47,400				
	TOTAL				981,580				

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 2
OF 4 SHEETS

PASSIVE PLAN INFRASTRUCTURE COST

[illegible]

SHEET 3
OF 4 SHEETS

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LOT DEVELOPMENT COSTS								
	216 GARDEN APTS								
	PAVING				84,000				
	DRAINAGE				13,100				
	WATER				20,200				
	SEWER				36,900				
	TOTAL				154,200				
	50 TOWNHOUSES								
	PAVING				37,320				
	DRAINAGE				6,965				
	WATER				11,200				
	SEWER				12,100				
	TOTAL				68,125				
	10 SINGLE FAMILY UNITS								
	PAVING				10,080				
	WATER				8220				
	SEWER				8220				
	TOTAL				26,520				

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 4
OF 4 SHEETS

PASSIVE PLAN INFRASTRUCTURE COST

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LOT DEVELOPMENT COSTS								
	70 SINGLE FAMILY UNITS								
	PAVING				58,800				
	WATER				45,480				
	SEWER				45,480				
	TOTAL				149,760				
	32 SINGLE FAMILY UNITS								
	PAVING				29,220				
	WATER				22,050				
	SEWER				22,050				
	TOTAL				73,320				
	LOT DEVELOPMENT TOTAL				471,985				
	AVG. SINGLE FAMILY COST								
	$249,600/112 = 2229/\text{UNIT}$								
	AVG. MULTI-FAMILY COST								
	$222,385/266 = 836/\text{UNIT}$								
	MAX. COST DIFFERENCE	145	6		270				
	BETWEEN SINGLE FAMILY	140	6		840				
	UNITS	140	4		560				
					1400				

SUMMARY OF QUANTITIES AND COST ESTIMATES

SHEET 1
OF 4 SHEETS

CENTRAL UTILITY PLAN INFRASTRUCTURE COST

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LAND DEVELOPMENT COSTS								
	TOWN COSTS (1979)								
	WATER LINE TO RD "C"	2200	LF	25	55,000				
	RD "C" - 4 LANE SECTION	1600	LF	120	192,000				
	RD "C" - 2 LANE SECTION	3750	LF	40	150,000				
	BRIDGE		LS		200,000				
	STORM DRAINAGE		LS		35,770				
	WATER SYSTEM		LS		30,750				
	SANITARY SEWERS		LS		75,100				
	TOTAL				738,620				
	VILLAGE COSTS (1980)								
	ROADS	8650	LF	55	475,750				
	PED. & BICYCLE PATH	31,400	LF	5	157,000				
	STORM DRAINAGE		LS		169,350				
	WATER SYSTEM		LS		125,950				
	SANITARY SEWERS		LS		50,500				
	TOTAL				978,550				

SHEET 2
OF 4 SHEETS

[illegible]

SHEET 3
OF 4 SHEETS

ITEM NO.	ITEM	QUANTITY		MATERIAL AND LABOR FURNISHED BY THE CONTRACTOR		MATERIAL FURNISHED BY OTHERS		SUMMARY	
		AMOUNT	UNIT	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST
	LOT DEVELOPMENT COSTS								
	204 GARDEN APTS								
	PAVING				75,480				
	DRAINAGE				17,630				
	WATER				9,100				
	SEWER				29,800				
	TOTAL				142,010				
	11 SINGLE FAMILY UNITS								
	PAVING				8,580				
	WATER				6,570				
	SEWER				6,570				
	TOTAL				21,720				
	58 TOWNHOUSES								
	PAVING				54,300				
	DRAINAGE				13,100				
	WATER				18,500				
	SEWER				24,900				
	TOTAL				110,800				

Appendix 5

Trombe Wall Analysis

Trombe Wall Analysis

Month	(1) Heating Load estimate (MMBtu's)	(2) Solar radi- ation absorbed (MBtu/ft ²)	(3) Soalr radiation (MMBtu)	(4) Solar load ratio (SLR) (3 ÷ 1)	(5) Solar heating fraction (SHF) ²	(6) Remain- ing heat- ing load (MMBtu's) ³
Oct.	3.36	23.3	6.5	1.94	.75	.84
Nov.	6.03	24.8	6.9	1.15	.55	2.70
Dec.	10.37	23.7	6.64	.64	.35	6.72
Jan.	8.95	24.3	6.80	.76	.41	5.28
Feb.	7.57	22.2	6.22	.82	.43	4.30
Mar.	7.21	21.3	5.96	.83	.43	4.08
April	3.87	17.6	4.93	1.27	.59	1.58
				TOTAL		25.40

New natural gas heating consumption (MMBtu's)⁴ 31.8

Former natural gas heating consumption (MMBtu's) 41.2

Percentage of heating supplied by Trombe wall 23%

¹With no solar gain

²According to Balcomb's analysis, the fraction
of heating supplied by solar is as follows:

$$SHF = 1.014 - (1.039 \cdot e^{-.705 \times SLR})$$

³The remaining heating load is computed as

$$(1) \times 1 - (5)$$

⁴Computed as the total heating load divided
by natural gas heating efficiency (.8)

Appendix 6

Life-Cycle Cost Model Program

```

1      C2345678901234567890123456789012345678901234567890123456789012
      C
      C LIFE CYCLE CCST PCDEL
      C
5      PROGRAM LOCM(TAPE7,REPORT,TAPE1,TAPE2,INPUT,OUTPUT,
2      TAPE8,TAPE9,TAPE10,TAPE11,TAPE12,TAPE13,TAPE21,TAPE22,TAPE23,
3      TAPE3=REPORT,TAPE5=INPUT,TAPE6=OUTPUT)
      C
      INTEGER AYEAR
10     INTEGER BASEYR
      INTEGER CHAR1(9,4),CHAR2(9,2),CHAR3(9,1)
      INTEGER IERROR(4)
      INTEGER JCOPY(14)
      INTEGER JDESC1(6,3)
15     INTEGER JDESC2(10,2)
      INTEGER JDESC3(8,3)
      INTEGER JDESC4(11)
      INTEGER JDESC5(4,2)
      INTEGER JDESC6(12)
20     INTEGER JDESC(4)
      INTEGER JEN(3)
      INTEGER JFMT(2)
      INTEGER JTITLE(4)
      INTEGER L0,L1,L2,SITE,CONSTR
25     INTEGER REPLY
      INTEGER ITYPE,JDESCR
      INTEGER S2,C2
      INTEGER QUAN
      REAL PASSEL(5),REVEL(3),TWOEL(3)
30     REAL DEVL,DEVINC,DEVSV,DEVINC
      REAL ECONSV,ETHOSV,NGCONSV,NGTWSV
      REAL QESV,QNGSV,QF3SV
      REAL AMEN(3)
      REAL CA1CON(2,53,6),CA1CNI(2,53,6),CA1DEV(2,53,5)
35     REAL CA1DEVI(2,53,5),CA1EN(2,53,5),CA1ENI(2,53,5)
      REAL CA2CON(2,53,10),CA2CNI(2,53,10),CA2DEV(2,53,10)
      REAL CA2DEVI(2,53,10),CA2EN(2,53,10),CA2ENI(2,53,10)
      REAL C1CON(6),C1CNI(6),C1DEV(6),C1DEVI(6),C1EN(6),C1ENI(6)
      REAL C2CON(10),C2CNI(10),C2DEV(10),C2DEVI(10),C2EN(10),C2ENI(10)
40     REAL C2SUM
      REAL ESA2(3)
      REAL I1,I2,I3
      REAL QEN(3)
      REAL STOTAL(12)
45     REAL SVAL(12)
      REAL VAR(11)
      REAL YRPCT(3)
      LOGICAL LACC
      LOGICAL LINF
50     LOGICAL LOCO
      LOGICAL LSTN
      COMMON/CHARS/CHAR1,CHAR2,CHAR3
      COMMON/CMPOC1/RATE2
      COMMON/ERR/ERRORP
55     COMMON/IC/KIN,KOUT
      EQUIVALENCE (VAR(1),EXLIFL)
      EQUIVALENCE (VAR(2),I3)

```



```
60      EQUIVALENCE (VAR(3),ESC1)
      EQUIVALENCE (VAR(5),ESC2F)
      EQUIVALENCE (VAR(6),ESC2G)
      EQUIVALENCE (VAR(7),I1)
      EQUIVALENCE (VAR(9),ESC2T)
      EQUIVALENCE (VAR(10),I2)
65      DATA BASEYR/1981/
      DATA ISEN/0/
      DATA ITAF/1/
      DATA IVAR/0/
      DATA(JDESC1(1,I),I=1,3)/"DETACHED D","WELLING UN","ITS
70      DATA(JDESC1(2,I),I=1,3)/"CLUSTER DW","WELLING UN","ITS
      DATA(JDESC1(3,I),I=1,3)/"INSTITUTION","NAL FACILI","TIES
      DATA(JDESC1(4,I),I=1,3)/"COMMUNITY ","FACILITIES","
      DATA(JDESC1(5,I),I=1,3)/"TOTAL ","
      DATA(JDESC1(6,I),I=1,3)/"INTEREST ","
75      DATA(JDESC2(1,I),I=1,2)/"SINGLE FAM","ILY (1600)"
      DATA(JDESC2(2,I),I=1,2)/"SINGLE FAM","ILY (2200)"
      DATA(JDESC2(3,I),I=1,2)/"TOWNHOUSE ","(1200)"
      DATA(JDESC2(4,I),I=1,2)/"TOWNHOUSE ","(1500)"
      DATA(JDESC2(5,I),I=1,2)/"APARTMENT ","(950)"
      DATA(JDESC2(6,I),I=1,2)/"APARTMENT ","(1300)"
80      DATA(JDESC2(7,I),I=1,2)/"SENIOR HIG","H SCHOOL"
      DATA(JDESC2(8,I),I=1,2)/"FIRE-POLIC","E STATION"
      DATA(JDESC2(9,I),I=1,2)/"GOLF CLUBH","OUSE"
      DATA(JDESC2(10,I),I=1,2)/"COMMERCIAL"," SPACE"
85      DATA(JDESC3(1,I),I=1,3)/"SUMMARY RE","PORT"
      DATA(JDESC3(2,I),I=1,3)/"ELEMENTAL ","REPORT"
      DATA(JDESC3(3,I),I=1,3)/"CONSTRUCTI","ON COST IN","PUT DATA"
      DATA(JDESC3(4,I),I=1,3)/"DEVELOCPHEN","T COST INP","UT DATA"
      DATA(JDESC3(5,I),I=1,3)/"ENERGY COS","T INFUT DA","TA"
      DATA(JDESC3(6,I),I=1,3)/"SENSITIVIT","Y ANALYSIS"," SUMMARY"
90      DATA(JDESC3(7,I),I=1,3)/"ANNUAL COS","T SUMMARY ","
      DATA JDESC4(1)/"ANAL. PER."
      DATA JDESC4(2)/"CONST FIN"
      DATA JDESC4(3)/"CONST ESC"
85      DATA JDESC4(5)/"ELEC. ESC"
      DATA JDESC4(6)/"GAS ESC"
      DATA JDESC4(7)/"DISC RATE"
      DATA JDESC4(9)/"THERM ESC"
      DATA JDESC4(11)/"ROI CAP."
100      DATA(JDESC5(1,I),I=1,2)/"CONVENTION","AL"
      DATA(JDESC5(2,I),I=1,2)/"PASSIVE ",""
      DATA(JDESC5(3,I),I=1,2)/"DECENTRALI",""
      DATA(JDESC5(4,I),I=1,2)/"CENTRAL UT","ILITIES"
      DATA JDESC6(1)/" STANDARD"
      DATA JDESC6(2)/" REVISED"
105      DATA(JFMT(I),I=1,2)/"(CX,12(SX,","F7.1)"
      DATA(JTITL(I),I=1,4)/4*
      DATA KCL/17/
      DATA KIN/7/
      DATA KPRG/1/
110      DATA LVEL/2/
      DATA LACC/.FALSE./
      DATA LINF/.FALSE./
      DATA LORG/.FALSE./
      DATA LSEN/.FALSE./
```

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115      DATA L1/10/
          DATA VERSION/3.0/
          DATA NAME1/"TAPE1"
          DATA NAME2/"TAPE2"
C
120      C PRESENT VOLUME FUNCTION
C
          PV(N)=1./(RATE1)**N
C
          REWIND 3
125          REWIND 7
          REWIND 3
          REWIND 10
          REWIND 11
          REWIND 12
130          REWIND 13
          ATIME=TIME(0)
          ADATE=DATE(0)
C
C START LFL & FFL ERROR PROCEDURES
135      C
          CALL EPRLF(IERROR(4),IERROR)
          CALL FRRFF(IERROR(4),IERROR)
C
C PRINT TERMINAL TITLE
140      C
          KOLT=KIN+1
          WRITE(6,901) VERSION,KCL,ADATE,ATIME
901      FORMAT(///
145          2 1X,"LIFE CYCLE COST MODEL",/
          3 1X,"VERSION",F4.1,"/",I2.2/
          4 2A10)
C
C GET RUN TIME INFORMATION
C
150      10 WRITE(KOLT,902)
          902 FORMAT(/1X,"ENTER SPECIAL TITLE:3")
          READ(KIN,903) JTITLE
          903 FORMAT(4A10)
          IF(EOF(KIN).NE.0) CALL SETT05,RETURNS(10)
155      C
C SET LSEN TO TRUE IF SENSITIVITY OPTION IS DESIRED.
C
          20 WRITE(KOLT,904)
          904 FORMAT(/1X,"SHALL THE SENSITIVITY OPTION BE ENABLED:3")
160      25 READ(KIN,905) REPLY
          905 FORMAT(A1)
          IF(EOF(KIN).NE.0) CALL SETT05,RETURNS(20)
          IF(REPLY.EQ."N") GO TO 33
          LSEN=.TRUE.
165          IF(REPLY.EQ."1") IVAR=1
          IF(REPLY.EQ."2") IVAR=2
          IF(REPLY.EQ."3") IVAR=3
          IF(REPLY.EQ."4") IVAR=4
          IF(REPLY.EQ."5") IVAR=5
          IF(REPLY.EQ."6") IVAR=6
170          IF(REPLY.EQ."7") IVAR=7
          IF(REPLY.EQ."8") IVAR=8
          IF(REPLY.EQ."9") IVAR=9

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      IF (REPLY.EQ."F") IVAR=10
      IF (IVAR.NE.0) GO TO 26
      WRITE(KOUT,9031)
175  9031 FORMAT(/1X,"SELECT SENSITIVITY ANALYSIS VARIABLE"/
      1  " FROM THE FOLLOWING LIST: "/1X,
      2  "ANALYSIS PERIOD - A"/1X,
      3  "CONSTRUCTION FINANCING - F"/1X,
      4  "CONSTRUCTION ESCALATION - C"/1X,
180  5  "ELECTRIC FUEL ESCALATION - E"/1X,
      6  "GAS FUEL ESCALATION - G"/1X,
      7  "DISCOUNT RATE - D"/1X,
      8  "THERMAL FUEL ESCALATION - T"/1X,
      9  "ROI CAPITAL - P"/1)
185  WRITE(KOUT,9052)
      9052 FORMAT(/1X,"ENTER ANALYSIS VARIABLE CODE (8)")
      GO TO 25
      23  IF (IVAR.EQ.1) JFMT(2)="I7"
      30  WRITE(KOUT,906)
190  906  FORMAT(/1X,"ENTER MAX VALUE & INCREMENT")
      READ(KIN,*) VMAX,VINC
      IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(30)

C
C SET LACO TO TRUE IF ANNUAL COST OPTION IS DESIRED
195  C
      33  WRITE(KOUT,9131)
      9131 FORMAT(/1X,"SHALL ANNUAL COST OPTION BE ENABLED(8)")
      READ(KIN,905) REPLY
      IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(33)
200  IF (REPLY.EQ."Y") LACO=.TRUE.

C
C SET LINP TO TRUE IF INPUT DATA OPTION IS DESIRED
C
205  35  WRITE(KOUT,913)
      913  FORMAT(/1X,"SHALL INPUT DATA OPTION BE ENABLED (8)")
      READ(KIN,905) REPLY
      IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(35)
      IF (REPLY.EQ."Y") LINP=.TRUE.

C
210  C SET LOCO TO TRUE IF OPPORTUNITY COST OPTION IS DESIRED.
C
      110  WRITE(KOUT,915)
      915  FORMAT(/1X,"SHALL OPPORTUNITY COST OPTION BE ENABLED (8)")
      READ(KIN,905) REPLY
215  IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(110)
      IF (REPLY.EQ."Y") LOCO=.TRUE.

      40  WRITE(KOUT,907)
      907  FORMAT(/1X,"ENTER ANALYSIS CONSTRUCTION"/
      2  "X,"PERIOD PERIOD")
220  READ(KIN,*) EXLIFE,EL2
      IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(40)
      LO=EXLIFE
      IF (EXLIFE.GT.50) GO TO 430
      50  WRITE(KOUT,904)
225  904  FORMAT(/1X,"ENTER CONST DISCOUNT ROI"/
      2  "X,"FINANCE RATE CAPITAL")
      READ(KIN,*) I1,I2
      IF (EOF(KIN).NE.0) CALL SETTOS,RETURNS(50)

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60  WRITE(KOUT,909)
230 909  FORMAT(/1X,"ENTER ESCALATION RATES "/
      2 2X,"CONSTRUCTION")
      READ(KIN,*) ESC1
      IF (EOF(KIN).NE.0) CALL SETT05,RETURNS(60)
70  WRITE(KOUT,910)
235 910  FORMAT(/1X,"ENTER ENERGY ESCALATION RATES"/
      2 2X,"ELECTRICITY GAS THERMAL")
      READ(KIN,*) ESC2E,ESC2G,ESC2T
      IF (EOF(KIN).NE.0) CALL SETT05,RETURNS(70)
120  WRITE(KOUT,916)
240 916  FORMAT(/1X,"ENTER NAME OF MAIN DATA FILE :8")
      READ(KIN,903) NAME1
      IF (EOF(KIN).NE.0) CALL SETT05,RETURNS(120)
      IF (.NOT.LOC0) GO TO 133
130  WRITE(KOUT,917)
245 917  FORMAT(/1X,"ENTER NAME OF SECONDARY DATA FILE:8")
      READ(KIN,903) NAME2
      IF (EOF(KIN).NE.0) CALL SETT05,RETURNS(130)
C
C PREPARE FOR SENSITIVITY ANALYSIS
250 133  IF (.NOT.LSEN) GO TO 140
      I=1
135  IF (I.GE.13) GO TO 850
      CTVAL=VAR(IVAR)+(I-1)*VIAC
255  IF (CTVAL.GT.VMAX) GO TO 137
      SVAL(I)=CTVAL
      I=I+1
      GO TO 135
137  I=I-1
260  DO 138 II=6,9,3
      WRITE(II,9192)JDESC4(IVAR),(SVAL(III),III=1,I)
9192  FORMAT(/1X,A10,12(F7.1,3X))
138  CONTINUE
C
265  C BEGINNING OF LOOP
      C
140  REWIND 1
      REWIND 2
      REWIND 3
270  ISEN=ISEN+1
C
C READ HEADER LINES
C
275 911  READ(1,316) SITE,CONSTR
      FORMAT(7X,I1,A1)
C4  READ(1,*) SF
      IF (.NOT.LOC0) GO TO 145
      READ(2,*) S2,C2
C4  READ(2,*) SF2
280  C
      C PRINT OUT PAGE HEADER
      C
145  WRITE(3,319) (JDESC3(1,II),II=1,3),VERSION,KCL,JTITLE,NAME1,
      2  NAME2,ATIME,KPAGE
285 919  FORMAT(11-1," ",3A10,

```

```

2      " * LCCM ",F3.1,"/",I2.2,
3      " * ",4A10,
4      " * ",A7,
5      " * ",2A10,
6      " * PAGE ",I2)
290    WRITE(3,920)
920    FORMAT(/1X,"SHENANDOAH CASE STUDY",/
1      1X"PROJECT PLANNING AND DESIGN FOR ENERGY CONSERVATION")
C THIS FORMAT RESERVED FOR PROJECT HEADING
295    C
C PRINT ANALYSIS INFORMATION
C
      WRITE(3,921)
921    FORMAT(///1X,"ANALYSIS INFORMATION",
300    2      T45,"ANNUAL INTEREST RATES",
3      T81,"ANNUAL ESCALATION RATES")
      WRITE(3,922) SITE,CONSTR,I3,ESC1
922    FORMAT(1X,"SITE PLANNING OPTION ",8X,"L",I1,A1,
305    2      T45,"CONST FINANCING ",F5.2,"%",
3      T81,"CONSTRUCTION ",F5.2,"%")
      IF(SITE.EQ.0) II=1
      IF(SITE.EQ.1) II=2
      IF(SITE.EQ.2) II=3
      IF(SITE.EQ.3) II=4
310    IF(CONSTR.EQ."S") JJ=1
      IF(CONSTR.EQ."R") JJ=2
      WRITE(3,923) (JDESC5(II,I),I=1,2),JDESC6(JJ),I1
923    FORMAT(1X,2A10,"- ",410,
315    2      T45,"DISCOUNT RATE ",F5.2,"%",
3      T81,"ENERGY ")
      WRITE(3,924) L0,I2,ESC2E
924    FORMAT(1X,"ANALYSIS PERIOD ",6X,I2," YEARS",
320    2      T45,"R O I CAPITAL ",F5.2,"%",
3      T81," ELECTRICITY ",F5.2,"%")
      WRITE(3,925) L2,ESC2G
925    FORMAT(1X,"CONSTRUCTION PERIOD ",4X,I2," YEARS",
325    1      T81," GAS ",F5.2,"%")
      WRITE(3,926) SITE,L1,ESC2T
926    FORMAT(1X,"CONSERVATION LEVEL ",I1,"-",I2," ELEMENTS",
330    1      T81," THERMAL ",F5.2,"%")
C
C INITIALIZE CCST ARRAYS
C
      DO 150 I=1,6
335    C1CON(I)=0.
      C1COM(I)=0.
      C1DEV(I)=0.
      C1CVI(I)=0.
      C1EN(I)=0.
      C1EI(I)=0.
150    CONTINUE
      DO 160 I=1,10
340    C2CON(I)=0.
      C2COM(I)=0.
      C2DEV(I)=0.
      C2CVI(I)=0.
      C2EN(I)=0.

```



```

160  C2ENI(I)=0.
345  CONTINUE
      C2SUM=0.
      DO 180 I=1,53
      DO 180 II=1,2
      CA1CON(II,I,6)=0.
350  CA1CON(II,I,6)=0.
      DO 170 J=1,5
      CA1CON(II,I,J)=0.
      CA1CCNI(II,I,J)=0.
      CA1DEV(II,I,J)=0.
      CA1DEVI(II,I,J)=0.
355  CA1EN(II,I,J)=0.
      CA1ENI(II,I,J)=0.
      170  CONTINUE
      DO 160 J=1,10
      CA2CON(II,I,J)=0.
360  CA2CON(II,I,J)=0.
      CA2DEV(II,I,J)=0.
      CA2DEVI(II,I,J)=0.
      CA2FN(II,I,J)=0.
      CA2ENI(II,I,J)=0.
365  180  CONTINUE
      RATE1=1+I1/100.
      RATE2=1+I2/100.
      RATE3=I3/100.
      DO 162 I=1,3
370  GEN(I)=0.
      ANEN(I)=0.
      162  CONTINUE
      NSTART=2
      KBOND=L0
375  IOCC1=L2+1
      L0=IOCC1+L0-1
      185  ITAPE1=ITAPE*10+1
      ITAPE2=ITAPE*10+2
      ITAPE3=ITAPE*10+3
380  REWIND ITAPE1
      REWIND ITAPE2
      REWIND ITAPE3
      C
      C GET ELEMENT DATA ON ITAPE
385  C
      190  READ(ITAPE,*) IITYPE
      IF (EOF(ITAPE).NE.0) GO TO 390
      READ(ITAPE,903) UDESCR
      IF (EOF(ITAPE).NE.0) GO TO 820
390  READ(ITAPE,*) QUAN,AREAPCT
      IF (EOF(ITAPE).NE.0) GO TO 420
      READ(ITAPE,*) UCOST
      IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) FASSEL
395  IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) SEVEL
      IF (EOF(ITAPE).NE.0) GO TO 420
      READ(ITAPE,*) THOEL
      IF (EOF(ITAPE).NE.0) GO TO 420

```

```

400      READ(ITAPE,*) YRFCT
      IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) DEVS,DEVSINC
      IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) DEVL,DEVLINC
405      IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) UECOST,QENERE,ECONSV,ETWOSV,OFFSET1
      IF (EOF(ITAPE).NE.0) GO TO 820
      READ(ITAPE,*) UNGCOST,QENERNG,NGCONSV,NGTWOSV,OFFSET2
      IF (EOF(ITAPE).NE.0) GO TO 820
410      READ(ITAPE,*) UF3COST,QENERF3
      IF (EOF(ITAPE).NE.0) GO TO 820
      PASS=REV=TWO=0.
      CALL DETERM(IITYPE,INDEX)
      DO 362 I=1,3
415      PASS=PASS+PASSEL(I)
      REV=REV+REVEL(I)
      TWO=TWO+TWOEL(I)
362      CONTINUE
      QESV=ECONSV+ETWOSV+OFFSET1
420      QNGSV=NGCONSV+NGTWOSV+OFFSET2
      QF3SV=0.
      PASS=PASS+PASSEL(4)+PASSEL(5)
      UCOSTI=PASS+REV+TWO
      DCOST=DEVS+DEVL
425      DCOSTI=DEVSINC+DEVLINC
      CTCON79=UCOST*QUAN
      CICON79=UCOSTI*QUAN
      CTDEV79=DCOST*QUAN
      CIDEV79=DCOSTI*QUAN
430      CTENE=QENERE*UECOST*QUAN
      CIENE=QESV*UECOST*QUAN
      CTENNG=QENERNG*UNGOST*QUAN
      CIENNG=QNGSV*UNGOST*QUAN
      CTENF3=QENERF3*UF3COST*QUAN
435      CIEF3=QF3SV*UF3COST*QUAN
      CON79=CTCON79+CICON79
      DEV79=CIDEV79+CIDEV79
C
C FILE AWAY INPUT DATA
C
440      IF(.NOT.LINP) GO TO 220
      WRITE(ITAPE1,929) IITYPE,JDESCR,QUAN,AREAFCT,UCOST,UCOSTI,TWO,
1      (YRFCT(I),I=1,3),CON79
929      FORMAT(1+0,I2,3X,A10,6X,I3,7X,F5.2,"%",T41,F15.0,T56,F15.0,
445      1      T71,F15.0,T86,3(F7.0,"%"),T116,F17.0)
      WRITE(ITAPE2,930) IITYPE,JDESCR,DEVS,DEVSINC,DEVL,DEVLINC,DEV79
930      FORMAT(1+0,I2,3X,A10,T26,F15.0,T41,F15.0,T56,F15.0,T71,F15.0,
1      T86,F17.0)
      IF(CTENE.LE.0.AND.CTENNG.LE.0.AND.CTENF3.LE.0) GO TO 220
450      WRITE(ITAPE3,931) IITYPE,JDESCR,UECOST,QENERE,ECONSV,ETWOSV,
1      OFFSET1
      WRITE(ITAPE3,931) IITYPE,JDESCR,UNGOST,QENERNG,NGCONSV,NGTWOSV,
1      OFFSET2
931      FORMAT(1+0,I2,2X,A10,T29,F7.3,T46,F7.2,T61,F7.2,T74,F7.2,
455      1      T86,F7.2)
      WRITE(ITAPE3,9311) IITYPE,JDESCR,UF3COST,QENERF3

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3411 FORMAT(1H0,I2,2X,A10,T29,F7.2,T46,F7.2)
C
C ESCALATE COSTS TO PRESENT VALUE YEAR
460 C
220 ESA1=1.+(ESC1/100.)
    ESA2(1)=1.+(ESC2E/100.)
    ESA2(2)=1.+(ESC2G/100.)
    ESA2(3)=1.+(ESC2T/100.)
465 CTCON81=CTCON79*ESA1**NSTART
    CICON81=CICON79*ESA1**NSTART
    CTDEV61=CTDEV79*ESA1**NSTART
    CIDEV61=CIDEV79*ESA1**NSTART
C
470 C PUT CONSTRUCTION COST DATA INTO ARRAY
C
    TPCT=0.
    CTSUM=0.
    CISUM=0.
475 DO 230 I=1,L2
    TPCT=TPCT+YRFCT(I)
230 CONTINUE
    IF (TPCT.NE.100) GO TO 810
    DO 240 I=1,L2
480 CTCON=CTCON81*YRFCT(I)/100.*ESA1**(I-1)
    CICON=CICON81*YRFCT(I)/100.*ESA1**(I-1)
    CA1CON(ITAPE,I,INDEX)=CA1CON(ITAPE,I,INDEX)+CTCON
    CA2CON(ITAPE,I,ITYPE)=CA2CON(ITAPE,I,ITYPE)+CTCON
    CA1CONI(ITAPE,I,INDEX)=CA1CONI(ITAPE,I,INDEX)+CICON
485 CA2CONI(ITAPE,I,ITYPE)=CA2CONI(ITAPE,I,ITYPE)+CICON
    CTSUM=CTSUM+CTCON
    CISUM=CISUM+CICON
240 CONTINUE
C
490 C PUT DEVELOPMENT COST DATA INTO ARRAY
C
    DISUM=0.
    DISUM=0.
    TPCT=0.
495 CISUM=0.
    DO 231 I=1,L2
    TPCT=TPCT+YRFCT(I)
231 CONTINUE
    IF (TPCT.NE.100) GO TO 810
    DO 241 I=1,L2
500 CTDEV=CTDEV81*YRFCT(I)/100.*ESA1**(I-1)
    CIDEV=CIDEV81*YRFCT(I)/100.*ESA1**(I-1)
    CA1DEV(ITAPE,I,INDEX)=CA1DEV(ITAPE,I,INDEX)+CTDEV
    CA2DEV(ITAPE,I,ITYPE)=CA2DEV(ITAPE,I,ITYPE)+CTDEV
505 CA1DEVI(ITAPE,I,INDEX)=CA1DEVI(ITAPE,I,INDEX)+CIDEV
    CA2DEVI(ITAPE,I,ITYPE)=CA2DEVI(ITAPE,I,ITYPE)+CIDEV
    DISUM=DISUM+CTDEV
    DISUM=DISUM+CIDEV
241 CONTINUE
C
510 C SUM IF ENERGY USAGE BY FUEL
C
250 GEN(1)=GEN(1)+GENRE+QESV

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515      QEN(2)=QEN(2)+QENERNG+CNGSV
        QEN(3)=QEN(3)+GENERF3
        ANEN(1)=ANEN(1)+CTENE+CIENE
        ANEN(2)=ANEN(2)+CTENNG+CIENNG
        ANEN(3)=ANEN(3)+CTENF3
C
520      C PUT ENERGY DATA INTO ARRAY
C
        TYRPCT=SYRPCT=0.
        DO 3201 I=1,L2
        IF (I.NE.3) GO TO 310
525      TYRPCT=TYRPCT(1)+TYRPCT(2)+TYRPCT(3)
        CTENEI=CTENE*TYRPCT/100*ESA2(1)**(NSTART-1+I)
        CTENNGI=CTENNG*TYRPCT/100*ESA2(2)**(NSTART-1+I)
        CTENF3I=CTENF3*TYRPCT/100*ESA2(3)**(NSTART-1+I)
        CIENEI=CIENE*TYRPCT/100*ESA2(1)**(NSTART-1+I)
530      CIENNGI=CIENNG*TYRPCT/100*ESA2(2)**(NSTART-1+I)
        CIENF3I=CIENF3*TYRPCT/100*ESA2(3)**(NSTART-1+I)
        GO TO 312
310      IF (I.NE.2) GO TO 311
        SYRPCT=SYRPCT(1)+SYRPCT(2)
535      CTENEI=CTENE*SYRPCT/100*ESA2(1)**(NSTART-1+I)
        CTENNGI=CTENNG*SYRPCT/100*ESA2(2)**(NSTART-1+I)
        CTENF3I=CTENF3*SYRPCT/100*ESA2(3)**(NSTART-1+I)
        CIENEI=CIENE*SYRPCT/100*ESA2(1)**(NSTART-1+I)
        CIENNGI=CIENNG*SYRPCT/100*ESA2(2)**(NSTART-1+I)
540      CIENF3I=CIENF3*SYRPCT/100*ESA2(3)**(NSTART-1+I)
        GO TO 312
311      CTENEI=CTENE*YRPCT(I)/100*ESA2(1)**(NSTART-1+I)
        CTENNGI=CTENNG*YRPCT(I)/100*ESA2(2)**(NSTART-1+I)
        CTENF3I=CTENF3*YRPCT(I)/100*ESA2(3)**(NSTART-1+I)
545      CIENEI=CIENE*YRPCT(I)/100*ESA2(1)**(NSTART-1+I)
        CIENNGI=CIENNG*YRPCT(I)/100*ESA2(2)**(NSTART-1+I)
        CIENF3I=CIENF3*YRPCT(I)/100*ESA2(3)**(NSTART-1+I)
312      CTENI=CTENEI+CTENNGI
        CIENI=CIENEI+CIENNGI+CTENF3I
550      CA1EN(ITAPE,I,INDEX)=CA1EN(ITAPE,I,INDEX)+CTENI
        CA2EN(ITAPE,I,ITYPE)=CA2EN(ITAPE,I,ITYPE)+CTENI
        CA1ENI(ITAPE,I,INDEX)=CA1ENI(ITAPE,I,INDEX)+CIENI
        CA2ENI(ITAPE,I,ITYPE)=CA2ENI(ITAPE,I,ITYPE)+CIENI
3201      CONTINUE
555      CTENEI=CTENNGI=CTENF3I=0
        CTENI=CIENI=0
        DO 320 I=1,OCCL,L0
        CTENEI=CTENE*ESA2(1)**(NSTART-1+I)
        CTENNGI=CTENNG*ESA2(2)**(NSTART-1+I)
560      CTENF3I=CTENF3*ESA2(3)**(NSTART-1+I)
        CIENEI=CIENE*ESA2(1)**(NSTART-1+I)
        CIENNGI=CIENNG*ESA2(2)**(NSTART-1+I)
        CIENF3I=CIENF3*ESA2(3)**(NSTART-1+I)
        CTENI=CTENEI+CTENNGI
565      CIENI=CIENI+CIENNGI+CTENF3I
        CA1EN(ITAPE,I,INDEX)=CA1EN(ITAPE,I,INDEX)+CTENI
        CA2EN(ITAPE,I,ITYPE)=CA2EN(ITAPE,I,ITYPE)+CTENI
        CA1ENI(ITAPE,I,INDEX)=CA1ENI(ITAPE,I,INDEX)+CIENI
        CA2ENI(ITAPE,I,ITYPE)=CA2ENI(ITAPE,I,ITYPE)+CIENI
570      320 CONTINUE

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      GO TO 190
C
C CALCULATE INTEREST ON CONSTRUCTION
C
575 340 DO 420 I=1,L2
      PRINB=PRINI=0.
      DO 410 J=1,4
      PRINB=PRINB+CA1CON(ITAPE,I,J)
      PRINI=PRINI+CA1CONI(ITAPE,I,J)
583 410 CA1CON(ITAPE,I,6)=CA1CON(ITAPE,I,6)+RATE3*PRINB
      CA1CONI(ITAPE,I,6)=CA1CONI(ITAPE,I,6)+RATE3*PRINI
C
C FILL ALTERNATIVE ARRAY IF OPPORTUNITY COST OPTION IS ENABLED
C
585      IF(.NOT.LCCO) GO TO 430
      ITAPE=ITAPE+1
      IF(ITAPE.EQ.2) GO TO 195
C
C COMPARE ELEMENTS OF THE TWO ARRAYS
C
590      FOR OPPORTUNITY COST
C
      DO 422 INDEX=1,4
      DO 422 I=1,53
      CALL CMPCC(CA1CON(1,I,INDEX),CA1CON(2,I,INDEX))
      CALL CMPCC(CA1CONI(1,I,INDEX),CA1CONI(2,I,INDEX))
595      CALL CMPCC(CA1DEV(1,I,INDEX),CA1DEV(2,I,INDEX))
      CALL CMPCC(CA1DEVI(1,I,INDEX),CA1DEVI(2,I,INDEX))
      CALL CMPCC(CA1EN(1,I,INDEX),CA1EN(2,I,INDEX))
      CALL CMPCC(CA1ENI(1,I,INDEX),CA1ENI(2,I,INDEX))
600 422 CONTINUE
      DO 424 ICAT=1,10
      DO 424 I=1,53
      CALL CMPCC(CA2CON(1,I,ICAT),CA2CON(2,I,ICAT))
      CALL CMPCC(CA2CONI(1,I,ICAT),CA2CONI(2,I,ICAT))
605      CALL CMPCC(CA2DEV(1,I,ICAT),CA2DEV(2,I,ICAT))
      CALL CMPCC(CA2DEVI(1,I,ICAT),CA2DEVI(2,I,ICAT))
      CALL CMPCC(CA2EN(1,I,ICAT),CA2EN(2,I,ICAT))
      CALL CMPCC(CA2ENI(1,I,ICAT),CA2ENI(2,I,ICAT))
610 424 CONTINUE
C
C COMPUTE PRESENT VALUE COSTS
C
430 430 DO 450 I=1,L0
      PVF=PV(I-1)
615      DO 440 INDEX=1,4
      C1CON(INDEX)=C1CON(INDEX)+CA1CON(1,I,INDEX)*PVF
      C1CONI(INDEX)=C1CONI(INDEX)+CA1CONI(1,I,INDEX)*PVF
      C1DEV(INDEX)=C1DEV(INDEX)+CA1DEV(1,I,INDEX)*PVF
      C1DEVI(INDEX)=C1DEVI(INDEX)+CA1DEVI(1,I,INDEX)*PVF
620      C1EN(INDEX)=C1EN(INDEX)+CA1EN(1,I,INDEX)*PVF
      C1ENI(INDEX)=C1ENI(INDEX)+CA1ENI(1,I,INDEX)*PVF
      440 CONTINUE
      C1CON(6)=C1CON(6)+CA1CON(1,I,6)*PVF
      C1CONI(6)=C1CONI(6)+CA1CONI(1,I,6)*PVF
625      DO 450 INDEX=1,10
      C2CON(INDEX)=C2CON(INDEX)+CA2CON(1,I,INDEX)*PVF
      C2CONI(INDEX)=C2CONI(INDEX)+CA2CONI(1,I,INDEX)*PVF

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C2DEV(INDEX)=C2DEV(INDEX)+CA2DEV(1,I,INDEX)*PVF
C2DEVI(INDEX)=C2DEVI(INDEX)+CA2DEVI(1,I,INDEX)*PVF
630 C2EN(INDEX)=C2EN(INDEX)+CA2EN(1,I,INDEX)*PVF
C2ENI(INDEX)=C2ENI(INDEX)+CA2ENI(1,I,INDEX)*PVF
450 CONTINUE
DO 460 I=1,4
C1CON(5)=C1CON(5)+C1CON(INDEX)
635 C1CONT(5)=C1CONT(5)+C1CONI(INDEX)
C1DEV(5)=C1DEV(5)+C1DEV(INDEX)
C1DEVI(5)=C1DEVI(5)+C1DEVI(INDEX)
C1EN(5)=C1EN(5)+C1EN(INDEX)
C1ENI(5)=C1ENI(5)+C1ENI(INDEX)
640 460 CONTINUE
DO 470 I=1,10
470 CONTINUE
TOTAL=C1CON(5)+C1CONI(5)+C1EN(5)+C1ENI(5)+C1DEV(5)+C1DEVI(5)
+ C1CON(6)+C1CONT(6)
645 C
C PRINT REPORT
C
WRITE(3,932)
932 FORMAT(///T31,"PRESENT VALUE COST REPORT",/
2 1X,"COST CENTER",T31,"BASE",T46,"INCREMENTAL",
650 3 T61,"BASE",T76,"INCREMENTAL",T91,"BASE",
4 T106,"INCREMENTAL",/
5 T31,"CONSTRUCTION",T46,"CONSTRUCTION",
6 T61,"DEVELOPMENT",T76,"DEVELOPMENT",T91,
655 7 "ENERGY",T106,"ENERGY",/
8 T31,"COST",T46,"COST",T61,"COST",
9 T76,"COST",T91,"COST",T106,"COST",/)
DO 480 I=1,6
480 WRITE(3,933) (JDESC1(I,J),J=1,3),C1CON(I),C1CONI(I),
660 2 C1DEV(I),C1DEVI(I),C1EN(I),C1ENI(I)
933 FORMAT(1H0,2A10,A5,6F15.0)
WRITE(3,934) BASEYR
934 FORMAT(1H0,"* ALL COSTS ARE PRESENT VALUE DOLLARS.",
2 " JAN-1 ",I4)
665 WRITE(3,935) TOTAL
935 FORMAT(/1X,"TOTAL NET PRESENT VALUE - $ ",F20.0)
JCONSTR=1
IF(CONSTR.EQ."R") JCONSTR=2
ISITE=SITE+1
670 WRITE(3,936)
936 FORMAT(/////////1X,T110,"SITE PLAN"/)
WRITE(3,937) ((CHAR3(I,1),CHAR1(I,ISITE),CHAR2(I,JCONSTR)),I=1,9)
937 FORMAT(100X,3A10)
WRITE(3,938) JTITLE
675 938 FORMAT(/90X,4A10)
C
C PRINT ELEMENTAL REPORT
C
WRITE(3,939) (JDESC1(2,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
680 2 ADATE,ATIME,KPAGE
WRITE(3,939)
939 FORMAT(//1H0,"ELEMENT ",T31,"BASE",T46,"INCREMENTAL",
1 T61,"BASE",T76,"INCREMENTAL",T91,"BASE",
2 T106,"INCREMENTAL",T121,"TOTAL",/

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685      3      T31,"CONSTRUCTION",T46,"CONSTRUCTION",T61,
        4      "DEVELOPMENT",T76,"DEVELOPMENT",T91,"ENERGY",
        5      T106,"ENERGY",T121,"ELEMENTAL",/
        6      T31,"COST",T46,"COST",T61,"COST",T76,"COST",T91,
        7      "COST",T106,"COST",T121,"COST",/)
690      DO 490 I=1,10
        C2SUM=C2CON(I)+C2CONI(I)+C2DEV(I)+C2DEVI(I)+
        1      C2EN(I)+C2ENI(I)
        WRITE(3,940) (JDESC2(I,J),J=1,2),C2CON(I),C2CONI(I),
        1      C2DEV(I),C2DEVI(I),C2EN(I),C2ENI(I),C2SUM
695      940    FORMAT(1H0,2A10,7F15.0)
        C2SUM=0.
        490    CONTINUE
        C
        C PRINT ANNUAL COSTS IF NECESSARY
        C
700      IF(.NOT.LAC0) GO TO 499
        DO 492 I=1,L0
        DO 492 J=1,4
        CA1CON(1,I,5)=CA1CON(1,I,5)+CA1CON(1,I,J)
705      CA1CONI(1,I,5)=CA1CONI(1,I,5)+CA1CONI(1,I,J)
        CA1DEV(1,I,5)=CA1DEV(1,I,5)+CA1DEV(1,I,J)
        CA1DEVI(1,I,5)=CA1DEVI(1,I,5)+CA1DEVI(1,I,J)
        CA1EN(1,I,5)=CA1EN(1,I,5)+CA1EN(1,I,J)
        CA1ENI(1,I,5)=CA1ENI(1,I,5)+CA1ENI(1,I,J)
710      492    CONTINUE
        KPAGE=0
        494    KPAGE=KPAGE+1
        WRITE(3,919) (JDESC3(I,I),I=1,3),VERSION,KCL,JTITLE,
        2      NAME1,ADATE,ATIME,KPAGE
715      WRITE(3,9391)
        9391   FORMAT(//1H0," YEAR",T16,"BASE",T31,"INCREMENTAL",
        2      T46,"BASE",T61,"INCREMENTAL",T80,"BASE",
        3      T95,"INCREMENTAL",T110,"TOTAL",/
        4      T16,"CONSTRUCTION",T31,"CONSTRUCTION",T46,
720      T76,"DEVELOPMENT",T61,"DEVELOPMENT",T90,"ENERGY",
        5      T95,"ENERGY",T110,"ANNUAL",/
        6      T16,"COST",T31,"COST",
        7      T46,"COST",T61,"COST",T80,"COST",
        8      T95,"COST",T110,"COST",/)
725      IREG=(KPAGE-1)*25+1
        IEND=IREG+24
        DO 498 I=IREG,IEND
        ATOTAL=CA1CON(1,I,5)+CA1CONI(1,I,5)+CA1DEV(1,I,5)+CA1DEVI(1,I,5)+
        1      CA1EN(1,I,5)+CA1ENI(1,I,5)
730      498    ATOTAL=BASEYR+I-1
        WRITE(3,9401) AYEAR,I,CA1CON(1,I,5),CA1CONI(1,I,5),CA1DEV(1,I,5),
        2      CA1DEVI(1,I,5),CA1EN(1,I,5),CA1ENI(1,I,5),ATOTAL
        9401   FORMAT(1H0,I4," - ",I2,1X,7F15.0)
        IF(I.GE.L0) GO TO 499
735      499    CONTINUE
        SO TO 494
        C
        C INITIALIZE FOR SENSITIVITY ANALYSIS IF NECESSARY
        C
740      499   IF(.NOT.LSLN) GO TO 520
        VAR(1)=L0

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      STOTAL(IISCH)=TCTAL/1000000.
      VAR(IVAR)=VAR(IVAR)+VINC
      LO=VAR(1)-3
745      ITAPE=1
      IF (VAR(IVAR).LE.VMAX) GO TO 140
520      IF (.NOT. LINP) GO TO 620
      C
      C PRINT INPUT DATA
750      C
      ENDFILE 11
      ENDFILE 12
      ENDFILE 13
      REWIND 11
755      REWIND 12
      REWIND 13
      KPAGE=0
530      READ(11,943) JCOPY
      IF (EOF(11).NE.0) GO TO 541
      KPAGE=KPAGE+1
760      WRITE (3,919) (JDESCJ(3,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
      2      ADATE,ATIME,KPAGE
      WRITE(3,942)
765      542      FORMAT(//,1X,"TYPE",T7,"DESCRIPTION",T21,"QUANTITY",T31,
      1      "DEVELOPMENT",T46,"BASE",T61,"INCREMENTAL",T79,"CENTRAL",
      2      T91,"CONSTRUCTION",T121,"TOTAL",/
      3      T31,"PERCENTAGE",T46,"CONSTRUCTION",T61,"CONSTRUCTION",
      4      T79,"ELEMENT",T91,"PERCENTAGES",T121,"CONSTRUCTION",/
      5      T46,"UNIT",T61,"UNIT",T79,"UNIT",T91,"BY YEAR",T121,"COST",/
770      6      T46,"COST",T61,"COST",T79,"COST",T92,"1",T99,"2",T108,"3",/)
      WRITE(3,943) JCOPY
      DO 540 I=2,29
      READ(11,943) JCOPY
775      943      FORMAT(14A10)
      IF (EOF(11).NE.0) GO TO 541
      WRITE(3,943) JCOPY
      540      CONTINUE
      GO TO 530
      541      KPAGE=0
780      5301      READ(12,943) JCOPY
      IF (EOF(12).NE.0) GO TO 550
      KPAGE=KPAGE+1
      WRITE (3,919) (JDESCJ(4,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
      2      ADATE,ATIME,KPAGE
785      WRITE(3,9421)
      9421      FORMAT(//,1X,"TYPE",T7,"DESCRIPTION",T31,
      1      "BASE",T46,"INCREMENTAL",T61,"BASE",T76,
      2      "INCREMENTAL",T45,"TOTAL",/
      3      T31,"SITE",T46,"SITE",T61,"LOT",T76,"LOT",T95,"DEVELOPMENT",/
790      4      T61,"DEVELOPMENT",T76,"DEVELOPMENT",T95,"COST",/
      5      T31,"UNIT",T46,"UNIT",T61,"UNIT",T76,"UNIT",/
      6      T31,"COST",T46,"COST",T61,"COST",T76,"COST",/)
      WRITE(3,943) JCOPY
795      DO 5401 I=2,29
      READ(12,943) JCOPY
      IF (EOF(12).NE.0) GO TO 550
      WRITE(3,943) JCOPY

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800      5401 CONTINUE
          GO TO 5301
      550      KPAGE=0
      560      READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5501
          KPAGE=KPAGE+1
      805      WRITE(3,919) (JDESC3(5,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
          2      ADATE,ATIME,KPAGE
          WRITE(3,944)
      944      FORMAT(//,1X,"TYPE",2X,"DESCRIPTION",T31,"ELECTRICAL",T46,
          1      "ELECTRICAL",T61,"CONSERVATION",T76,"DECENTRAL",T91,
      810      2      "THERMAL",/
          3      T31,"ENERGY",T46,"ENERGY",T61,"UNIT",T76,"UNIT",
          4      T91,"UNIT",/
          5      T31,"UNIT",T46,"UNIT",T61,"SAVINGS",T76,"SAVINGS",
          6      T91,"OFFSET",/
      815      7      T31,"COST",T46,"CONSUMPTION",/)
          WRITE(3,943) JCOPY
          DO 570 I=2,29
          READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5501
      820      READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5501
          READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5501
          WRITE(3,943) JCOPY
      825      570 CONTINUE
          GO TO 550
      5501     REWIND 13
          READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5502
      830      KPAGE=0.
      5601     READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5502
          KPAGE=KPAGE+1
          WRITE(3,919) (JDESC3(5,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
      835      2      ADATE,ATIME,KPAGE
          WRITE(3,944)
      9441     FORMAT(//,1X,"TYPE",2X,"DESCRIPTION",T31,"NAT GAS",T46,
          1      "NAT GAS",T61,"CONSERVATION",T76,"DECENTRAL",T91,
          2      "THERMAL",/
      840      3      T31,"ENERGY",T46,"ENERGY",T61,"UNIT",T76,"UNIT",
          4      T91,"UNIT",/
          5      T31,"UNIT",T46,"UNIT",T61,"SAVINGS",T76,"SAVINGS",
          6      T91,"OFFSET",/
          7      T31,"COST",T46,"CONSUMPTION",/)
      845      WRITE(3,943) JCOPY
          READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5502
          DO 5701 I=2,29
          READ(13,943) JCOPY
      850      IF (EOF(13).NE.0) GO TO 5502
          READ(13,943) JCOPY
          IF (EOF(13).NE.0) GO TO 5502
          WRITE(3,943) JCOPY
          READ(13,943) JCOPY
      855      IF (EOF(13).NE.0) GO TO 5502

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5701 CONTINUE
GO TO 5601
5502 REWIND 13
      READ(13,943) JCOPY
360      IF (EOF(13).NE.0) GO TO 620
      READ(13,943) JCOPY
      IF (EOF(13).NE.0) GO TO 620
      KPAGE=0
      580 READ(13,943) JCOPY
865      IF (EOF(13).NE.0) GO TO 620
      KPAGE=KPAGE+1
      WRITE (3,919) (JDESC3(5,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
2      ADATC,ATIME,KPAGE
      WRITE(3,9442)
870      9442 FORMAT(//,1X,"TYPE",2X,"DESCRIPTION",T31,"THERMAL",T46,
1      "THERMAL",
2      /
3      T31,"ENERGY",T46,"ENERGY",
4      /
875      5 T31,"UNIT",T46,"UNIT",
6      /
7      T31,"COST",T46,"CONSUMPTION",/)
      WRITE(13,943) JCOPY
      DO 5702 I=2,29
890      READ(13,943) JCOPY
      IF (EOF(13).NE.0) GO TO 620
      READ(13,943) JCOPY
      IF (EOF(13).NE.0) GO TO 620
      READ(13,943) JCOPY
885      IF (EOF(13).NE.0) GO TO 620
      WRITE(13,943) JCOPY
      5702 CONTINUE
      GO TO 580
890      620 IF (.NOT.LCCO) GO TO 615
      LCCO=.FALSE.
      ITAPE1=21
      ITAPE2=22
      ITAPE3=23
C
895      C PRINT ONE LINE SUMMARY OF SENSITIVITY DATA
      C
615      IF (.NOT.LSEN) GO TO 650
      DO 500 I=1,9.3
      WRITE(1,941) NAME1,(ISTCAL(II),II=1,ISEN)
900      941 FORMAT(//1X,A7,12(1X,F7.1))
      500 CONTINUE
      ISEN=0
      CALL PLGLF(NAME1,1)
      510 WRITE(4001,916)
895      READ(4003) NAME1
      IF (EOF(4003).NE.0) CALL SETTOS,RETURNS(510)
      IF (NAME1.EQ."END") GO TO 660
      VAR(IVAR)=SVAL(1)
      GO TO 140
910      C
      C PRINT SENSITIVITY ANALYSIS SUMMARY
      C

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660 ENDFILE 2
915 REWIND 9
      KPAGE=0
      NAME1=""
670 READ(9,943) JCOPY
      IF (EOF(9).NE.0) GO TO 650
      KPAGE=KPAGE+1
920 WRITE(3,919) (JDESC3(7,I),I=1,3),VERSION,KCL,JTITLE,NAME1,
      2 ADATE,ATIME,KPAGE
      WRITE(3,953)
953 FORMAT(////)
      WRITE(3,943) JCOPY
925 DO 680 I=2,29
      READ(9,943) JCOPY
      IF (EOF(9).NE.0) GO TO 650
      WRITE(3,943) JCOPY
930 680 CONTINUE
      GO TO 670
C
C TIE UP LOOSE ENDS
C
935 650 ENDFILE 3
      ENDFILE 6
      CALL RENLF(NAME1,1)
      CALL RENLF(NAME2,2)
      CALL RETLF("TAPE7")
940 CALL RETLF("TAPE8")
      CALL RETLF("TAPE9")
      CALL RETLF("TAPE10")
      CALL RETLF("TAPE11")
      CALL RETLF("TAPE12")
945 CALL RETLF("TAPE13")
      CALL RETLF("TAPE21")
      CALL RETLF("TAPE22")
      CALL RETLF("TAPE23")
      STOP
C
350 C ERROR PROCESSING
C
910 WRITE(6,948) ITYPE,JDESCR
948 FORMAT(1X,"CONSTRUCTION PERCENTAGES NOT EQUAL TO 100%"/
955 2 10X,4A10,3X,I4)
      GO TO 280
920 WRITE(6,949)
949 FORMAT(1X,"INSUFFICIENT OR EXCESS INFORMATION IN DATA")
      GO TO 390
930 WRITE(6,950)
950 FORMAT(1X,"ANALYSIS PERIOD EXCEEDS MAXIMUM OF 50 YEARS -"
960 2 /1X,"ANALYSIS PERIOD IS NOW SET TO 50 YEARS")
      LO=50
      GO TO 50
950 WRITE(6,952)
965 952 FORMAT(1X,"TOO MANY VALUES SPECIFIED BY RANGE & INCREMENT"/
      2 1X,"FIRST 12 VALUES USED")
      GO TO 137
      END

```

Appendix 7

Design of a Solar-Thermal Central Community System

Design of a Solar-Thermal Central Community System

I. Description of System

Several books are available which contain the description of technical methods for the design of solar systems^{7,8,9}, whereas most of these methods require accurate meteorological, insolation and demand data over short periods of time, a shortcut method has been developed by Beckmann, et al.¹⁰ which requires only average monthly insolation and load data to determine the fraction of the annual load to be supplied by the sun, f , as a function of collector area.

Before going into the description of this so called f -chart method, Appendix C shows the schematic of the system proposed by Dura-Built Construction Company, Inc.⁶ to supply 51% of the annual heating and cooling loads of a community of 15 energy conserving homes at Shenandoah, Georgia. A similar system can be designed to meet the thermal loads of the community which interests us in this report.

Solar energy is collected by a field of flat plate collectors. Since the temperatures required to power absorption refrigeration units are above 180°F, vacuum tube flat plate solar collectors are used. A solution consisting of 65% water and 35% ethylene glycol is continuously circulated through the collectors; the heat picked up by this antifreeze solution is discharged in a heat exchanger which raises the temperature of the water contained in a hot water storage tank. If the temperature of the stored water exceeds a predetermined value, say 250°F, excess solar energy is discarded in a

* See Central Utility Bibliography for notes.

heat dump.

Hot water from the storage tank is pumped to each house, where individual heat exchangers generate domestic hot water and warm air for space heating. Hot water is also pumped to the absorption chiller, which generates chilled water at 45°F to be used in air conditioning. Condensing water from the chiller is cooled in a cooling tower, mixed with fresh make-up water and returned to the chiller.

When solar energy is not available and the temperature of the water in the storage tank drops below acceptable levels, auxiliary heaters located either in the central plant or in each residential unit make up for the deficit in energy supply. These heaters are to be powered with dependable fuels such as natural gas or oil.

II. The f-Chart Method

The f-chart is a plot of the fraction of the monthly load supplied by solar energy as a function of two parameters, X and Y, defined as follows:

$$X = F_R U_1 \times (F_R' / F_R) \times (T_{ref} - \bar{T}_a) \times \Delta_t \times A / L \quad (1)$$

$$Y = F_R (\tau\alpha)_n \times (F_R' / F_R) \times (\overline{\tau\alpha}) / (\tau\alpha)_n \times \bar{H}_T \times A / L \quad (2)$$

The terms in equations (1) and (2) are listed below:

- A = solar collector area (m²)
- F_R' = collector-heat exchanger efficiency factor
- F_R = collector heat removal efficiency factor
- U₁ = collector overall energy loss coefficient (W/C-m²)
- T_{ref} = reference temperature (100°C)
- L = monthly total load (Joules)
- $\bar{T}_a$ = monthly average ambient temperature (°C)

- Δ_t = number of seconds in the month
 $\overline{H}_T$ = monthly average daily radiation incident on the collector surface per unit area (Joules/m²)
 n = number of days in the month
 $(\overline{\tau\alpha})$ = monthly average transmittance-absorptance product
 $(\tau\alpha)_n$ = transmittance-absorptance product normal to collector surface

Figure 1 is the f-chart for liquid systems taken directly from reference 10. This chart applies to systems intended for heating purposes only; for heating and cooling applications, a new f-chart must be generated.

The terms XL/A and YL/A in equations (1) and (2) are independent of total load and also independent of collector area. They can be determined from meteorological data, collector efficiency and collector-heat exchanger efficiency data as explained below. Collector orientation worksheet 1 includes all the terms required in the calculation of monthly values of $\overline{H}_T$. (See reference 10 for the definition of terms appearing in the worksheet which are not defined in this report. The worksheets also refer to figures, equations and Appendices found in reference 10). A collector inclination angle, s , of 30° was chosen in this worksheet in agreement with the optimized value given by Dura Built Construction Company.⁶

F-chart worksheet 1 lists monthly heating loads, chiller COP's, and cooling loads for the community of interest. The last column is the total load, L , calculated from the expression:

$$L = \text{Heating load} + \frac{\text{Cooling Load}}{\text{COP}} \quad (3)$$

Collector orientation worksheet 2 is used to calculate the value of $(\overline{\tau\alpha}) / (\tau\alpha)_n$.

The values for $F_r U_1$ and $F_r (\tau\alpha)_n$ are obtained from a plot of collector efficiency versus the quantity $(T_i - T_a) I_T$, where

- T_i = temperature of the fluid entering the collector ($^{\circ}\text{C}$)
- T_a = outside ambient temperature ($^{\circ}\text{C}$)
- I_T = rate at which solar radiation is incident on the collector surface per unit area, (watts/m^2)

The plot yields a straight line having a slope equal to $F_r U_1$ and a vertical axis intercept equal to $F_r (\tau\alpha)_n$. Values of I_T and collector efficiency can be generated from performance collector test results such as the ones shown in Figure 2 for GE vacuum tube flat plate collectors (model TC-100). I_T is read directly from the upper curve for incident radiation and the efficiency is taken as the ratio between incident and collected radiation. By doing this for several local times, a series of points can be plotted as shown in Figure 3, and a straight line drawn through them. The intercept and slope of this line have values equal to 0.7 and -2.14 respectively. Thus, $F_r (\tau\alpha)_n = 0.7$

$$\text{and } F_r U_1 = 2.14$$

Finally, F_r' / F_r can be obtained from Figure 2.5 (reference 10) after assuming a collector-heat exchanger effectiveness, E_c , of 0.6, and a collector fluid flow rate of $\frac{0.015 \text{ gal}}{\text{min.}}$ per square foot of collector area. The values are the same values used in the design of the system proposed by Dura Built.⁶ With a value of 0.95 for the parameter F_r' / F_r , F-chart worksheet 2 can then be completed. The values XL/A and YL/A listed in this worksheet are the same for any system to be installed in the Shenandoah area, independently of monthly loads and collector area.

The system designed by Dura Built has specific loads which are to be partially met with a collector area of 3324 ft^2 ($\approx 310\text{m}^2$). The values of X and Y for this system are listed in Table 3, together with the corresponding solar load fractions, f's, found in reference 6. Figure 2 is the resultant plot of f as a function of X and Y for systems designed for heating and cooling (red lines), superimposed on the f-chart for heating only (black lines).

Figure 2 can now be used to determine solar load fractions for any values of X and Y, provided that the following parameters are the same as for the Dura Built system: collector-heat exchanger effectiveness = 0.60

$$\text{collector fluid flow rate} = \frac{0.015\text{gal}}{\text{min.ft}^2\text{collector}}$$

and

$$\text{storage capacity} = \frac{1.15\text{gal}}{\text{ft}^2\text{collector}}$$

F-chart worksheet 3 includes a list of values of X/A and Y/A corrected from values of XL/A and YL/A using the total load demanded by the community of interest (see last column in F-chart worksheet 1). The same worksheet lists monthly values of X, Y, and f for several collector areas, and also the annual fraction of the load supplied by solar energy, F. Figure 3 can be plotted from F-chart worksheet 3. The annual fraction supplied by the sun can then be read from Figure 3 for any collector area in the range indicated.

III. First Costs (Equipment and Installation)

The initial cost of the backup system components does not depend on the solar collector area, since backup systems should be sized to meet peak loads even if no solar energy can be collected. The peak heating load to be expected in January is 7.7×10^6 Btu/hr, and the peak cooling load in July is 1.55×10^7 Btu/hr. If a central heater is installed instead of

individual home furnaces and water heaters, the central heater must be capable of supplying 1.55×10^7 Btu/hr (where 0.5 is the COP of the absorption chiller). Also, the absorption chiller and cooling tower should be sized to provide 1.55×10^7 Btu/hr (1,300 tons of refrigeration).

The approximate cost of these components, installation included, is as follows:

Heater	\$350,000
1300 ton Absorption Chiller	\$250,000
3900 ton Cooling Tower	\$500,000
Controls for Tower Heater and Chiller	<u>\$ 50,000</u>
Total non-solar	\$1,150,000

The cost of solar components does depend on the collector area to be installed. The approximate cost of these components is listed below as a function of total collector area, A , in m^2 :

Vacuum tube collector	\$255.00 A
Doubleheader kits	\$ 32.60 A
Mounting kits	\$ 2.60 A
Solar integrator kit	\$.50 A
Water distribution & coil connection	\$142.60 A
Collector field pipe	\$ 14.60 A
Installation collectors	\$ 13.30 A
Collector field site	\$ 81.60 A
Pumps	\$ 57.00 $A^{0.5}$
Storage tank (1.5 ga /ft ²) and supports	\$143.50 $A^{0.7}$
Heat dump	\$ 20.0 $A^{0.7}$
Glycol/water heat exchanger	<u>\$ 38.6 $A^{0.6}$</u>
Total solar	$\$461.2A + 57A^{0.5} + 38.6A^{0.6} + 163.5A^{0.7}$

Since the last three terms in this series are small compared to the first one, the cost of solar components can be approximated by a linear function in the range $10,000 < A < 20,000 m^2$, namely:

$$\text{Total Solar Cost} \approx \$472A$$

The cost of the entire system is then:

$$\text{Total First Cost} = \$1,150,000 - 472A \quad (4)$$

This cost does not include the cost of piping for distributing the utilities to the community and it does not include the cost of individual heat exchangers.

IV. Operating and Maintenance Costs

Maintenance costs are only slightly above those for conventional systems. The only non-conventional type of equipment is the solar collector, which requires low maintenance. Individual tubes in the collector can be easily replaced, and an average useful life of 15 years can be expected. Operating costs are obtained by adding the cost of operating the solar and the non-solar components, some of which are functions of the collector area. The cost of operating the solar side can be assumed to be a linear function of the collector area, approximated by the following functions:

$$\text{Solar Cost/yr} = \$0.17A C_E, \text{ where}$$

C_E is the cost of conventional energy, in \$/MMBtu.

The cost of operating the non-solar side is:

$$\text{Non-solar Cost/yr} = \text{Annual Load} \times (1-F) \times C_E$$

The total operating cost is then:

$$\$0.17A C_E + \frac{\text{Annual Load}}{10^6} \times (1-F) \times C_E, \quad (5)$$

where the Annual Load and F are read from F-chart worksheet 1 and Figure 3 respectively.

V. Sample Calculation

If a solar participation of 50% is desired, the required collector area is read from Figure 3 as 12,400m².

The annual load from F-chart worksheet 1 is

5.834 x 10¹³ joules, or 5.53 x 10¹⁰ Btu.

Then, the total first cost from equation (4) is:

$$\$1,150,000 + 472(12,400) = \$7 \text{ million}$$

The annual operating cost at a rate C_E of \$3/MMBtu is (equation (5)):

$$\begin{aligned} & \$0.17 \times 12,400 \times 3.00 + \frac{5.53 \times 10^{10}}{10^6} \times (1-.5) \times 3 \\ &= \frac{\$6,325}{\text{yr}} + \frac{\$82,950}{\text{yr}} + \frac{\$89,275}{\text{yr}} \end{aligned}$$

Average Monthly Loads

Month	Heating Load (Btu)	Cooling Load (Btu)	Electric Load (Btu)
JAN	2.042×10^9	2.146×10^8	1.310×10^9
FEB	1.659×10^9	3.815×10^8	1.183×10^9
MAR	1.378×10^9	4.627×10^8	1.310×10^9
APRIL	7.312×10^8	2.289×10^9	1.286×10^9
MAY	2.515×10^8	3.229×10^9	1.310×10^9
JUNE	0	3.212×10^9	1.123×10^9
JULY	0	3.226×10^9	1.001×10^9
AUG	0	3.218×10^9	1.001×10^9
SEPT	1.770×10^8	3.004×10^9	1.268×10^9
OCT	8.270×10^8	2.397×10^9	1.310×10^9
NOV	1.185×10^9	4.436×10^8	1.268×10^9
DEC	1.766×10^9	4.083×10^8	1.310×10^9
TOTAL	1.002×10^{10}	2.259×10^{10}	1.724×10^{10}

Appendix 8

Recommended Indigenous Plant Materials

RECOMMENDED INDIGENOUS PLANT MATERIALS

1. Suggested heavy shading species for east and west wall exposures:

Trees:

1. Acer Saccharum - Sugar Maple
2. Cedrus species - Cedars
3. Liquidambar Styraciflua - Sweet Gum
4. Magnolia Grandiflora - Southern Magnolia
5. Magnolia Soulangiana - Saucer Magnolia
6. Quercus species - Oaks
7. Pinus Virginiana - Virginia Pine
8. Pinus Strobus - White Pine

Shrubs:

1. Camellia Sasanqua - Sasanqua Camellia
2. Ilex Vomitoria - Yaupon Holly
3. Ligustrum species - Privet
4. Photinia Glabra - Japanese Photinia
5. Photinia Serrulata - Chinese Photinia
6. Viburnum Tomentosum - Leatherleaf Viburnum

Vines:

1. Ficus Pumila - Creeping Fig
2. Wisteria Floribunda - Japanese Wisteria

2. Suggested heavy shade deciduous tree species with wide spread for parking lots and roads:

1. Acer Saccharum - Sugar Maple
2. Celtis Laevigata - Sugar Hackberry
3. Fagus Grandiflora - American Beech
4. Fraxinus Americana - White Ash
5. Nyssa Sylvatica - Black Gum
6. Plantanus Occidentalis - Sycamore
7. Quercus Alba - White Oak
8. Quercus Borealis - Red Oak
9. Quercus Phellos - Willow Oak
10. Quercus Virginiana - Southern Live Oak

3. Suggested light shading deciduous trees for cooling ground surfaces of southern building exposures:

1. Cledastris Lutea - American Yellowwood
2. Gleditsia Tricanthos - Honey Locust
3. Lagerstroemia Indica - Crepe Myrtle
4. Robinia Pseudoacacia - Black Locust

4. Dense medium-sized deciduous shrubs for breeze channelization and ground protection:

1. *Chenomeles Lagenaria* - Flowering Quince
2. *Chimonanthus Praecox* - Wintersweet
3. *Hamamelis Vernalis* - Vernal Witchhazel
4. *Hydrangea Quercifolia* - Oakleaf Hydrangea
5. *Rhododendron species* - Azaleas

5. Dense Evergreen trees for wind protection on north and northwest exposures:

1. *Cedrus species* - Cedars
2. *Pinus Virginiana* - Virginia Pine
3. *Pinus Strobus* - White Pine
4. *Magnolia Grandiflora* - Southern Magnolia
5. *Magnolia Souleangeana* - Saucer Magnolia
6. *Tsuga Canadensis* - Eastern Hemlock