SYSTEMS ENGINEERING APPLIED TO THE TERRASET SCHOOL

by

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INTRODUCTION

In the beginning, when man first climbed down from the trees, he made his home in caves. There he stayed, underground for thousands of years, until progress brought him up to the surface. Now more millenia have passed, and man is once again beginning to move back underground - not into caves, but into new schools especially designed to be buried beneath the earth.

The reason? In a word: Energy. An underground school can be heated with some 60 to 75 percent less energy than one built above ground, for several reasons.

1. The temperature of the earth just a few feet beneath the surface varies only about 10 degrees throughout the year. Most of the time it hovers around $50^{o}F$. Obviously it takes a lot less energy to heat a school surrounded by 50^{o} earth than it does to heat one standing in 10^{o} air.
2. Underground schools have very little surface area exposed to the weather. As a result they have much less heat loss due to infiltration of cold winter winds.
3. Underground temperatures lag about three months behind surface temperatures. This means the soil around the school is warmest just about the time the heating season begins and cool in the summer.

Energy savings are impressive, but they are not the only virtues of underground construction. Living underground wastes less space on the surface. A playground or a tennis court can be located over the school. Living underground is also very quiet and private. Exterior maintenance is just about eliminated. Storms pass harmlessly overhead. And, since underground schools are largely concrete, fire is of little concern.

But are not underground schools dark, damp and depressing? They do not have to be. Good, modern designs are usually surprisingly bright and airy. Many are built around glass-walled atriums that not only let in light but provide a central courtyard.

Another approach is to build the school into the south face of a hill. Most of the southern side of the school can be glass. This lets in plenty of light, and also provides a good opportunity for collection of solar heat. Since underground living is so energy-efficient, it is ideally suited to solar heat.

Underground schools can be damp, but that problem is easily solved by dehumidification. Probably the biggest problem with underground schools is that they are not suited to all types of building sites. Rocky sites or those with relatively high water tables can cause real problems. Building costs? Some architects say they are somewhat cheaper to build, others say it costs a bit more to build underground. In any case, savings in energy and maintenance costs make underground schools far cheaper to build and operate. In addition, it is life-cycle costs rather than initial costs that really count.[1]

Terraset School Background

The Terraset School is "Fairfax County's futuristic schoolhouse that is buried in earth to be heated and cooled by the ground and the sun."[2]

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[1]The Washington Post, February 10, 1979.

[2]Ibid.

It is a highly energy-efficient elementary school facility. "The building uses earth cover, sophisticated waste heat reclaim, and a solar heating and cooling system so that it uses substantially less energy than a conventional facility of equivalent size and function."[3] The Terraset School, located in Reston, Virginia, was completed in February, 1977 and is operated by the Fairfax County Public School System. In 1975 the Fairfax County School System undertook to develop an energy-efficient elementary school facility. The building, developed by the Department of Design and Construction of the Fairfax County School System, was designed by the firm of Davis, Smith and Carter. Terraset is an earth-covered, cast-in-place, reinforced concrete structure with exceptional outdoor visibility. The building area (see Figure 1), 69,000 square feet gross indoor space, houses more than 1,050 students and 50 administrative personnel.

The Terraset School was conceived to maximize energy efficiently in building design and use in an innovative educational facility. The school's physical plant is set in a hill with natural light provided by a continuous vista of windows in the learning centers, a skylight and an entrance courtyard. The roof of the school is covered by two to three feet of dirt which insulates the building and helps to manage its heating and cooling needs. The building's heating and cooling system combines heat reclaim, solar energy, and a conventional electric boiler.

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[3] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

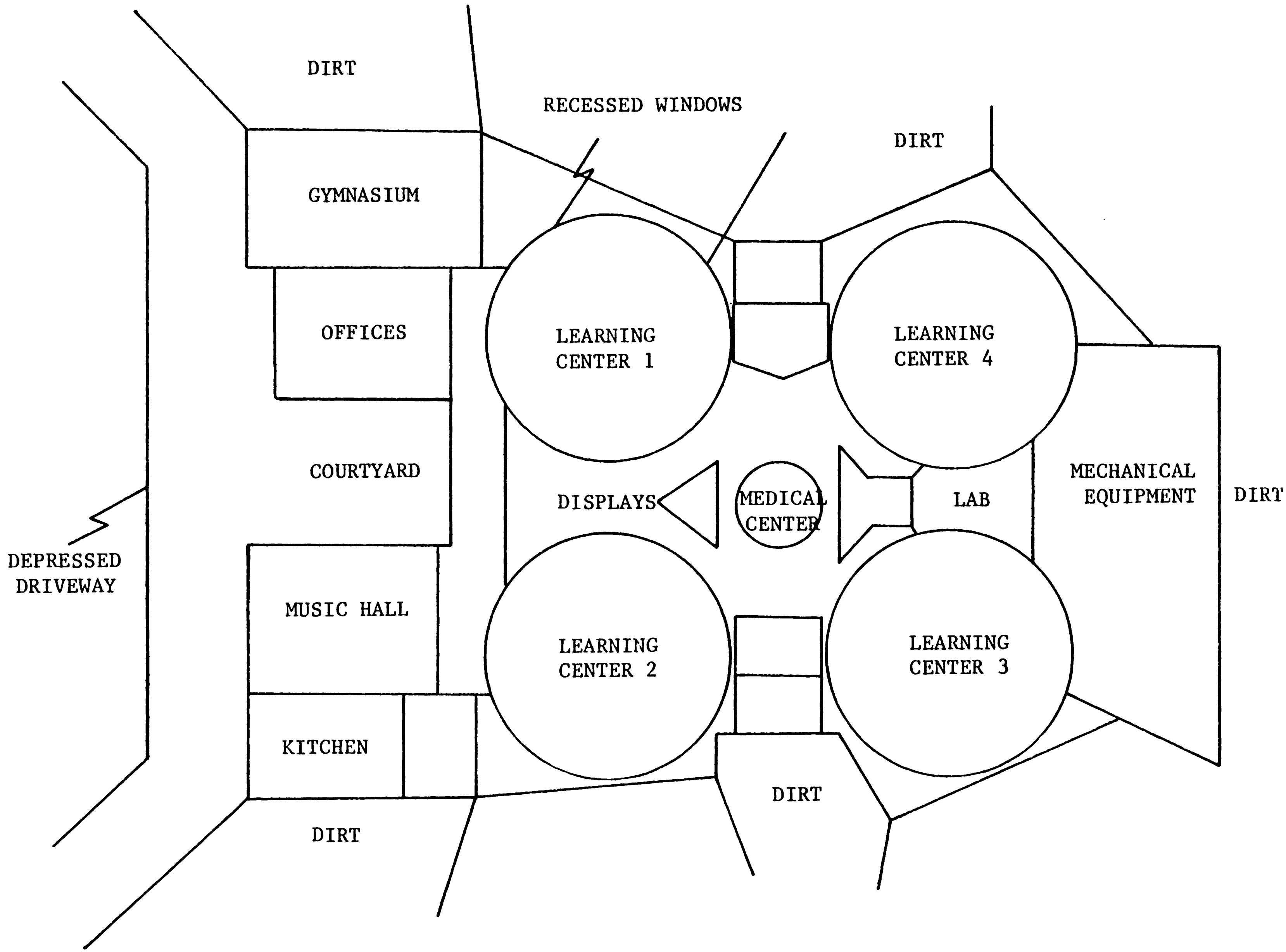

Figure 1. Terraset Floor Plan

Construction costs were $2,470,200. The heating, ventilating and air conditioning system, not including the solar subsystem, cost an additional $393,000. Electricity powers the building's mechanical system. The building also uses a solar assisted heat pump/heat reclaim heating and cooling hydronic system, central air handling, variable air volume (VAV) induction zone boxes, plenum air return through light fixtures, perimeter convective heating, auxiliary electric boiler, 100% outside air capability with enthalpy control, and computerized data collection, monitoring and control for the solar-assist portion of the heating/cooling system.

The Terraset facility has received wide recognition for innovative school design as well as for its unique energy conserving features. Awards include:

- The Owens-Corning 1975 Energy Conservation Award (first place) for Institutional Buildings.

- The 1976 American Association of School Administrators A.I.A. Walter Taylor Award.

- The Northern Virginia Charter A.I.A. "Honor Award" and Citation for Energy, 1977.

In November 1975, the University for Petroleum and Minerals in Dhahran, Saudi Arabia, provided funding of $625,000 for the installation of an advanced solar heating and cooling system in the Terraset School. Subsequent to this construction grant, the al Dir'iyyah Institute provided funds to the Terraset School energy project. As a condition of the grants, the University of Petroleum and Minerals and the al Dir'iyyah Institute, a tax exempt philanthropic association, retained the right, for five years, to observe, monitor and record the construction and operation of Terraset School and its energy systems. These organizations also have the right to designate a certain number of students and engineers who may visit the school and gain operation experience in using its energy systems.

> The Terraset solar system makes use of Owens-Illinois, Inc. evacuated solar collector tubes.[4]

The solar system is used to supply energy for space heating and cooling.

"The Fairfax County Public School System has, as a result of the grant which financed the solar system, an as yet unmet obligation to the al Dir'iyyah Institute and the University of Petroleum and Minerals, Dhahran, Saudi Arabia, to permit the education and training of students at the school site. Such activities will not be financed by the Fairfax County Public School System and are to be carried out in such a manner so as not to disrupt the normal activities of the Terraset School."[5]

The al Dir'iyyah Institute and the Fairfax County Public School System determined in September of 1977 that an organizational mechanism was necessary to handle the emerging research, educational and community service demands and opportunities at the Terraset School. The Terraset Foundation was organized to perform these functions. The Foundation's organizers believe that the Foundation is a means of financing, coordinating, and performing the many research, educational and community service activities critical to realizing the full national value of the Terraset experience.

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[4] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

[5] Ibid.

The Fairfax County School Board has approved the establishment of the Terraset Foundation and the participation of school system employees on its Board of Directors. The Virginia Polytechnic Institute and State University, working through the Virginia Center for Coal and Energy Research, will serve as technical consultant, advisor, and research and development coordinator directly responsible to the Terraset Foundation. Virginia Polytechnic Institute and State University is the designated state agency for this type of activity. This thesis falls under the above guidelines for research.

Definition of Systems Engineering

> Systems Engineering is an evolutionary outgrowth of scientific and technical progress beginning a quarter century ago when it became apparent that the social potentialities of machines as tools was far overshadowed by the possibilities exhibited when machines of somewhat different but complementary functions were embedded within a complex organization or system. Experience with our modern factory, communication, power distribution, military, transportation, urban, and health delivery systems demonstrates, however, that a properly coordinated and functioning system, with out undesirable side effects, is best achieved through efforts applied before the system comes into being. A major aspect of Systems Engineering is its concern for the total 'life cycle' of the system which may include planning, design, development, testing, production operations, and disposal.
>
> As engineers upgrade their technology and weave it into the fabric of society, they must realize that they are generating the hardware or technology that each of us uses in our daily activity, such as missiles, automobiles, telephones, power plants, and factories, react on software as manifest through our statutes, business doctrines, ethics, mores, religious attitudes, behavioral patterns, and the economics of the market place. Therefore, there is a need at the broad policy-making level for a better understanding of the total S-T-E-P (sovial-technological-

> economic-political) system. Because of the complexity of S-T-E-P systems, we have no choice but to marshal the most powerful and comprehensive methods on analysis.[6]

It is interesting to note that the al Dir'iyyah Institute (which normally does not engage in research itself) states that it "..... supports studies of present energy sources and the economic, political and social impact of energy supply and demand."[7] "Economic," "political," and "social" are the E, P and S of S-T-E-P! Hopefully, Virginia Polytechnic Institute and this thesis will be able to complement their efforts by supplying the T of S-T-E-P.

> Specifically, systems engineering constitutes the application of scientific and engineering efforts to (1) transform an operational need into a description of system performance parameters and a preferred system configuration through the use of an iterative process of functional analysis, synthesis, optimization, definition, design, test and evaluation; (2) integrate related parameters and assure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and (3) integrate reliability, maintainability, logistic support, human factors, safety, security, structural integrity, producibility and other related specialties into the total engineering effort. The systems engineering process, in this evolving of functional detail and design requirements, has as its goal the achievement of the proper balance among operational (e.g., performance effectiveness), economic, and logistics factors. The process employs a sequential

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[6] Master's Degrees in Systems Engineering, Northern Virginia, Virginia Polytechnic Institute and State University, Extension Division Graduate Program in Engineering.

[7] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

> and iterative methodology to reach cost effective solutions, and the information development through this process is used to plan and integrate the engineering effort for the system as a whole. Actually, regardless of the system type and size, design commences with a feasibility study accomplished for the purposes of establishing a set of requirements, constraints, and design criteria. Based on the result, functional analyses and allocations are generated to apportion the appropriate system-level requirements down to the subsystem, unit, and lower indenture levels of the system. Trade-off studies and system optimization are performed to evaluate the various alternative approaches that are considered feasible in meeting the identified need with the output reflecting a preferred system configuration. This configuration is documented via the system specification.
>
> The steps just described represent conceptual design and preliminary system design and are iterative in nature. This portion of the systems engineering process may be quite repetitive until the ultimate output constitutes a system configuration that will not only meet performance requirements but one that can be operated and supported in an effective and efficient manner throughout its planned life cycle.[8]

Masters Degree Thesis Application

The objective of this thesis is to demonstrate the application of Systems Engineering to the needs of the Terraset School.

The tools of Systems Engineering applicable to the Terraset School are:

- Needs Analysis
- Functional Analysis
- Test Requirements Analysis
- System Life Cycle Cost Analysis

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[8] Benjamin S. Blanchard, Engineering Organization and Management (Englewood Cliffs, NJ: Prentice-Hall, 1976), pp. 119-120.

- Allocation Procedures
- Technical Performance Measurement

As previously stated, one of the major characteristics of Systems Engineering is its iterative nature. In order to demonstrate this aspect as well as the problems associated with embarking on a typical real-world systems engineering effort, this thesis will begin by documenting each of the author's steps in the tedious path of the Needs Analysis:

1. August 30, 1977 - met with Dr. Michelsen (Graduate Committee Chairman) to have Proposed Plan of Study signed; he inquired as to whether I had chosen a thesis topic yet and suggested the possibility of using the Terraset Research Program at the Virginia Polytechnic Institute.
2. September 21, 1977 - called Dr. Michelsen to inquire as to the status of the Terraset Research Program.
3. September 27, 1977 - met with Dr. Michelson and decided to write an unsolicited proposal, including a Statement of Work, to the Virginia Polytechnic Institute (Reference Appendix 1) concerned with simulation and optimization of the Terraset School heating system.
4. September 30, 1977 - mailed a copy of Appendix 1 to Dr. Drew and Dr. Michelsen.
5. October 5, 1977 - met with Dr. Drew and Dr. Michelsen, received approval of Terraset Research Program as a thesis subject.
6. October 11, 1977 - mailed a copy of Appendix 1 to Professor Peterson.

7. October 17, 1977 - spoke to Dr. Michelsen and decided to write a Task Description.
8. November 14, 1977 - spoke to Dr. Michelsen regarding status of the Virginia Polytechnic Institute's involvement in Terraset.
9. November 16, 1977 - met with Dr. Michelsen and Mr. Al Hlavin (Director, Educational Facilities Planning and Construction, Fairfax County Public Schools), decided to write a thesis proposal (Reference Appendix 3).
10. November 18, 1977 - received comments from Professor Peterson regarding Appendix 3.
11. November 23, 1977 - spoke to Dr. Michelsen about the additional need for a total energy balance and system level documentation to Terraset
12. December 2, 1977 - spoke to Dr. Michelsen concerning an expansion of Appendix 3.
13. January 10, 1978 - requested Mr. Al Hlavin to be a member of the graduate committee.
14. January 12, 1978 - revised Appendix 3 (Reference Appendix 4).
15. February 22, 1978 - met with Dr. Michelsen, Professor Blanchard and Professor Peterson, discussed contents Appendix 4 and decided on another revision of the thesis proposal (Reference Appendix 5).
16. March 6, 1978 - spoke to Dr. Michelsen about writing a letter to the Virginia Polytechnic Institute concerned with the practical utilization of the results of the thesis (Reference Appendix 6).

17. April 4, 1978 - received go-ahead from Dr. Michelsen to begin writing the actual thesis and made plans to obtain all available documentation on Terraset from him.

As can be seen from the above, it actually took from August 30, 1977 to April 4, 1978 (8 months) for the author to finalize a statement of the systems engineering thesis effort for the Terraset Program. This type of activity is not elaborated on in systems engineering text books. However, this usually occurs in the real-world.

The 8 month period was, in retrospect, a reflection of Dr. Michelsen's and my own struggle to define the payoff of this thesis to Terraset. What I did not realize at the time is that a specific payoff cannot be defined early in a Systems Engineering effort. This is a major "Lesson Learned" as a result of writing this thesis. One can define the Systems Engineering methodology and tools to be used but one cannot list the specific outcome. The iterative procedure <u>must</u> be implemented to produce an outcome!

RESULTS

First Iteration

Needs Analysis

The Primitive Statement of Need was obtained from a proposal prepared and submitted by the Terraset Foundation to the Assistant Secretary for Conservation and Solar Applications, U.S. Department of Energy, as follows:

a. School Instrumentation

Select, install and operate an instrumentation system (temperature, flow and power measuring devices for energy use in the school) to monitor energy availability and use in order to determine (through offline calculations) an overall energy balance on the total school and occupants, and to compare the results of school performance with a typical school not equipped with solar assist, soil insulation covering, and extensive heat recovery systems. This instrumentation will be compatible with the Accurex system (see (e) below). Select, install and operate a solar and climatic data collection station which will have the capability to monitor and record solar insolation, sky radiation, wind, air temperature, relative humidity and other variables at the Terraset School site.

Completion data: September, 1979; 1 3/4 years into the project.

Direct costs: $197,440 for the building instrumentation, and $35,000 for the Solar and Climatic Data Station.

b. Measurement, Other FPCS Schools

Establish a range of energy use measurements per square foot of floor space for a representative sample of other elementary schools in the Fairfax County system. In several cases this is likely to require some limited instrumentation of these schools to break out heating and cooling from other energy uses (lighting, service water, etc.). This step will provide a control against which to gauge Terraset results.

Completion date: September, 1978; 3/4 years into the project.

Direct costs: $102,200.

c. HVAC Manual Control and Information

Select, install and operate a total HVAC Control system which will include capability to measure and record the performance of the school's complex HVAC system remotely, and to provide information for manually controlling the operating parameters of the system. The current HVAC control system runs the heating and cooling processes adequately, but provides no data on the operation of these processes. The incorporation of remote monitoring and performance evaluation will provide a means for a trained engineer to make decisions on operating conditions and needs for maintenance and inspection.

Completion date: March, 1980; 2 1/2 years into the project.

Direct costs: $44,700.

d. Solar Closed Loop Control

Modify the hardware installed in (c) above to maximize solar energy utilization through the use of a feedback control system operating on closed loop computer control. Such a closed loop control system will also be useful in assuring reliability and ease of operation. A comparison of performance in past years with (1) savings through system management and (2) optimization studies using a simulator is desirable in order to verify effectiveness. Most HVAC control systems today fall short on incorporating total energy systems management concepts into their design.

Completion date: September, 1981, 3 3/4 years into the project.

e. Plan Accurex System

Design, cost and complete contract arrangements to install an Accurex system.

Completion date: September, 1981; 3 3/4 years into the project.

Direct costs: $8,000.

f. Install NSDAS System

Install additional monitoring devices, more sensitive instruments and hardware determined to be necessary in (3) above for precise energy balance calculations and to make the tie-in to the NSDAS.

Completion date: September 1982; 4 3/4 years into the project.

Direct costs: $161,450.

Phase II: Conduct Research; Install and Test Improvements; Design Total Energy Systems Usable in Other Buildings.

g. HVAC Simulator

Design and develop a physical model of the Terraset School's total heating and cooling system which can be used as a simulator for the school programmed for varying occupancy load and summer/winter operations. The objective will be to:

- Predict school performance.
- Determine how to optimize the school's performance without interfering with school operation.
- Illustrate and educate others about the versatility and performance potential of Terraset School and similar designs.

The initial design effort of the simulator will concentrate on accuracy, versatility and ease of operation.

Completion date: March, 1980; 2 1/4 years into the project.

Direct costs: $109,200.

h. HVAC/Solar Improvements

Propose and analyze improvements to the HVAC and solar assistance system by preliminary process design and economic analysis studies and when possible by testing improvements on the simulator; and thereafter, design, contract and install the most promising ones in the system. The use of a simulator for predicting performance of process improvements represents a significant contribution, particularly if the logic and methodology developed can be applied to other buildings as well as the Terraset School. Subsequent comparisons of simulator predictions and school performance are a necessity to validate simulator performance. If valid, the simulator provides a powerful tool then for carrying out school design concepts as outlined.

Completion date: 1983. Analysis of potential design changes will be initiated shortly after project start-up, and will continue almost to the end of the 5-year program.

Direct costs: $266,700.

Potential design changes to be evaluated include:

- Maximizing use of solar heated hot water for heating school service water directly.

- Operating collectors at much lower temperature and using hot water for solar assisted heat pump.

- Improving use of solar assist system through baffling in storage tanks to control temperature stratification.

- Comparing different operating modes of collector storate units, e.g., constant temperature storage versus continuous circulation, draining collectors at night.

- Operating the air conditioning conventionally with a cooling tower late at night to generate and store cold water for day time use (potentially attractive if time-of-use electric rates are put into effect).

- Operating absorption air conditioners at off-design conditions to establish capacity at lower and high solar collector temperatures.

- Adding systems to recover and utilize heat from vented classroom air.

- Changing ground cover to vary conduction, convection, and transpiration losses and thereby determining the optimum.

i. Design methodologies

Develop and test design methodologies for schools (using perhaps an expanded simulation model) which will utilize a total energy management system concept giving consideration to optimum solar usage; architectural design, school layout and use; and societal factors.[9]

At this point, the actual Needs Analysis starts. The first step is to validate the need.

The process of determining the absolute value of the need and its relative value to other needs is called Needs Analysis. Determining the need is part of problem definition. A need is defined as a lack, want, desire or demand. Needs Analysis is a planning subcycle that operates on a large number of needs that could be satisfied and, by repeated sifting, chooses only a few to pursue in the next subcycle. It is essential to start screening with a very large number of possible new systems ideas. Six general areas of searching are:

1. general objectives relative to the need.
2. organizational resources and constraints.
3. market characteristics
4. state of the competition
5. consumer preferences
6. design requirements

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[9] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

> In answering questions in these areas, completeness is more important than accuracy.[10]

The general objectives of the need are investigated, based on technical information available in October 1978, as follows:

1. "Is the new concept for a product or service? (Hereafter the word product will refer to either.)"[11]

It is for products (Temperature measuring devices, flow measuring devices, power measuring devices, solar and climatic data collection station, limited instrumentation for other schools, a total HVAC Control System with a minicomputer tied into microprocessor, a feedback control system, an Accurex system, a tie-in to the NSDAS, and a HVAC simulator) and for services (energy balance on the total school and occupants, a comparison of the results of a range of energy use measurements per square foot of floor space for a representative sample of other elementary schools in the Fairfax County system, design and development of a physical model of the Terraset total heating and cooling system improvements to the HVAC and solar assistance system by preliminary process design and economic analysis studies and development and test design methodologies for schools).

2. "Do the products meet a new need?"[12]

Yes, the products will assist in improving research, technology transfer and education.

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[10] A. Hall, <u>A Methodology for Systems Engineering</u> (New Jersey: D. Van Nostrand, 1965), pp. 167-169.

[11] <u>Ibid.</u>, p. 170.

[12] <u>Ibid.</u>, p. 170.

3. "Do the new products lead to new functions?"[13]

Yes, the products will lead to new procedures for operating Terraset's new hardware and will be a source of data.

4. "Does it meet an existing or permanent need more effectively - e.g., for lower cost, better quality or improved stability?"[14]

It meets existing needs of education, energy conservation, control and lower cost. It is intended to meet a permanent need for a working/testing laboratory.

5. "Does it open a new line of products or complete an old line?"[15]

It opens a new area of education/demonstration versus pure research.

6. "Is the purpose to open a new market or to expand the present market?"[16]

As a result of the success at Terraset School thus far, plans are underway to design a similar new underground elementary school for Burke Center and a buried Reception Center to serve the Terraset School.

7. "Is the purpose to use more effectively production or distribution facilities, labor and raw materials or to overcome shortages of these?"[17]

Not applicable.

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[13]A. Hall, <u>A Methodology for Systems Engineering</u> (New Jersey: D. Van Nostrand, 1964), p. 170.

[14]<u>Ibid</u>., p. 170.

[15]<u>Ibid</u>., p. 170.

[16]<u>Ibid</u>., p. 170.

[17]<u>Ibid</u>., p. 170.

8. "Does the product overcome a trouble or improve the safety of an existing product?"[18]

The new product will provide data on the operation and characteristics of the heating and cooling processes which is absent with the present HVAC control system.

9. "Does the product make use of a new device, theory, material, method or some other item of new technology, and, if so, with which of the questions above can the application be identified?"[19]

The product makes use of the relatively new technology of systems engineering and solar energy use - management. The product is also a laboratory and simultaneously an educational facility.

The organizational resources and constraints are investigated as follows:

1. "What latitude does the corporate charter permit in new undertakings? Should legal advice be sought to clarify the legal climate generally?"[20]

Both Terraset School's and Virginia Polytechnic Institute's charter permit this type of new undertaking. Legal advice is not needed.

2. "Would stockholder, management and government reaction be favorable to this new venture?"[21]

Government reaction would be favorable.

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[18] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[19] Ibid., p. 171.

[20] Ibid., p. 171.

[21] Ibid., p. 171.

3. "Can patents, copyrights and trademarks be obtained for the product by application, purchase or exchange?"[22]

Not applicable.

4. "Can the organization make use of present technology in which it already possesses rights and expertness?"[23]

5. Capital Investment factors:

a. "How much new capital will be needed and are excess funds available for launching the product?"[24]

Approximately $1,700,000 will be needed from the Department of Energy. Funds are not being made available at the present time.

b. "How will the capital be distributed among production tooling, research and development, real estate, power, transportation and communication lines, or other?"[25]

Funds will be distributed as shown in Table 1.

c. "Are the fiscal policies sufficiently flexible and is the organization capable of rising and distributing the needed funds?"[26]

The lack of funding is responsible for the current delay in the program.

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[22] A. Hall, <u>A Methodology for Systems Engineering</u> (New Jersey: D. Van Nostrand, 1965), p. 171.

[23] <u>Ibid</u>., p. 171.

[24] <u>Ibid</u>., p. 171.

[25] <u>Ibid</u>., p. 171.

[26] <u>Ibid</u>., p. 171.

TABLE 1. TERRASET FUNDING[1]

	1978	1979	1980	1981	1982	TOTAL
Research, Phase I	$342,740	$ 52,600	$ 17,000	$ 64,600	$128,450	$ 605,390
Research, Phase II	4,000	90,300	171,200	105,900	67,500	438,900
Education/Utilization	55,000	37,500	40,000	33,000	26,500	192,000
Overhead @ 36%	144,600	64,900	82,200	73,300	80,100	445,100
TOTAL	$546,340	$245,300	$310,400	$276,800	$302,550	$1,681,390

[1] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977, p. 2.

6. System Engineering and development factors:

a. "Does the breadth and depth of talent needed to develop the product exist or can it be obtained?"[27]

The talent exists in the Fairfax County Public School System and in the Virginia Polytechnic Institute.

b. "What parts of the project will need to be let to subcontractors (market survey, packaging, manufacturing, etc.)?"[28]

At a minimum, the hardware selection and installation will need to be let to a subcontractor.

7. Production factors:

a. "Are present facilities in the form of labor, machines, space and warehousing adequate and useful for the new product or will new facilities be needed?"[29]

The present HVAC System and Solar Assist structure will be partially modified.

b. "Is production, research and development a prerequisite, and if so, which of the above questions applies to this aspect"[30]

Not applicable.

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[27] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[28] Ibid., p. 171.

[29] Ibid., p. 171.

[30] Ibid., p. 171.

8. Material Factors:

a. "Will new or unusual raw materials be needed, and if so, is there an available and dependable supply at reasonable and stable prices?"[31]

No.

b. "Are substitutes available in emergencies?"[32]

Not applicable.

c. "Will transportation and storage costs require alteration of present arrangements?"[33]

No.

The market characteristics are then investigated, as follows:

1. "Who, in terms of classes of people, industries, businesses and institutions, will use the product?"[34]

The Fairfax County Public School System, its students and the Department of Energy will use the product.

2. "How many consumers will be in each class?"[35]

Fairfax County Public School System - approximately 5 employees; Terraset School - more than 1,050 students and 50 administrative personnel; Department of Energy - approximately 10 employees.

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[31] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[32] Ibid., p. 171.

[33] Ibid., p. 171.

[34] Ibid., p. 172.

[35] Ibid., p. 172.

3. "Where is the market - e.g., what is its geographical distribution and extent by class of consumer?"[36]

The present market is the Terraset School.

4. Time factors:

a. "When is the product wanted and can a measure of urgency be attached?"[37]

The product is needed as soon as possible.

> "Moreover, the Fairfax County Public School System has, as a result of the grant which financed the solar system, an as yet unmet obligation to the al Dir'iyyah Institute and the University of Petroleum and Minerals, Dhahran, Saudi Arabia, to permit the education and training of students at the school site. Such activities will not be financed by the Fairfax County Public School System and are to be carried out in such a manner so as not to disrupt the normal activities of the Terraset School."[38]

b. "What is the growth projection? What is the initial demand, growth rate, time of saturation, decline rate and life of the market?"[39]

Not applicable.

c. "Among which classes and market locations can be obtained the best schedule for developing the market?"[40]

Not applicable.

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[36] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[37] Ibid., p. 172.

[38] Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

[39] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[40] Ibid., p. 172.

5. "Which of the following factors should be, and can be, isolated and measured for long and short-range forecasting; price of product; price of related products; consumer income, education, family status, age, sex, occupation, etc.?"[41]

Price of product, price of related products, education factors, hardware installation time, maintenance requirements and testing requirements can be isolated for forecasting.

6. "Which factors, from the questions above, limit the market?"[42]

Price and growth projection.

7. "Is promotion needed to develop the market, and, if so, what kind, when, where, how long and how costly?"[43]

Yes, promotion is needed to develop interest by the Department of Energy. Political and technical interest should be developed until the contract is awarded. Cost should be minimal.

8. "Are there any important market trends in tastes, productivity increases, and the like?"[44]

The market trend for solar energy programs is downward at the moment. "So far Treasury Secretary W. Michael Blumenthal and the Office of Management and Budget have vigorously opposed greatly increased spending on solar energy, or creation of the Solar Bank. Blumenthal, in a January 19 memo to the president obtained by the Washington Post, said

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[41]A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[42]Ibid., p. 172.

[43]Ibid., p. 172.

[44]Ibid., p. 172.

that all the options "violate sound fiscal, tax and financial policy." The proposals to boost solar energy "are inconsistent with other policy determinations you have made," he told Carter."[45]

Next, the state of the competition is investigated, as follows:

1. "Is competition internal, i.e., among the existing line of products of competing organizations?"[46]

It is external. The competition is with other facilities teaching similar hands-on courses, or conducting research.

2. "Does the proposed product have internal or external substitutes?"[47]

Not applicable.

3. "What factors are involved in the competition (price, quality or similar features)?"[48]

4. "What are the tactics and strategies of competing organizations, and what are their capabilities?"[49]

Unknown at present.

5. "How fast can competitors respond with competing products, and do they present the threat of real technical obsolescence?"[50]

Competitors can respond with new courses and research proposals.

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[45]The Washington Post, January 27, 1979.

[46]A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[47]Ibid., p. 173.

[48]Ibid., p. 173.

[49]Ibid., p. 173.

[50]Ibid., p. 173.

6. "Can competition be overcome by price-cutting, advertising, product improvement or other means?"[51]

Competition may be overcome by cost reduction, and/or politics.

The answers to the above four sets of questions show that the product is well conceived and useful. There appear to be political and possibly cost obstacles arising from lack of organization resources. However, there appears to be an economic and technical demand for the product.

Finally, individual preferences, habits and motivations are investigated as follows:

1. "Why would anyone buy this product (for its utility, for survival, self-gratification, gain, to satisfy a competitive spirit or an asthetic instinct)?"[52]

The Department of Energy and Fairfax County should fund this product for its utility and uniqueness as well as to receive better information on the performance of earth sheltered facilities for the next generation, e.g., Burke Center.

2. "What are all the uses for the product?"[53]

It is used: for education and training of Saudi Arabina students, to monitor energy availability and use in order to determine an overall energy balance on the total school, to monitor and record solar variables at the school, to provide a control against which to gauge Terraset

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[51] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 173.

[52] Ibid., p. 173.

[53] Ibid., p. 173.

results, to measure and record the performance of HVAC system, to tie in to the NSDAS, to simulate varying occupancy load and summer/winter operations and to develop and test methodologies for new school designs.

3. "When is the product used (continuously, daily, seasonally)? Will a number of individuals share the use of the product or service? If so, can arrival time distributions be predicted?"[54]

The product is used continuously. Both the technical staff as well as the teachers and students at Terraset will use the product. Therefore, arrival times can be predicted. The duty cycle will be 100% and the availability will be 100% for worst case weather conditions.

4. "How long is each instance at use; can holding (or service) time distributions be predicted?"[55]

Use in continuous and service time distributions can be predicted.

5. "What relative importance do individuals attach to the various parameters of quality, convenience, size, shape, weight, style?"[56]

The relative importance of parameters are: Cost simulation - Department of Energy; Education reliability - Fairfax County Public School System; and Convenience - Terraset School personnel.

6. "What additional human engineering data are needed on visual, aural, tactile and other user properties?"[57]

User adaptation to the classroom design is needed.

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[54] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 171.

[55] Ibid., p. 173.

[56] Ibid., p. 173

[57] Ibid., p. 173.

7. "What are the user preferences for alternative price structures, credit and billing practices?"[58]

Not applicable.

Finally, the design requirements stemming from needs research are obtained in preparation for the construction of the system model, as follows:

1. "Which design features does the market want? If the wanted system is similar to an existing system, which operating maintenance and other features should be retained?"[59]

The design feagures wanted are: low cost, high availability, low MTBF (Mean Time Between Failures), ease of maintenance, properly human factored, good spare parts availability, adequate documentation, and quality information on performance. The system should also be easy to test and operate.

2. "For the selected features, what are the independent system variables, and what range of each of these satisfies the most important market uses?"[60]

The independent system variables are: (1) system response time via computer control: 15 min., (b) micro processor data recorder: paper tape every X number of hours (in tenths), (c) solar and climatic data collection station recorder: paper tape every X number of hours (in tenths).

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[58]A. Hall, <u>A Methodology for Systems Engineering</u> (New Jersey: D. Van Nostrand, 1965), p. 173.

[59]<u>Ibid.</u>, p. 174.

[60]<u>Ibid.</u>, p. 174.

Types of simulator variables: outside temperature, ambient humidity, ambient precipitation, ambient wind direction, ambient wind velocity, sunlight amount entering rooms, sunlight strength, earth cover thickness, electricity cost/KW hr., amount of heat reclaim, inside temperature desired/room, thermal loss locations, thermal loss levels, thermal storage tank level, length of operating time desired, time of day, day of year, month of year, solar collector efficiency, number of people/room, number of thermal sources/room, and amount of thermal source/room.

4. "If applicable technical standards exist, are these consonant with the values of the required system variables, or do new standards need to be developed?"[61]

Applicable standards do not appear to exist.

5. "What is the complete list of inputs and outputs supplied by and for the users?"[62]

The inputs and outputs are as follows:

INPUTS	OUTPUTS
solar energy	thermal energy - heating
wind	thermal energy - cooling
electrical energy	room humidity control
ambient temperature	minimum operating cost
ambient humidity	hot running water
ambient precipitation	cold running water
hardware materials	education and training vehicle
operating temperature desired	energy balance
	instrumentation readouts
heat source - people	Accurex instrumentation points
heat source - hardware	NSDAS data link
funding	simulator
Fairfax County water	hot water excess from solar tank vented air and humidity

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[61] A. Hall, A Methodology for Systems Engineering (New Jersey: D. Van Nostrand, 1965), p. 174.

[62] Ibid., p. 174.

6. "Is there any preference for functions and devices needed to realize the wanted features?"[63]

Preferences have not been defined as yet.

7. "Shall the system be designed to match particular market charactersitics (class or mass market sectors), or is a universal system wanted?"[64]

The system shall be designed to match the existing Terraset School environment.

8. "To which user preferences shall the design cater (size, styling, quality, materials)?"[65]

The design shall cater to all user preferences.

9. "What are the market desires and prejudices on safety, on a design adaptable to minor changes on simplicity and on equipment life?"[66]

The market desires are as follows: safety - satisfy Fairfax County building codes; adaptable to minor changes - software should be adaptable to simulation results; simplicity - maximum possible; and equipment life - maximum possible.

10. "To what extent will the equipment need servicing? Who will supply it, and will spare parts and special personnel be needed?"[67]

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[63] A. Hall, <u>A Methodology for Systems Engineering</u> (New Jersey: D. Van Nostrand, 1965), p. 174.

[64] <u>Ibid</u>., p. 174.

[65] <u>Ibid</u>., p. 174.

[66] <u>Ibid</u>., p. 174.

[67] <u>Ibid</u>., p. 174.

Equipment can only be serviced if the activity will not interfere with school activities. The Fairfax County School System will supply the servicing. Spare parts must be specified. A special Terraset School technician should be provided.

On Wednesday, June 7, 1978 the author toured the Terraset School and met with the principal, Mrs. Marge Thompson. As a result, the Primitive Statement of Need has been modified, as follows:

- Monitor and analyze the operations of the heating and cooling system of the Terraset School.
- Provide a linkage between the Terraset School and other solar energy data gathering and analysis systems, both public and private, operating in the United States and through the world.
- Serve as a point of contact for the public to learn about Terraset and for the Reston Community to express its interest and concerns.
- Prepare and publish reports, monographs and analyses based on studies undertaken at Terraset.
- Supply and operate needed monitoring and analytical equipment required for studies and analyses of the operation of the Terraset facility.
- Conduct workshops, seminars, and visitations for domestic and foreign scholars, professionals, and other interested persons.

In addition, the following data was gathered by the author:

1. The Hot Water Absorption Chiller (backup for AC) was inoperative.

2. The Honeywell HVAC AC hardware was inoperative (ambient environment was hot and humid) resulting in the school being hot and humid.

3. The solar reflector panels leak due to wind forces.

4. An unknown quantity of hot water is dumped as excess from the Hi-Temp Solar Tank.

On November 21, 1978, I spent a day in the Terraset School, as one of its students. In fact, I accompanied Mark Seneca, a 6th grader, from 8:40 a.m. until 4:30 p.m., in an effort to experience the real life impact of learning at Terraset. I rode the school bus with him to school, attended all of his classes, ate lunch with him and his friends and attended an after-school Math Club meeting with him. During the day, I spoke with Mark's teacher, other teachers and faculty, and Mark's classmates regarding "what it was like to go to school at Terraset." My findings, which will modify the previous two statements of need are:

1. The school is too hot in the summer: (a) no AC back-up operating to date, (b) principal has no operational procedures from which to refer when AC goes down (e.g., open all doors and windows that night to trap in cool evening air for the next day), (c) large window area for visibility, light and psychology of being in a buried school let it too much heat by convection (Note: experiments are being run to determine the best filter to place over the glass).

2. The collectors leak: (a) some leakage is due to wind effects, (b) some leakage is due to vandalism (students throwing rocks), (c) snow and ice accumulates in the winter causing dangerous pieces of ice to fall (Note: students must exit the school at rear entrances to avoid the ice and water while the specially designed bus pick-up location is in the front of the school).

3. I believe it would be beneficial to have a visual feedback display in the lobby to reflect energy usage - what the status of all the systems are at a glance.

4. The teachers' work space needs privacy.

5. The humidity is on the dry side.

6. Each teacher would like his own thermostat (learning centers facing the sun are too hot).

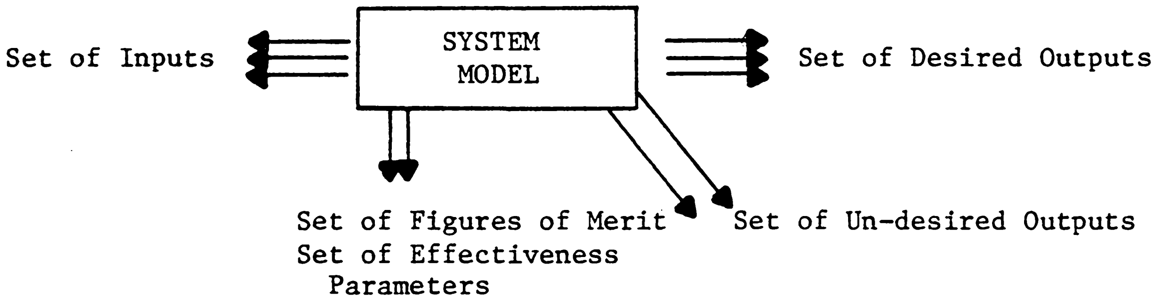
Finally, regarding iteration of the Needs Analysis, the Virginia Polytechnic Institute and State University prepared an Interim Report on Terraset School entitled "Heating, Ventilating, Air Conditioning and Solar System," dated September, 1978. The results of this report will now be melded into the Needs Analysis, as follows:

Final Statement of Need or System Requirements:

- Define a new instrumentation system for measurement, control and display of temperature, flow rates and power.
- Provide manual override control of the entire heating and cooling system and provide procedures.
- Provide for total automatic energy systems management and observation.
- Maintain and strengthen Terraset's good-will image with the community.
- Provide for an NSDAS interface.
- Prepare and publish a complete description and documentation of the facilities.
- Provide system level life-cycle cost trade-off studies for alternative selection.

The status of the system will now be "frozen" and the author will get on with the work of thesis writing.

The system model can now be defined. The superstructure of the system model is shown below:



The Set of Inputs are:

- Internal: (1) human body heat, (2) human exhaled water vapor, (3) temperature desired, (4) hot and cold potable water (quantity), (5) hot potable water temperature desired, (6) lighting, (7) maintenance expertise, (8) A_o (Operational Availability) requirement.
- External: (1) county supplied electricity, (2) ambient air temperature, (3) ambient ground temperature, (4) ambient humidity (rain, snow, ice), (5) ambient ground water content, (6) solar energy, (7) wind, (8) county supplied water, (9) soil cover (type and thickness), (10) county budget appropriation, (11) fungus, (12) sunlight, (13) infiltration at doors).

The Set of Desired Outputs are:

- Temperature.
- Humidity.
- A_o.

- Hot potable water.
- Optimum economic operation.
- Use of roof area.
- Automatic control of energy management.
- Manual control of energy management.
- Visual display of total system operations.
- Good learning environment.
- Minimal exterior maintenance requirements.
- NSDAS interface.

The Set of Undesired Outputs are:

- Increased maintenance.
- Falling water, ice and snow from solar collectors.
- Heat losses through concrete/soil cover.
- Low A_o.
- Low maintainability.
- Poor/nonexistent technical documentation.
- Electrical power consumption.
- Ventilated heat.
- Additional training required for maintenance.
- Hot water expelled to environment from the Hi-Temp Solar Tank.
- Lack of operational procedures from which to refer when failures occur.
- Classrooms facing the sun are too hot due to solar heat entering the windows.
- Solar collector leakage problems.
- Infiltration at doors.

The Set of Figures of Merit are:

- Monthly electricity bill.
- A_o.
- MTBF (mean time between failure).
- MTTR (mean time to repair).
- Efficiency.
- Total life-cycle cost.
- Classroom temperature.

The Set of Effectiveness Parameters are:

- Availability/life-cycle cost.
- Reliability/life-cycle cost.

The Set of Constraints is then developed for the input, system and output as follows:

- Constraints on Input: (1) student maximum number of 1,050, (2) solar energy is not always available, (3) county budget appropriation for Terraset is less than the county budget level for non-solar equipped schools.
- Constraints on System: (1) cannot interfere with education system, (2) safety and ease of maintenance requirements, (3) $A_o \geqslant 0.99$, (4) windows should not permit excessive solar energy entry, (5) must be socially acceptable to students, teachers and community, (6) must be politically acceptable, (7) low MTBF, (8) low MTTR, (9) Repair concept must be reasonable.
- Constraints on Output: (1) potable kitchen hot water temperature $\geqslant 120^{\circ}F$, (2) county pollution regulations, (3) minimum solar collector leakage.

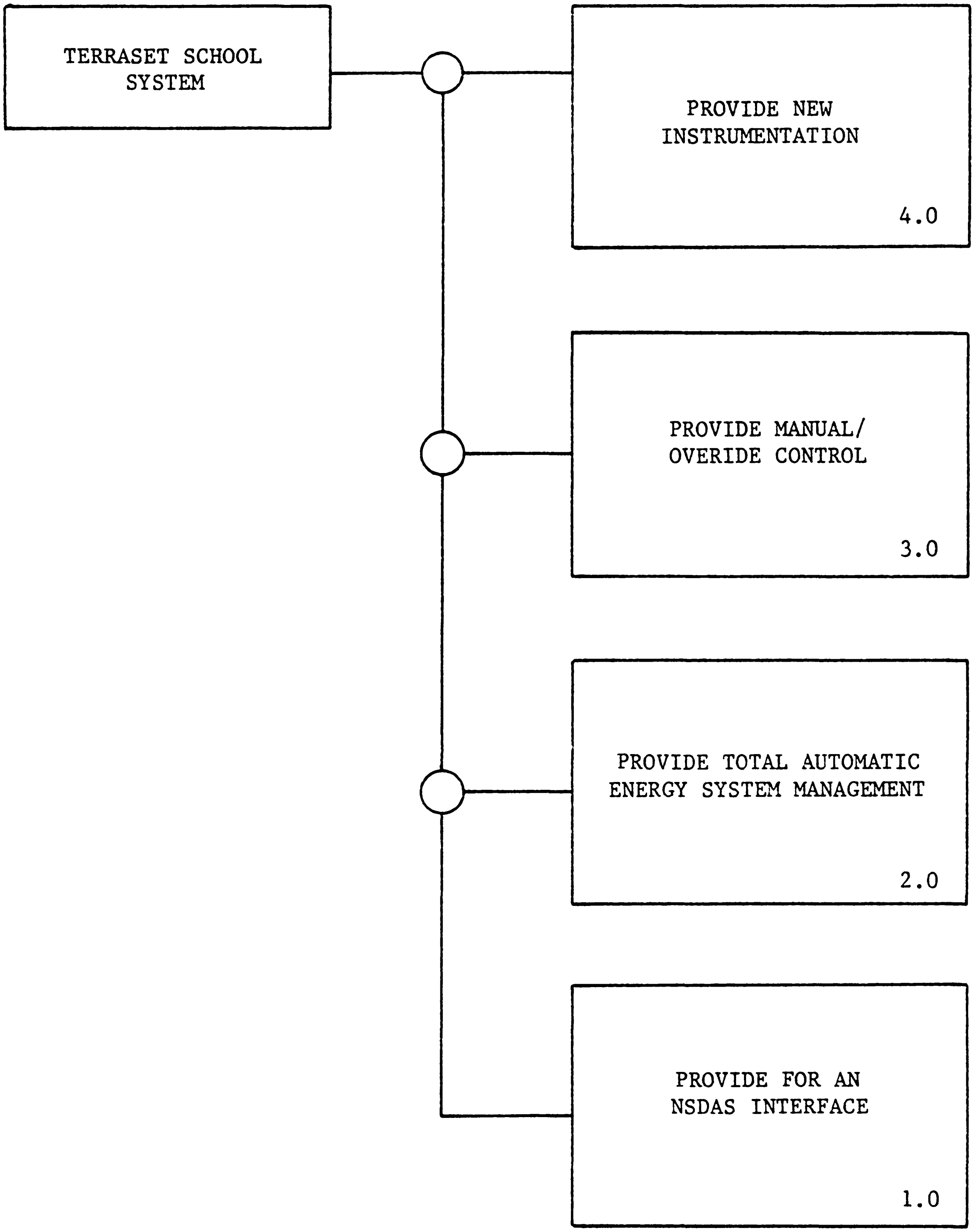
Functional Analysis

The next step in the systems engineering process is Functional Analysis. This process leads to the definition of operational and maintenance performance requirements. It starts with the translation of the results of the Needs Analysis into Functional Flow Diagrams, Table 2, that are a block diagram portrayal of the functions which must be met to satisfy total system needs. The Functional Flow Diagrams are developed from the operational requirements, which follow.

The contents of the Requirements Matrix, Table 3, are then compared to the System Requirements (last iteration of the Needs Analysis). This iteration technique yields the following requirements list, which can be used to modify the Terraset System Model:

- Parameter list to achieve a total automatic energy systems management.
- Heat balance analysis for system optimization when in automatic control.
- Tree-diagram logic flow for the system optimization when in automatic control.
- Control valve list to achieve system optimization when in automatic control.
- System display layout design to include parameters required to achieve total automatic energy systems management.
- System display layout design to include control valves required to achieve total automatic energy systems management - to be combined with preceding bullet.
- Single-point failure analysis for entire system.

TABLE 2. FUNCTIONAL FLOW DIAGRAM



The first level expansions are developed as follows:

TABLE 2. FUNCTIONAL FLOW DIAGRAM (CONT.)

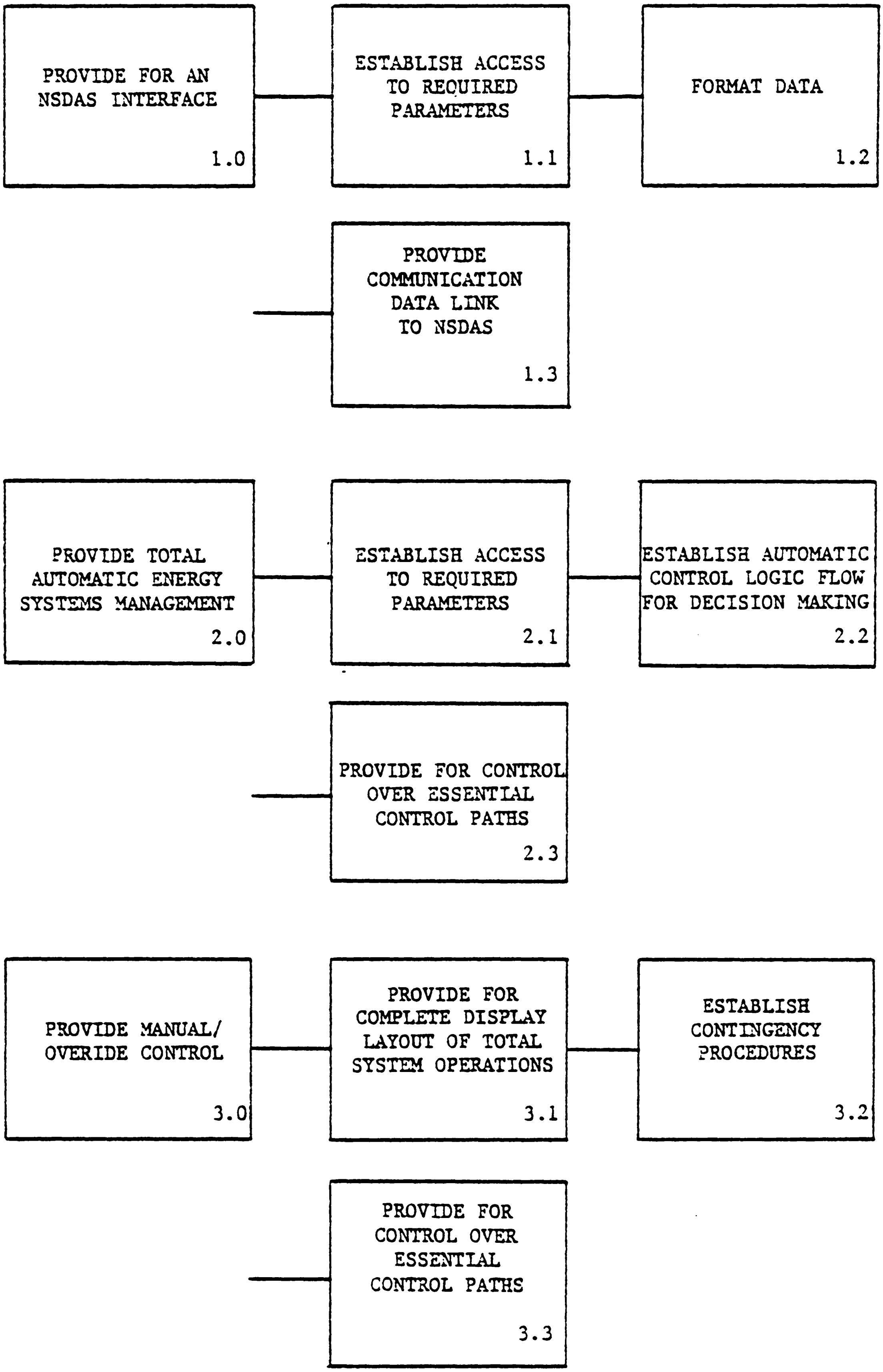
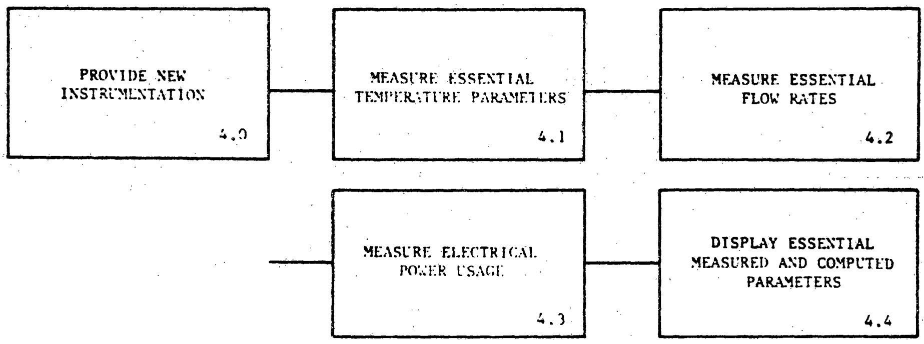


TABLE 2. FUNCTIONAL FLOW DIAGRAM (CONT.)



The second expansions are developed as follows:

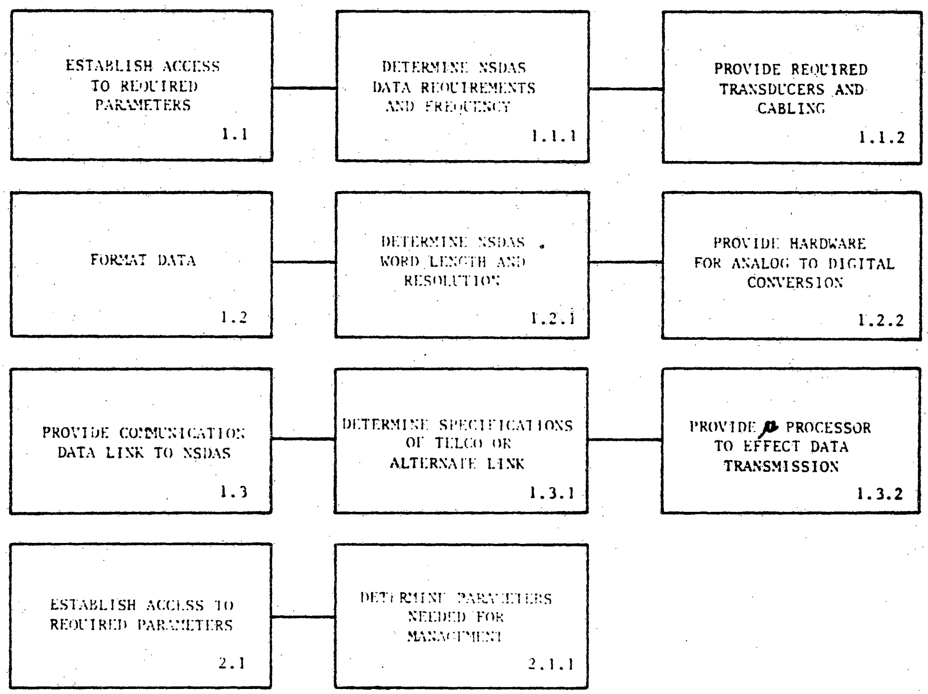


TABLE 2. FUNCTIONAL FLOW DIAGRAM (CONT.)

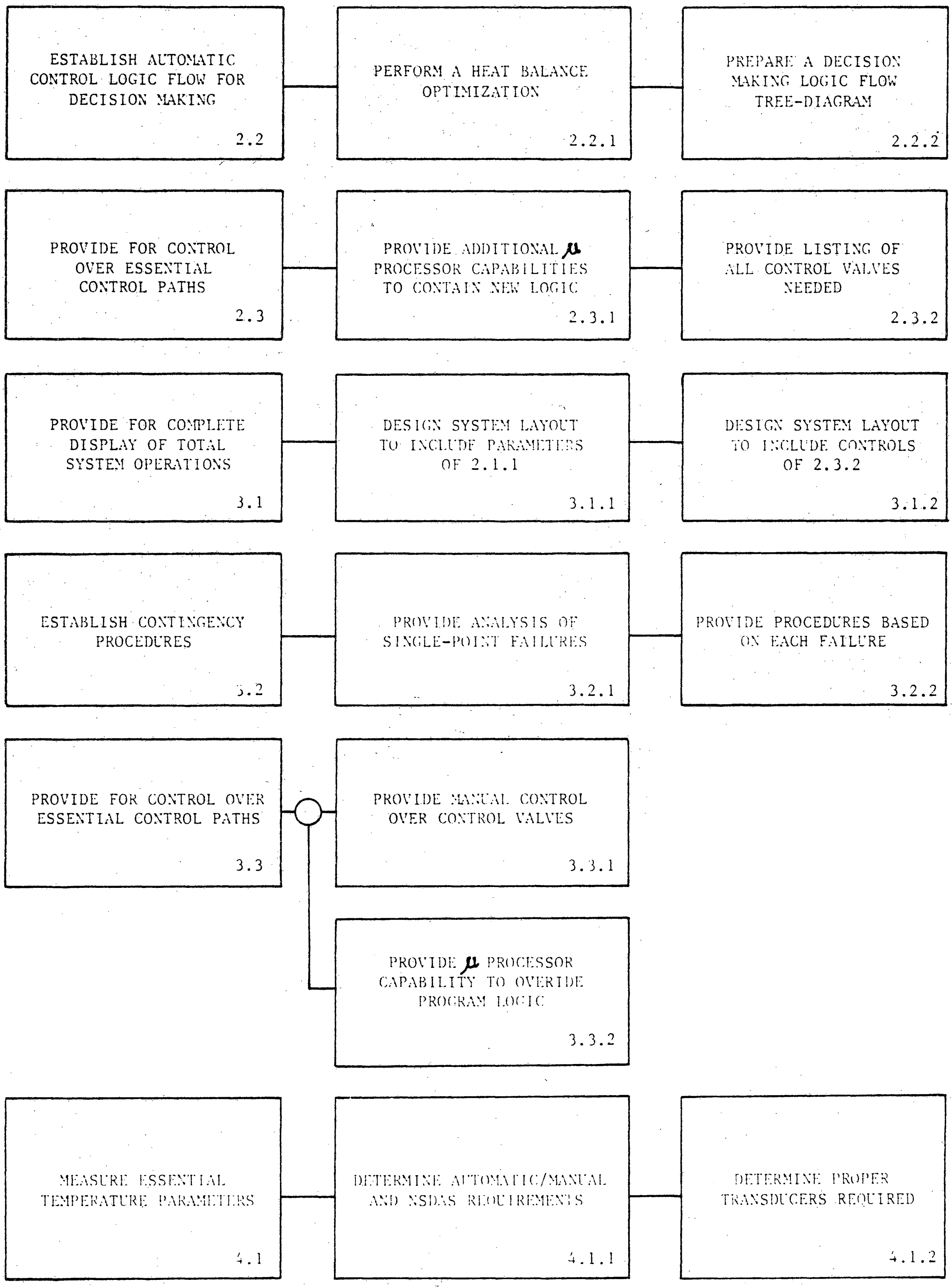
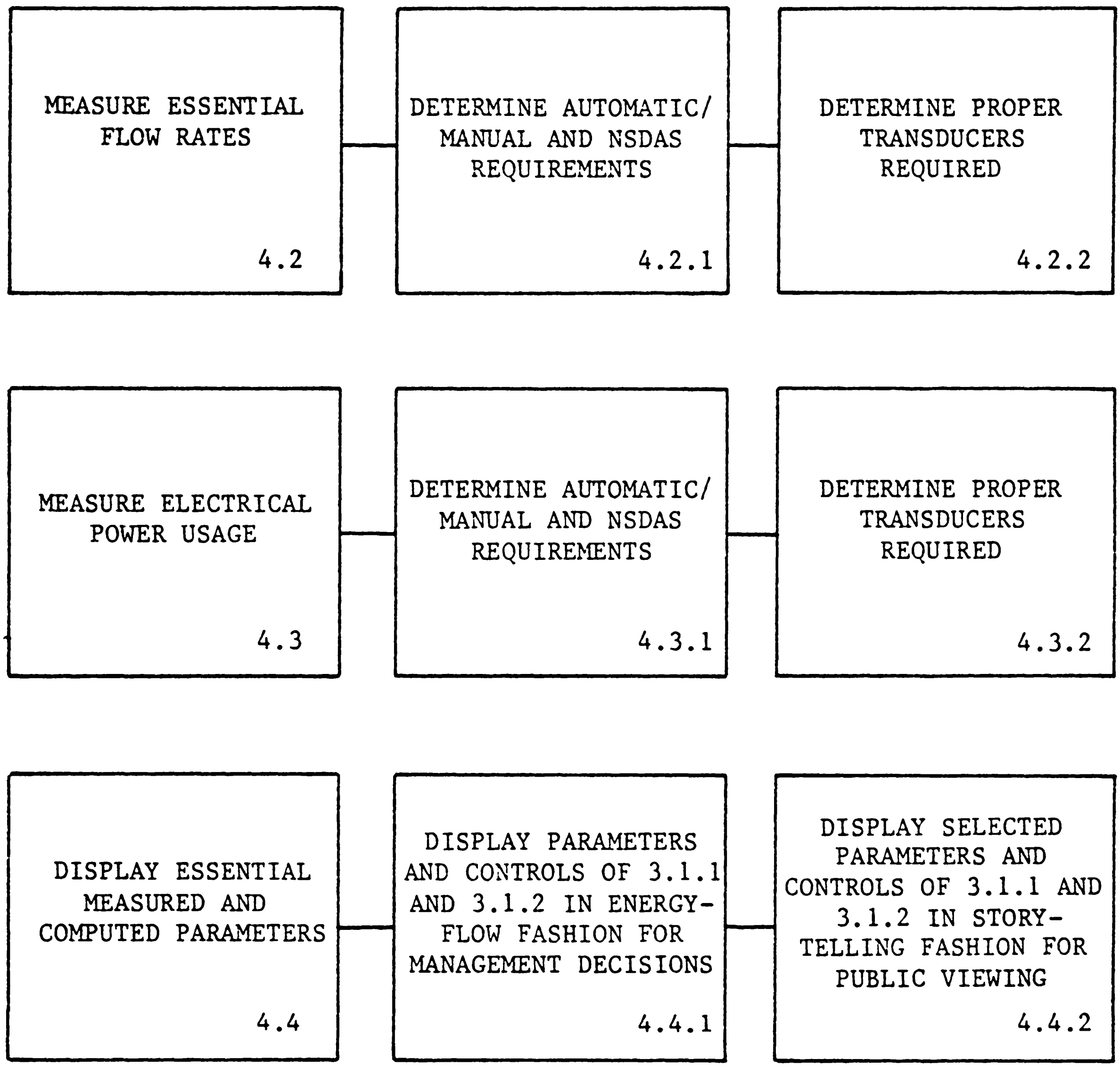


TABLE 2. FUNCTIONAL FLOW DIAGRAM (CONT.)



A Requirements Matrix can now be generated, to close the loop back to the operational need, as follows:

TABLE 3. REQUIREMENTS MATRIX

FUNCTION	HARDWARE	SOFTWARE	PERFORMANCE	FACILITIES	TECH DATA	OPERATOR INTERFACE	DOCUMENTATION	COMMENTS
1.0			X		X			
1.1	X							
1.1.1			X		X			
1.1.2	X							
1.2		X						
1.2.1					X			
1.2.2	X							
1.3	X							
1.3.1	X	X			X			
1.3.2								
2.0			X					
2.1	X							
2.1.1			X				X	Parameter list is needed
2.2			X					
2.2.1			X					Thermal analysis is needed
2.2.2							X	A tree-diagram is needed
2.3	X					X		
2.3.1		X		X				
2.3.2			X					Listing of all control valves is needed
3.0	X		X			X		
3.1	X			X		X		
3.1.1							X	System layout design is needed
3.1.2							X	System layout design is needed
3.2			X					
3.2.1							X	Single-point failure analysis is needed
3.2.2							X	Contingency procedures are needed
3.3			X					
3.3.1	X							
3.3.2		X						
4.0	X							
4.1	X							
4.1.1					X		X	
4.1.2	X							
4.2	X							

TABLE 3. REQUIREMENTS MATRIX (CONT.)

FUNCTION	HARDWARE	SOFTWARE	PERFORMANCE	FACILITIES	TECH DATA	OPERATOR INTERFACE	DOCUMENTATION	COMMENTS
4.2.1					X		X	
4.2.2	X							
4.3	X							
4.3.1							X	
4.4				X		X		
4.4.1				X		X		Management display design is needed
4.4.2				X		X		

- Contingency procedures for hardware single point failures.
- A display for management decision making.
- A display for public viewing and education.

The Requirements Matrix reveals that a need statement regarding accuracy tolerances for system parameters is required. The most obvious areas of expanded concentration are in software and reliability analysis. In addition, the requirement for support equipment has not been defined. The next iteration can examine these to determine to what extent a need exists.

At this point, the author feels responsible for pointing out that if Systems Engineering had been applied to Terraset from the beginning of the program, the ten item requirements list would be far shorter or nonexistent. In any case, these requirements, at a minimum, should be examined for application to the Burke Center Elementary School now under construction.

The ten items in the previous list of new requirements should be satisfied at this point. However, due to the need for expediency in completing this thesis, they will not be addressed. On the other hand, one item that can be iterated at this point follows an iteration cycle going back to the Needs Analysis. It yields the following standards, codes and performance criteria related to question number 4 (page 31) (from this paper) concerned with "design requirements stemming from needs research," as follows:

- ASHRAE Standard 93-77. METHODS FOR TESTING THE THERMAL PERFORMANCE OF SOLAR COLLECTORS. ASHRAE, 345 East 47th Street, New York, New York 10017.

- ASHRAE Standard 94-77. METHODS OF STORING THERMAL STORAGE DEVICES BASED ON THERMAL PERFORMANCE. ASHRAE, 345 East 47th Street, New York, New York 10017.
- FLORIDA SOLAR ENERGY CENTER TEST METHODS AND MINIMUM STANDARDS FOR SOLAR COLLECTORS. Florida Solar Energy Center 300 State Road 401, Cape Canaveral, Florida 32920 (November 1976).
- INTERIM PERFORMANCE CRITERIA FOR SOLAR HEATING AND COMBINED HEATING AND COOLING SYSTEMS AND DWELLINGS. Prepared for the U.S. Department of Housing and Urban Development by the National Bureau of Standards Available from GPO. SD Catalog No. C13.6/2:504.
- UNIFORM SOLAR ENERGY CODE. International Associations of Plumbing and Mechanical Officials, 5032 Alhambra Avenue, Los Angeles, California 90032.

The maintenance performance analysis can be performed once the operational functions are defined. The operational functions can be derived from Figure 2, Solar System, and Figure 3, Hydronic System, as follows in Figure 4, the Terraset System Operational Functional-Flow Diagram.

There should be specific performance requirements (temperature, flow rate, water level, etc.) for each operational function. "A check of the applicable function will indicate either a GO or NO-GO decision. A NO-GO indication (constituting a symptom of malfunction) provides a starting point for the development of detailed maintenance functional

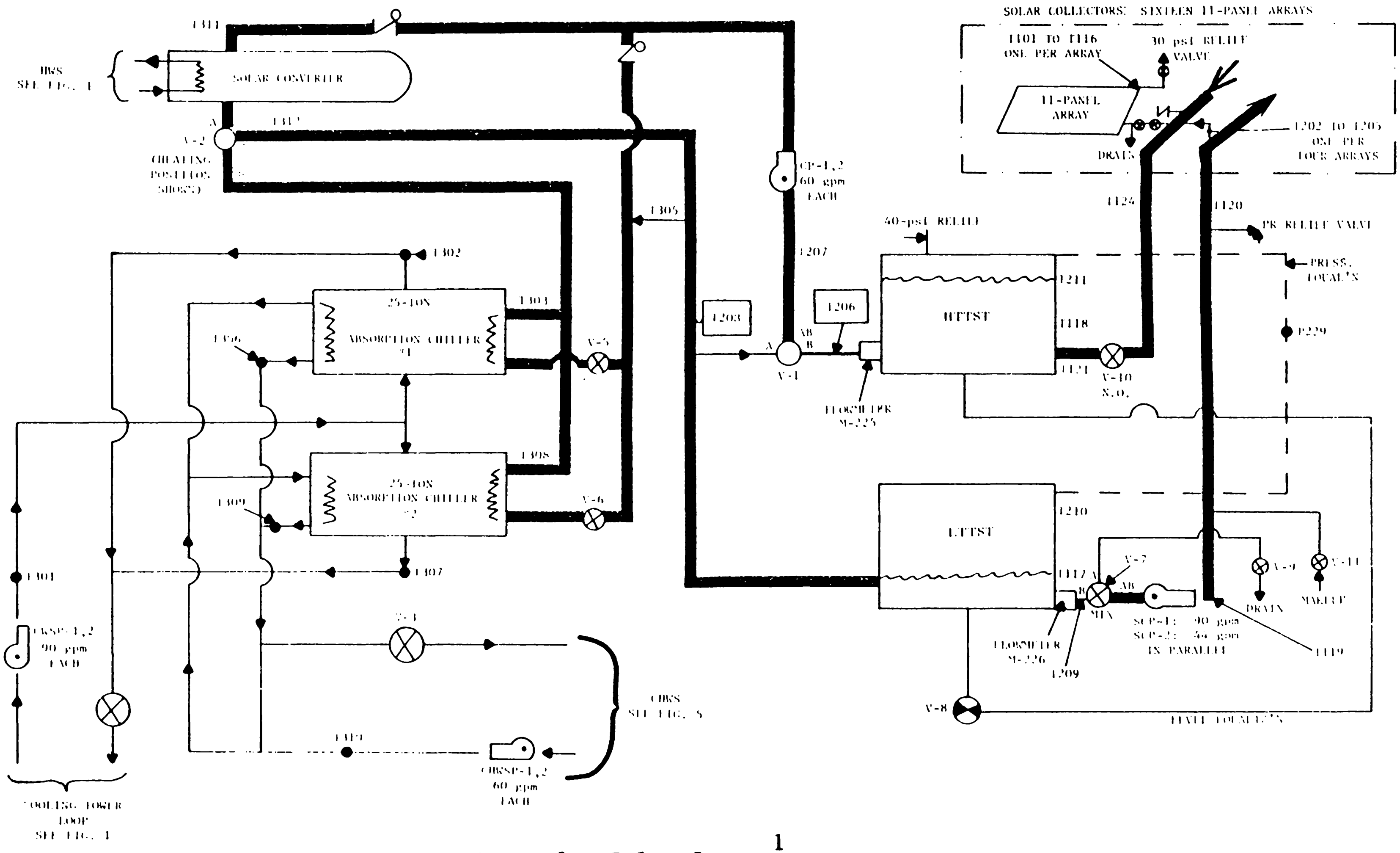


Figure 2. Solar System[1]

[1] D. L. Michelsen, R. L. Whitelaw, Terraset Elementary School, Heating, Ventilating, Air Conditioning, and Solar System Interim Report, Virginia Polytechnic Institute and State University, September 8, 1978.

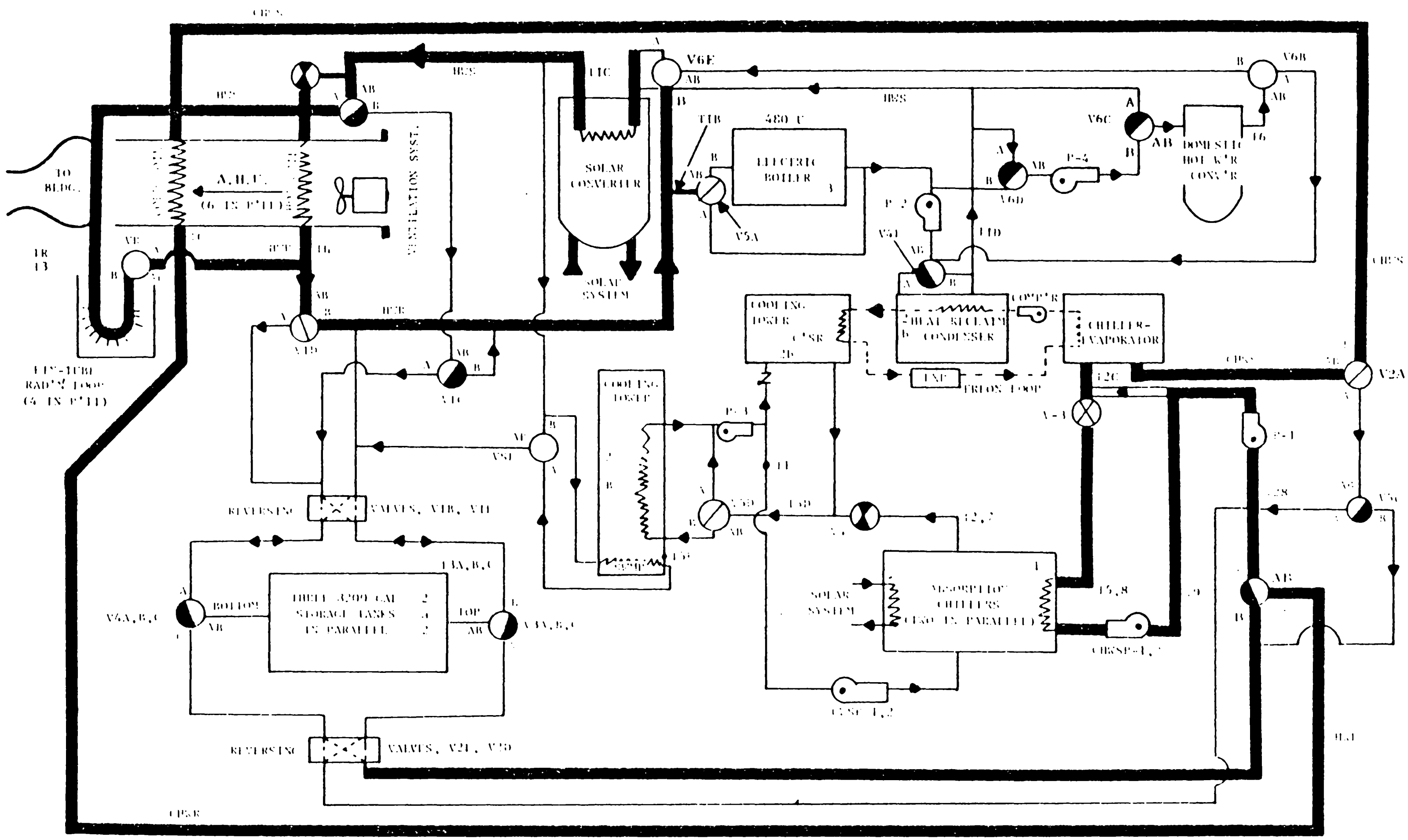


Figure 3. Hydronic System[1]

[1]D. L. Michelsen, R. L. Whitelaw, Terraset Elementary School Heating, Ventilating, Air Conditioning, and Solar System Interim Report, Virginia Polytechnic Institute and State University, September 8, 1978.

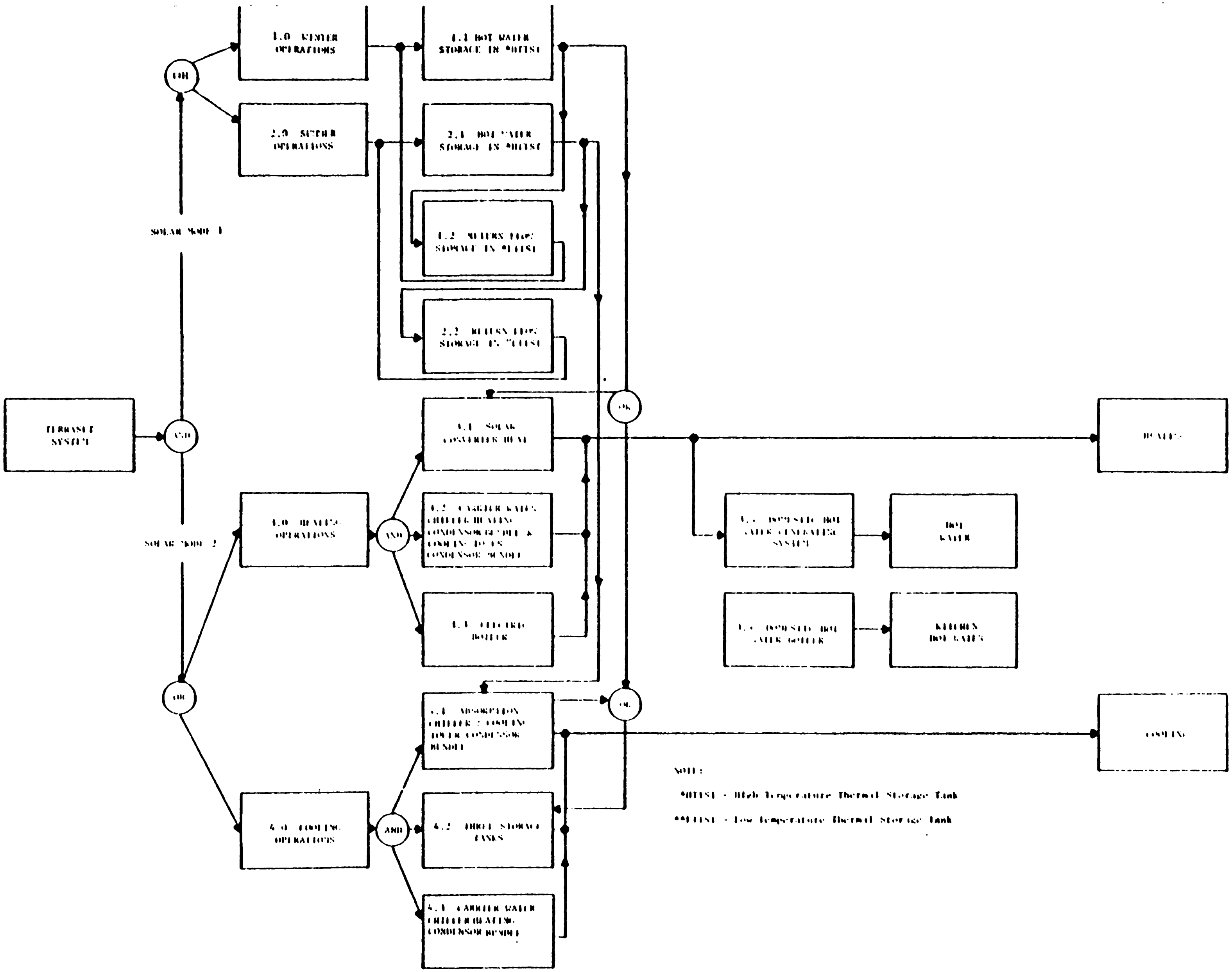


Figure 4. Terraset System Operational Function - Flow Diagram

flows and logic trouble shooting diagrams."[68] A gross-level maintenance functional flow is illustrated in Figure 5, Terraset Maintenance Functional Flow Diagram.

The corresponding maintenance elements for each "Localize Fault" box in Figure 5, Terraset Maintenance Functional Flow Diagram, are as follows:

- 6.1: T124, T211, T118, T121, V-10.
- 6.2: same as 6.1.
- 6.3: T206, T207, T311, T312, T210, T117, T120, M-225, V-1, CP1&2, V-2, M-226, V-7, SCP1&2, V-9, V-11, P229, TIC.
- P-3, T5E, V5D.
- V5A, P-2.
- 6.7: T-6, V-6B, V-6C, P-4.
- 6.8: TBD.
- 6.9: freon loop, compressor.
- 6.10: VIB, VIE, V4A BC, V2E, V2D, V3ABC, T 3ABC.
- 6.11: T 5,8, CHWSP-1,2, T9, P-1, V2C, V-3

After each fault is localized the applicable unit should be removed from the system and replaced with a spare. Next, the malfunction should be isolated to the faulty assembly within a unit. Then, the faulty assembly should be replaced with a spare, or inplace repair of the equipment should occur. Next, verification of the repair should occur,

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[68] Benjamin S. Blanchard, Logistics Engineering and Management (Englewood Cliffs, NJ: Prentice-Hall, 1974), p. 96.

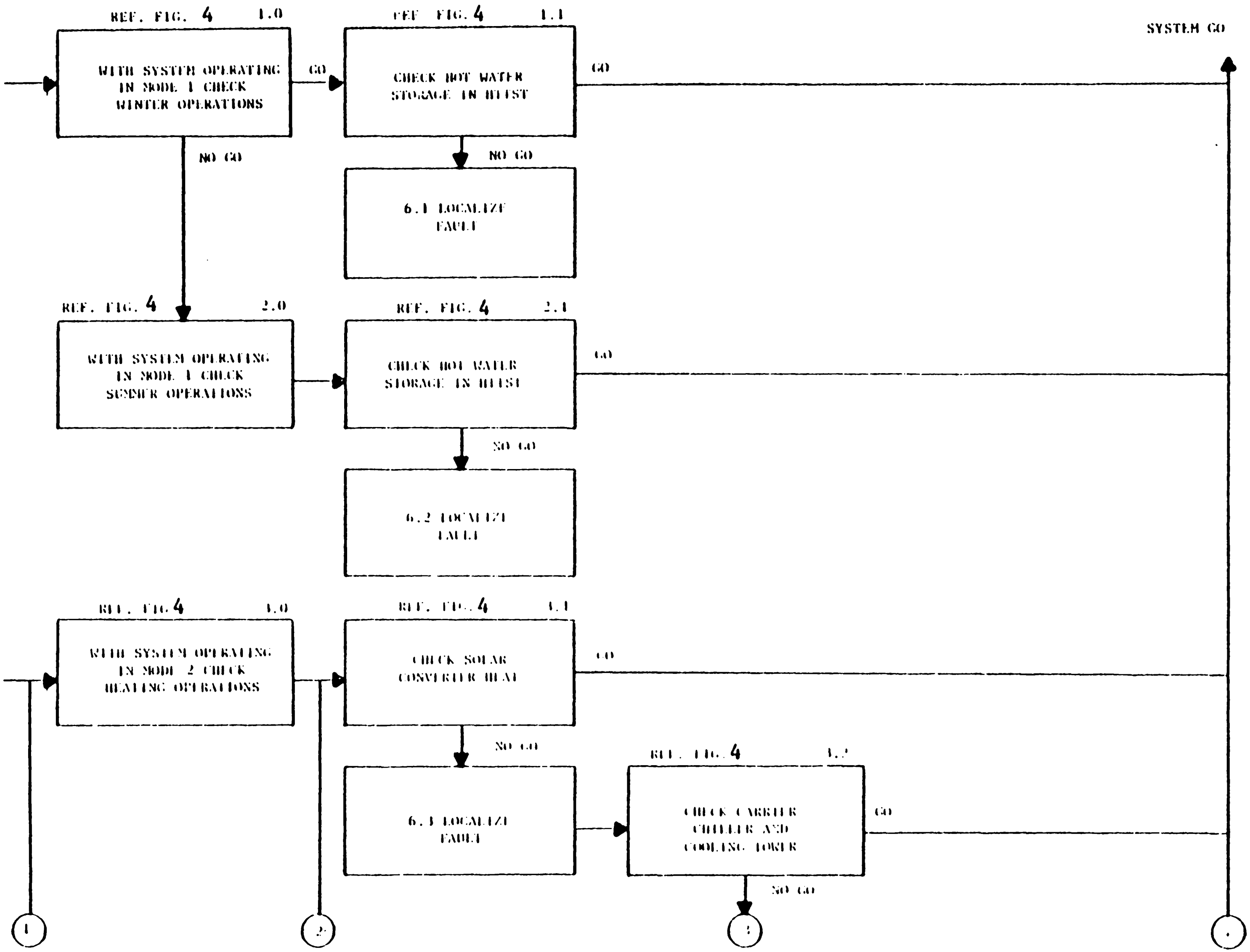

Figure 5. Terraset Maintenance Functional Flow Diagram

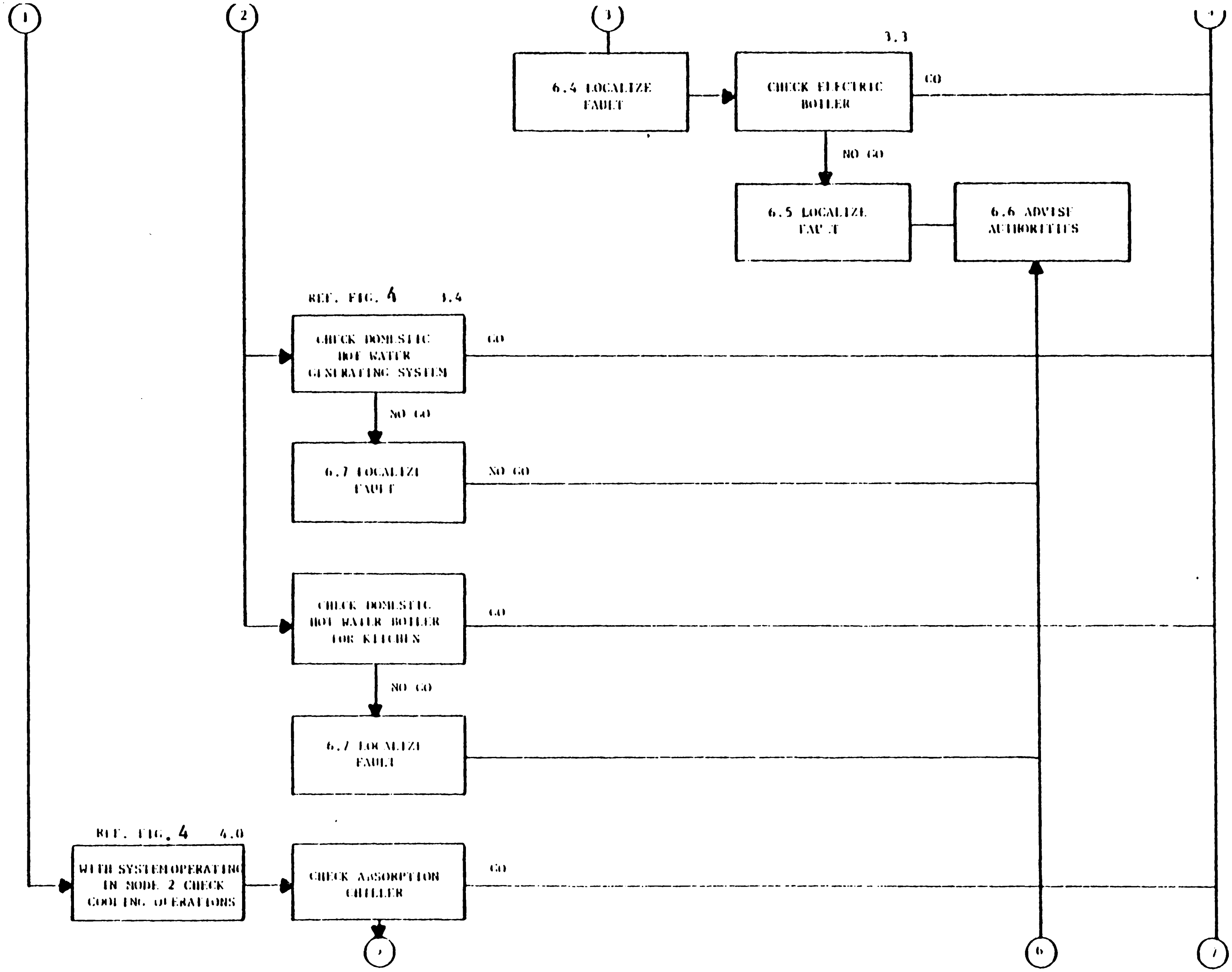

Figure 5. Terraset Maintenance Functional Flow Diagram (Cont.)

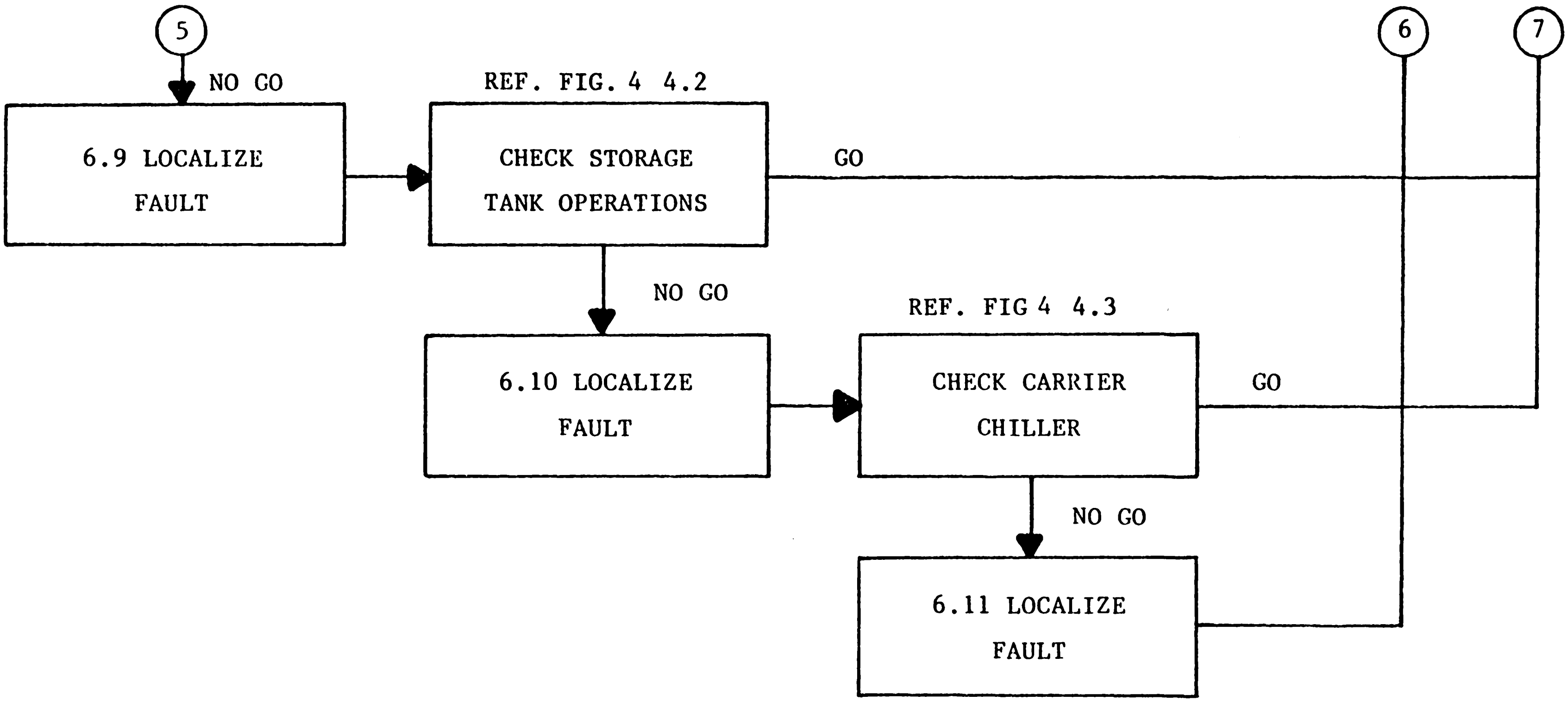

Figure 5. Terraset Maintenance Functional Flow Diagram (Cont.)

followed by a test of the applicable unit. Finally, the operational unit is returned to stock.[69]

This facet of the Functional Analysis not only provided a list of maintenance elements to check when a system fault occurs but brought to light the fact that logistic resources need to be defined as well as preventive maintenance procedures. This maintenance concept/functional-flow development process is iterative and should be continued throughout the improvement efforts of the heating and cooling systems.[70]

Test Requirements Analysis

The Functional Analysis tool has brought about the requirement for bench test procedures. Similarly, support equipment, servicing, and inspections for tests need to be defined. Test requirements analysis is also iterative and should be continued throughout the improvement efforts of the heating and cooling systems.

System Life Cycle Cost Analysis

As the Introduction stated, ".....it is life cycle costs rather than initial costs that really count."[71] In this vein, the life cycle cost of Terraset will be analyzed and then compared to that at nearby Hunters Woods Elementary School (if date is available) or to a similar school. "The Hunters Woods school is similar to Terraset in size and function

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[69]Benjamin S. Blanchard, Logistics Engineering and Management (Englewood Cliffs, NJ: Prentice-Hall, 1974), p. 96.

[70]Ibid., p. 98.

[71]The Washington Post, February 10, 1979.

but Hunters Woods was completed about 10 years ago (1968) and has a capacity of about 980 students."[72]

When evaluating a system, the aspect of total life-cycle cost (cost of acquisition, ownership and ultimate disposal) should be considered and not just procurement price alone. Life cycle cost includes all costs associated with research and development, investment (construction) installation and checkout, operation and maintenance, and ultimate system phaseout. It covers all hardware, software data and associated logistic support.[73] A comprehensive classification of life cycle cost is presented in Figure 6, Cost Breakdown Structure.

Therefore, this life cycle cost (LCC) analysis will include the following: (1) Research and Development (R&D), (2)Investment, (3) Operations and Maintenance (O&M), and (4) Phase Out.

LCC is present value (or total cost of the system) based on a discount rate of 10 percent and a system life of 50 years. The LCC of Terraset Elementary School is estimated to be:

1. Research and Development, and
2. Investment[74]

General Construction		$2,470,200	
HVAC		393,000	
	TOTAL	$2,863,200,	1st year
Solar		625,000,	2nd year

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[72]A. C. Hlavin and A. A. Martin, "The Terraset School," Unpublished Ms, Fairfax County Public Schools, Fairfax, VA, 1978, Introduction (pages unnumbered).

[73]Benjamin S. Blanchard, Logistics Engineering and Management (Englewood Cliffs, NJ: Prentice-Hall, 1974), p. 316.

[74]Solar and Energy Conservation Research and Demonstration at the Terraset School, Virginia Polytechnic Institute and State University, Reston, Virginia, December 17, 1977.

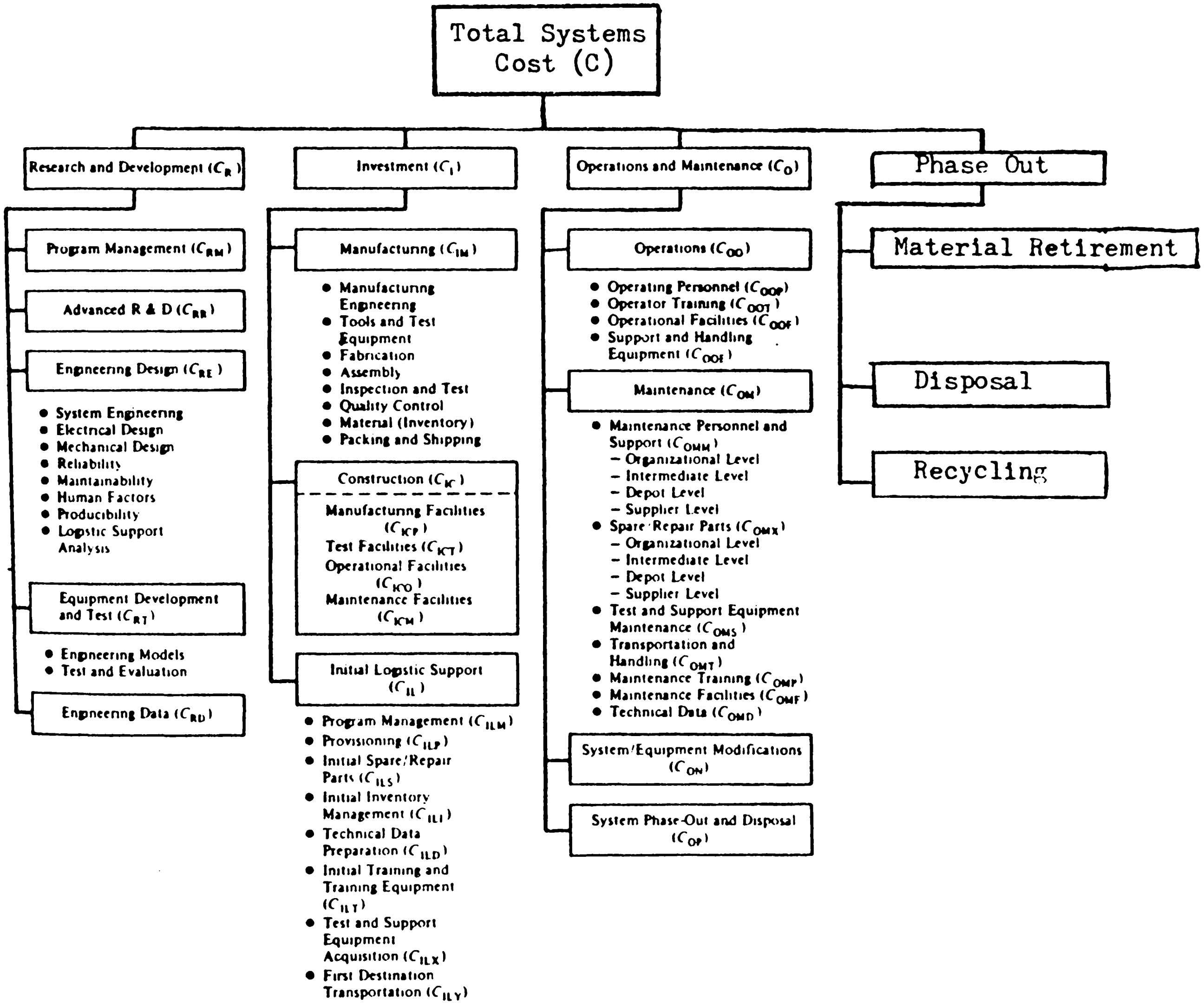

Figure 6. Cost Breakdown Structure[1]

[1]Benjamin S. Blanchard, <u>Logistics Engineering and Management</u>, (Englewood Cliffs, NJ: Prentice-Hall, 1974), p. 316.

3. Operation and Maintenance

   a. Maintenance personnel mileage cost/year (Reference Table 2, O&M Data from Terraset and Hunters Woods) = $463.

   b. Labor cost/year (Reference Table 2, O&M Data from Terraset and Hunters Woods) = $4,562.

   c. Material cost/year (Reference Table 4, O&M Data from Terraset and Hunters Woods) = $544.

TABLE 4. O&M DATA FROM TERRASET AND HUNTERS WOODS[1]

SCHOOL	NO. OF JOBS	MAN HRS.	MILEAGE COST	LABOR COST	MATERIAL COST	TOTAL* COST
Terraset	107	757.2	$463.20	$4,562.22	$ 544.20	$5,569.62
Hunters Woods	110	832.1	$555.25	$4,887.82	$1,657.20	$9,099.67

   d. Electricity (Reference Table 5, Terraset and Hunters Woods Electricity Data) = $\$150.19/\text{day} \times \frac{365 \text{ days}}{\text{year}} = \$54{,}819$.

   e. Water (Reference Table 6, Terraset Water Usage, and Table 5, Terraset Water Usage Cost) = $\$2.79/\text{day} \times \frac{365 \text{ days}}{\text{year}} =$ $1,018. Total = $32,418.

4. Phase Out

   Assume 20 percent of initial investment = $632,940.

Total LCC = $3,407,377 (Reference Table 8, Terraset Life Cycle Cost Breakdown).

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[1]Table compiled from information received from Cliff Philips, Fairfax County Public Schools, Support Services Department, Maintenance Division, Telecon, 3/8/79.

TABLE 5. TERRASET AND HUNTERS WOODS ELECTRICITY DATA

UNCORRECTED FOR WEATHER DIFFERENCE

HUNTERS WOODS

1977-78					1978-79						
Month	Billing Days	KW-HR Used	$ Cost	Average Cost/Day	Month	Billing Days	KW-HR Used	$ Cost	Average Cost/Day	Percent Change KW-HR	Percent Change Dollars
OCT	(29)	139,680	$ 4,022.08	138.69	OCT	(29)	107,280	$ 3,317.20	114.39	-23.2	-17.52
NOV	(32)	151,200	4,418.82	138.09	NOV	(31)	134,640	4,015.10	129.52	-10.95	- 9.14
DEC	(30)	210.960	6,085.14	202.84	DEC	(31)	169,920	4,909.15	158.36	-19.45	-19.33
JAN	(33)	287,280	8,504.92	257.72	DEC	(33)	231,120	6,550.16	198.49	-19.55	-22.98
		789,120	$23,030.96				642,960	$18,791.61	Average = 150.19		

TERRASET

Month	Billing Days	KW-HR Used	$ Cost	Average Cost/Day	Month	Billing Days	KW-HR Used	$ Cost	Average Cost/Day	Percent Change KW-HR	Percent Change Dollars
OCT	(29)	102,528	$ 2,952.29	101.80	OCT	(31)	71,424	$ 2,208.49	71.24	-30.34	-25.19
NOV	(32)	120,384	3,518.22	109.94	NOV	(29)	59,328	1,769.22	61.01	-50.72	-49.17
DEC	(30)	126,720	3,655.24	121.84	DEC	(31)	73,728	2,130.07	68.71	-41.82	-41.73
JAN	(33)	172,800	5,115.74	155.02	JAN	(33)	95,616	2,709.85	82.12	-44.67	-47.03
		522,432	$15,241.49				300,096	$ 8,817.63	Average = 70.77		

Terraset Monthly Cost/ft^2 (For Oct. 78 thru Jan. 79) $= \frac{\$8,817.63 \div 4}{69,100 \text{ ft}^2} = \underline{3.19 \text{ cents}}$

Hunters Woods Monthly Cost/ft^2 (For Oct. 78 thru Jan. 79) $= \frac{\$18,791,61 \div 4}{80,284 \text{ ft}^2} = \underline{5.85 \text{ cents}}$

Terraset cost saving over Hunters Woods $= \frac{5.85-3.19}{5.85} = \underline{45.47\%}$

TABLE 6. TERRASET WATER USAGE[1]

QUARTER	QUARTER USAGE (GAL.)	DAILY USAGE (GAL.)
12/77	484,000	5,319
3/78	297,000	3,264
6/78	418,000	4,593
9/78	255,000	2,802
12/78	358,000	3,934

TABLE 7. TERRASET WATER USAGE COST

QUARTER	USAGE (GAL./DAY)	COST*	COST/DAY
12/77	5,319	$3.72	$2.79 (12/77–12/78)
3/78	3,264	2.28	
6/78	4,593	3.22	
9/78	2,802	1.96	
12/78	3,934	2.75	

*Calculated at 70¢/1,000 gal., source: Fairfax County Water Authority, telecon, 3/7/79.

[1]Table compiled from information received from Jim McCulley, Terraset Foundation Research Engineer, telecon 3/7/79.

TABLE 8. TERRASET LIFE CYCLE COST BREAKDOWN

COST ITEM	YEAR 1	YEAR 2	YEAR 3-49	YEAR 50
R&D Investment	$2,863,200	$551,500	--	--
O&M	$32,418	$34,838*	$34,838*	$34,838*
Phase Out	--	--	--	$682,940
Total Cost	$2,895,618	$586,338	$34,838	$717,778
**Discount Factor	0.9091	0.8264	8.1612	0.0085
Present Value	$2,632,406	$484,550	$284,320	$6,101

*Labor and Material Costs increased 15 percent above Hunters Woods after year 1.[1]

**$P = F \frac{1}{(1 + i)^n}$.

[1]Increase from information received from A. C. Hlavin, Facilities Planning and Construction, Fairfax County Public Schools, telecon, 3/8/79.

The LCC of Hunters Woods Elementary School is estimated to be:

1. Research and Development

2. Investment[75]

Design	59,580
Construction	1,191,592
TOTAL	$1,251,172

3. Operation and Maintenance

   a. Maintenance personnel mileage cost/year (Reference Table 4, O&M Data from Terraset and Hunters Woods) = $555.

   b. Labor cost/year (Reference Table 4, O&M Data from Terraset and Hunters Woods) = $7,100.

   c. Material cost/year (Reference Table 4, O&M Data from Terraset and Hunters Woods) = $1,657.

   d. Electricity (Reference Table 3, Terraset and Hunters Woods Electricity Data) = $150.19/day X $\frac{365 \text{ day}}{\text{year}}$ = $54,819.

   e. Water (Assume Terraset data) = $1,018 Total = $65,149.

4. Phase Out

   Assume 20 percent of initial investment = $250,234.

Total LCC = $2,725,116 (Reference Table 9, Hunters Woods Life Cycle Cost Breakdown, assuming inflation rates shown).

As can be seen from Table 8, Terraset Life Cycle Cost Breakdown and Table 9, Hunters Woods Life Cycle Cost Breakdown:

Terraset LCC = $3,407,377.

Hunters Woods LCC = $2,725,116.

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[75] Information received from A. C. Hlavin, Fairfax Planning and Construction, Fairfax County Public Schools, telecon, March 8, 1979.

TABLE 9. HUNTERS WOODS LIFE CYCLE COST BREAKDOWN

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10-49	YEAR 50
R&D	--	--	--	--	--	--	--	--	--	--	--
Investment	$1,250,172	--	--	--	--	--	--	--	--	--	--
O&M	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149
Phase Out	--	--	--	--	--	--	--	--	--	--	$250,234
Total Cost	$1,316,321	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$65,149	$315,383
Inflation Rate	6%	6%	6%	6%	7%	7%	8%	8%	8%	--	--
*Constant Worth Dollars	$2,223,897	$103,838	$97,960	$92,415	$91,375	$85,397	$82,069	$75,990	$70,361	$65,149	$315,383
Discount Factor	0.9091	0.8264	0.6944	0.6830	0.6209	0.5644	0.5131	0.4665	0.4240	4.1660	0.0085
**Present Value	$2,021,745	$85,812	$68,023	$63,119	$56,735	$48,198	$42,110	$35,449	$29,833	$271,411	$2,681

TOTAL LCC = $2,725,116

*Constant Worth Dollars = Total Cost $(1 + \text{Inflation Rate})^n$

$$**P = F \frac{1}{(1 + i)^n}$$

The Terraset LCC is 20 percent more than the Hunters Woods LCC.

The 20 percent increase in LCC must be analyzed in perspective. Terraset utilizes new technologies and must therefore suffer higher front-end (R&D and Investment) costs. With respect to the Burke Center Elementary School, Terraset is a "learning curve" for it. The cost of the first unit (Terraset) is usually higher than the cost of the follow-on units. Fairfax County must decide if the 20 percent increase in LCC is justifiable. The Burke Center school and others following it should be lower in cost.

A gross level analysis is feasible to perform at this point by selecting categories expected to have a major impact on the increase in LCC (other than inflation). Improving the reliability and/or maintainability characteristics in a future design will result in R&D and investment costs which are already too large. Such inprovements will result in lower O&M cost, which is already low - 47 percent lower ($34,839 versus $65,149). For the same reason, it would not be justifiable to attempt to improve Terraset's reliability or maintainability for a cost decrease. Therefore, the conclusion is that a future design should decrease its R&D and investment (construction) costs since the savings in O&M alone do not compensate.

Allocation Procedures

"Allocation procedures involves the allocation of top-level system factors (LCC, A_o, MTBF, MTTR, human factors, safety, etc.) to the various subelements of the system with the objective of providing some definitive guidelines for the designer of each appropriate element."[76]

> There factors must be allocated to lower indenture levels of the system to provide technical parameters and constraints, functional requirements, and design criteria where needed. Otherwise, individual engineering designers assigned to different elements of the system and working independently will establish their own goals, and the results when combined may not comply with the initially established requirements for the overall system. Thus, it is necessary to first establish requirements at the system level and then allocate these requirements to the depth necessary to provide guidance in the design process. Subsequently, as design progresses, it is necessary to check (on a continuing basis) to ensure that the design results at the lower indenture levels are in turn compatible with the overall system requirements.[77]
>
> In summary, the purpose of allocation is to provide, as an input, some guidelines to the design engineer to assist him in developing a product that will be compatible with system requirements. These guidelines may be stated both qualitatively and quantitatively and will vary from system to system. At times, it may be impossible to meet the allocated parameters when considering available technology and tradeoffs must be made with other elements of the system. In such instances, the allocations are revised and the best approach is defined representing a modified baseline. In any event, a baseline of some type must be established before proceeding further.[78]

Therefore, since allocation procedures are a design tool and since Terraset is already designed, the author will not apply this tool of

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[76] Benjamin S. Blanchard, Engineering Organization and Management (Englewood Cliffs, NJ: Prentice-Hall, 1975), p. 128.

[77] Ibid., p. 128.

[78] Ibid., p. 129.

Systems Engineering due to its inappropriateness at this time.

However, again the author feels the responsibility to point out the lack of a previous application of Systems Engineering to Terraset. The use of allocation procedures should have influenced the design process. If this had been done, allocation would have considered all significant system parameters stated in the form of maximum or minimum requirements (with tolerance bands where appropriate) to include:

- System effectiveness factors, such as operational availability, reliability, maintainability and dependability.
- System performance parameters such as efficiency, cost, volume and capacity.
- Factors covering the system support capability, such as supply times between echelons of Fairfax County maintenance, spare/repair parts availability, test and support equipment utilization and availability, facility utilization, personnel effectiveness and maintenance turnaround times.
- Life-cycle cost factors, which include research and development cost, investment or production cost, operation and maintenance support cost, and equipment phase-out and disposal cost.[79]

Technical Performance Measurement

The objective of technical performance measurement (TPM) is to provide a means for providing earliest visibility to the controller of the resources that he or she is or is not going to meet the finite

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[79] Benjamin S. Blanchard, Engineering Organization and Management (Englewood Cliffs, NJ: Prentice-Hall, 1976), p. 129.

performance objectives of a new design with the available resources in the designated time frame.

Specifically TPM:

- Monitors the calculated/measured design parameters and compares these to final values.
- Insures that the status of all parameters are reviewed on a regular basis and that exceptions are highlighted.

As was the case with Allocation Procedures, TPM is clearly a Systems Engineering design tool and the author will not be able to effectively apply it to Terraset, which is already designed.

Again, the author must point out the lack of another instrument in the original design, which should be applied to Burke Center.

The effort thus far concludes one iterative cycle in the Systems Engineering process. For this specific Terraset application the system development process is represented in Figure 7. Terraset Systems Engineering Process.

An effort will now be made to make an iteration back to the start at Needs Analysis. This iteration or feedback loop is done to drive out a complete set of optimized requirements.

Second Iteration

Needs Analysis

The first iteration Needs Analysis, Final Statement of Need (p. 35), can now be modified as follows:

- Define a new instrumentation system for measurement, control and display of temperature, flow rates and power consumption.

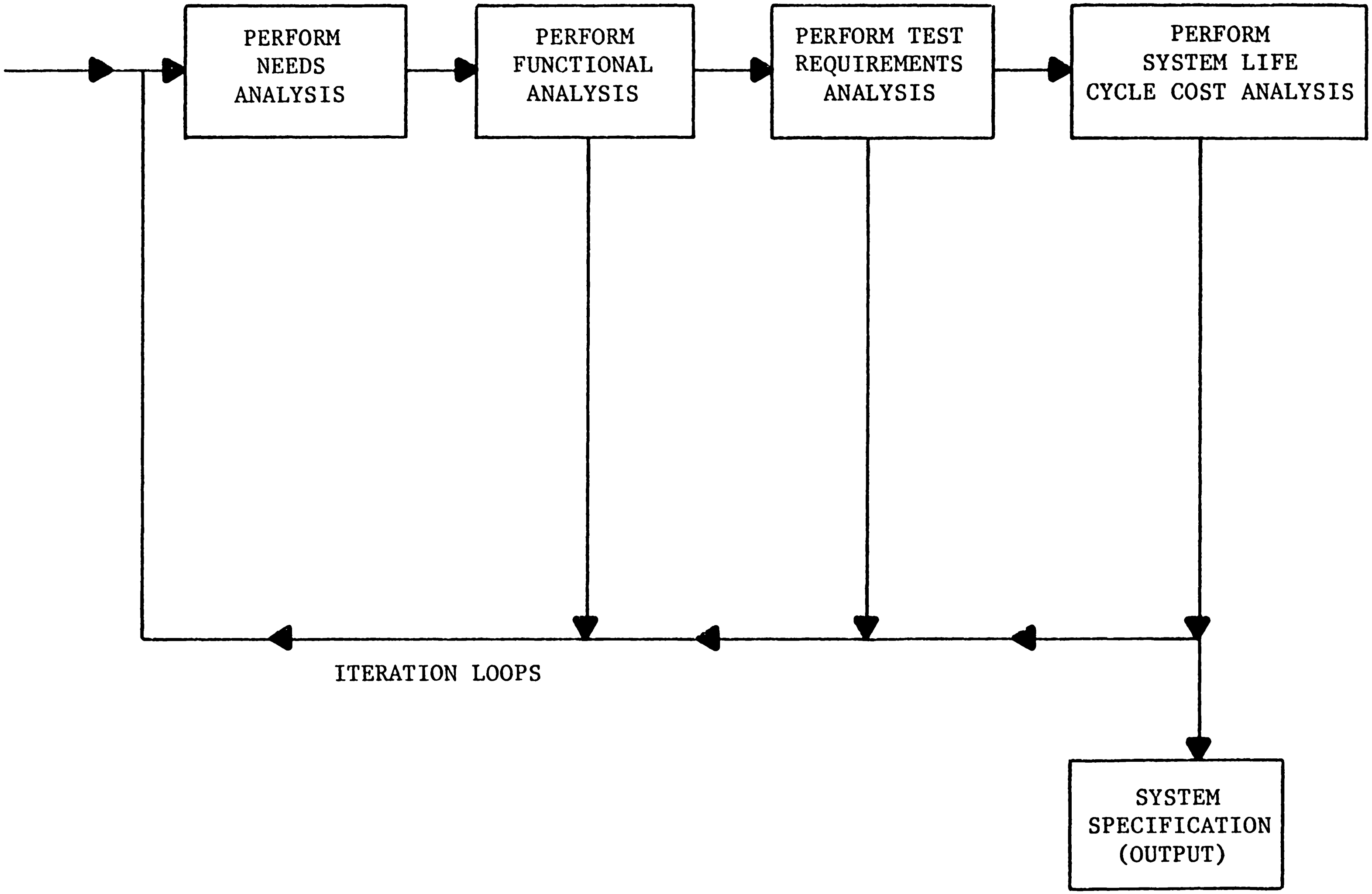

Figure 7. Terraset Systems Engineering Process

- Provide manual override control of the entire heating and cooling system and providing associated procedures.
- Provide for total automatic energy systems management and observation.
- Maintain and strengthen Terraset's good-will image with the community.
- Provide for an NSDAS interface.
- Prepare and publish a complete description and documentation of the facilities.
- Provide the system maintenance requirements.
- Provide recommendations for the Burke Center Elementary School presently under construction.

Simply stated, the Need is to improve the heating and cooling system at Terraset and to assist it in becoming a viable research vehicle for optimum energy management.

The System Model developed in the first iteration is acceptable as it now stands.

The author will now present a list of potential improvements to the system as a result of examination of the System Model and the rest of the thesis:

1. From the "Set of Undesired Outputs, No. 8, ventilated heat" investigate routing the ventilated heat back into the system instead of venting it to the atmosphere.
2. From the "Set of Undesired Outputs, No. 10, hot water expelled to environment from the Hi-Temp Solar Tank" investigate the

possible polluting effects this may be having on the nearby environment (assuming this hot water must be vented).

3. Investigate the use of solar hot water from the High Temperature Thermal Storage Tank or the 3 storage tanks for domestic hot water use versus the electric heating method now used.
4. Investigate heating water electrically at night and then storing in the High Temperature Thermal Storage Tank, Low Temperature Storage Tank and the 3 storage tanks at economical electricity rates for use the next day.

Functional Analysis

It is the author's intent in this second iteration to satisfy one or more items in the requirement list from the first iteration. The items will be chosen based on the author's interest, areas of engineering expertise and again, expediency.

The first requirement chosen is entitled: "a display for public viewing and education." The author feels the public can best be educated about Terraset operations with a dynamic display as shown in Figure 8, Terraset Display for the Public.

All "ON/OFF" and "HOT/COLD" indications and numerical readouts are intended to be LED type displays. As well as receiving a total picture of Terraset operations, the viewer can compare operating costs to Hunters Woods.

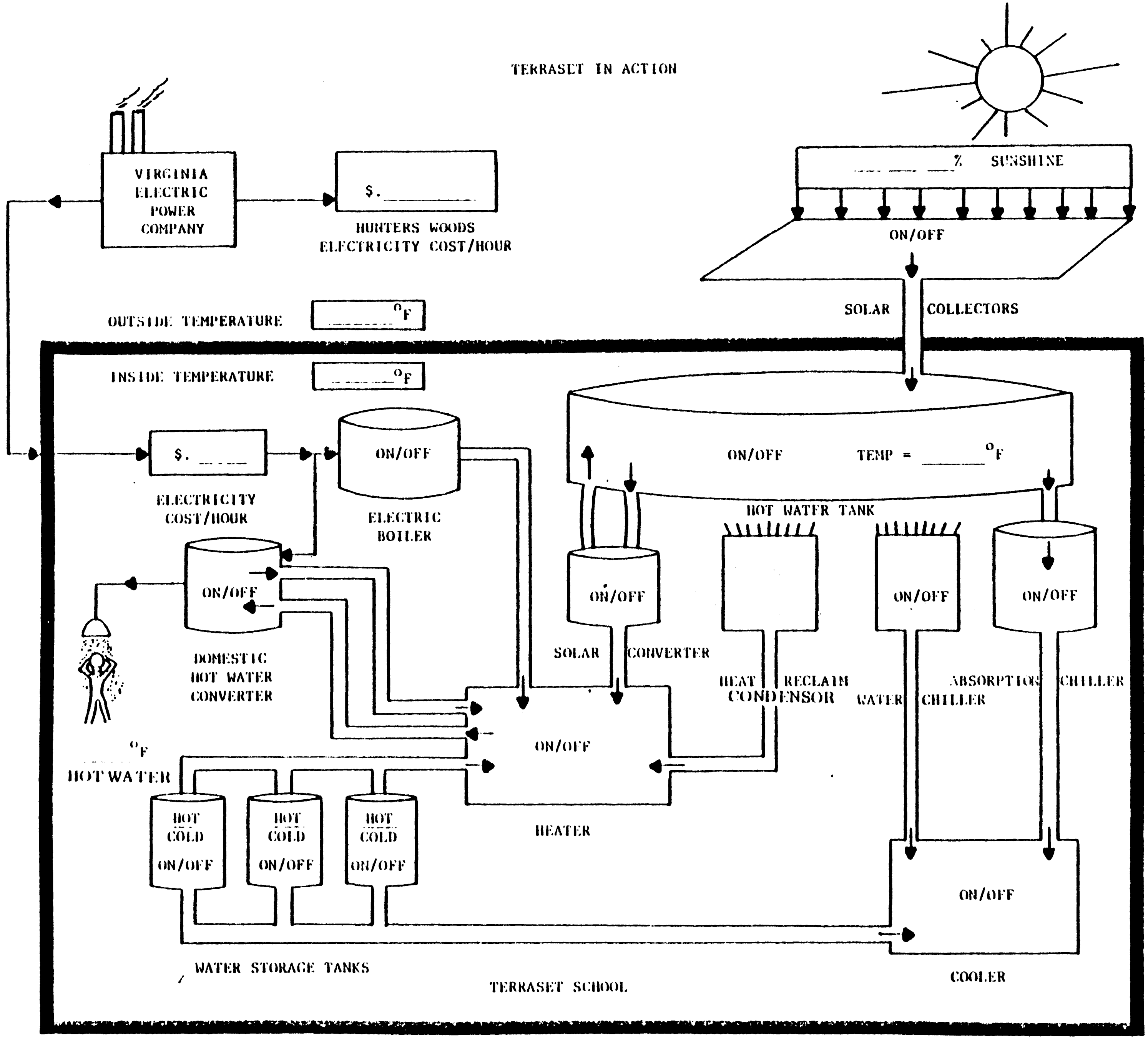

Figure 8. Terraset Display for the Public

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DISCUSSION

Terraset, which is performing simultaneously as a school and an R&D vehicle, was not Systems Engineered from its inception. The Needs Analysis and Functional Analysis of the Results section yielded an extensive list of neglected requirements. The complete list of requirements follows:

1. Parameter list to achieve a total automatic energy systems management.
2. Heat balance analysis for system optimization when in automatic control.
3. Tree-diagram logic flow for the system optimization when in automatic control.
4. Control valve list to achieve system optimization when in automatic control.
5. System display layout design to include parameters required to achieve total automatic energy systems management.
6. System display layout design to include control valves required to achieve total automatic energy systems management - to be combined with number 5 (preceding).
7. Single-point failure analysis for entire system.
8. Contingency procedures for hardware single point failures.
9. A display for management decision making.
10. A display for public viewing and education.
11. Accuracy tolerances for system parameters.
12. Support requirement.
13. Logistic resources defined.
14. Preventive maintenance procedures.

15. Bench test procedures.

16. Servicing defined.

17. Inspections for tests defined.

Terraset is a bold step in energy management. Any new undertaking in the forefront of technology is risky because of the large amount of R&D, and Investment funding required at the start of a program without any guarantee that the system will function as an efficient school. Fairfax County can optimize Terraset by utilizing Systems Engineering. However, the results of this thesis should be applied as soon as possible to both Terraset, to catch up (to reach the technological point Terraset would be at if a Systems Engineer were on the program from the beginning), and to new applications.

Additionally, the contents of Appendix 2 (Work Breakdown Structure and Task Descriptions) are applicable to Burke Center. The Work Breakdown Structure links objectives and activities with resources and can be the management tool for program planning, monitoring and control since it is iterative and can continue to evolve as the program evolves. The Task Descriptions completely define each element in the Work Breakdown Structure.

CONCLUSIONS

Fairfax County has several problems with the Terraset School. The major ones are:

- No thermal analysis for optimum energy management.
- No contingency procedures for single point failures.
- No display for management decision making.
- No display for public viewing and education.
- No preventive maintenance procedures.
- No testing procedures.
- No inspections defined.

This Systems Engineering effort should be continued to insure optimum operation of the school, both for educational purposes and as an R&D vehicle.

A Systems Engineer should be assigned to the Burke Center effort as soon as possible.

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APPENDIX 1

30 September 1977

Director, Engineering Extension in Northern Virginia
Dulles International Airport
Washington D.C. 20041

Attn: Dr. D.L. Michaelson

Subj: "The Simulation and Optimization at the Terraset School Heating System Equipped with Solar Assist," Unsolicited Proposal - - Statement of Work; submittal of.

Encl: (1) "The Simulation and Optimization of the Terraset School Heating System Equipped with Solar Assist", Unsolicited Proposal - - Statement of Work.
(2) Resume et Mr. O'Neil.

1. Enclosure (1) is the proposed statement of work anticipated for William J. O'Neil for a Masters Degree Thesis. Mr. O'Neil will be representing himself as a student and a Class A Consultant or a student and an incorporated business. The proposed statement of work is for systems engineering, technical and program management support to VPI and the Terraset Foundation.

2. Mr. O'Neil has extensive experience in systems engineering. His relevant experience was in the Apollo Program as well as his current support to the U.S. Navy. Please refer to Enclosure (2) for details. At the present time Mr. O'Neil is engaged in performing almost identical program management and in providing technical support for three programs for the U.S. Navy.

3. For any additional information please contact the undersigned,

William J. O'Neil

THE SIMULATION AND OPTIMIZATION
OF THE
TERRASET SCHOOL HEATING SYSTEM EQUIPPED WITH SOLAR ASSIT

UNSOLICITED PROPOSAL
Submitted by

WILLIAM J. O'NEIL
6 Running Brook Lane
Sterling, Virginia 22170

STATEMENT OF WORK

Mr. O'Neil will provide systems engineering, technical and program management assistance to VPI and the Terraset Foundation as required for the Terraset School Heating System.

The general categories of support services include:

° Program Management Support

- Budget Planning
- Budget Execution
- Coordination and Liaison
- Program Management Analysis
- Technical and Engineering Management Analysis

° System Requirements Definition

° Configuration Management

- Needs Analysis
- Functional Analysis
- Configuration Identification
- Configuration Control
- Documentation
- Record Keeping

° Development of Preliminary Design Concepts

° System Synthesis and Optimization

° Detailed Design Definition

° Development of Operational and Simulation Concepts

The Technical and Engineering assistance to be provided will include, but not be limited to the following:

° Provide a Management Plan

° Provide a Work Breakdown Structure

° Provide an Organization Chart

- Compile, review and utilize appropriate documention from ERDA-SOLAR and associated periodicals
- Provide and maintain a design history
- Evaluate the durrent monitoring and control logic
- Define requirement for the new Sunkeeper type hardware
- Define interface requirements for the Sunkeep System, new hardware, central processor, simulator and Accurex System
- Dument a system level handbook
- Define requirements for the simulator
- Develop testing requirements and procedures
- Conduct presentions and briefings

RESUME

William J. O'Neil
6 Running Brook Lane
Sterling, Virginia 22170
(703)430-6918

Date of Birth: Sept. 6, 1944
Height: 6'1"
Weight: 165 lbs.

EDUCATION: R.C.A. Institutes, Incorporated, New York, New York
Graduated, 1966. Electronics Technology

New York University, Bronx, New York
Graduated, 1969. Bachelor of Engineering (Electrical Engineering

Virginia Polytechnic Institute and State University
College of Engineering, Reston, Virginia
Candidate for Master of Systems Engineering Degree

EXPERIENCE:

1976 to Present — Scientific Management Associates, Riverdale, Md. - Senior Systems Engineer. Providing systems engineering, product assurance, ship installation and life cycle cost support to Ford Aerospace and Communications Corp. for the SEAFIRE Program.

1972 to 1976 — Vitro Labs, Silver Spring, Md. - System Integration Section, Project Leader, Software integration. Responsible for the System Functional Diagram representation of the computer software for the Gunnery Improvement Program and MK 92 Program. In addition, was responsible for the total MK 92 effort. As a systems engineer, my specific responsibilities included system level problem solving, ECP review and software analysis. As a result, was in daily contact with the programming facility and land based test site at Dahlgren. Also responsible for scheduling, budget estimations and personnel evaluation.

Prior to this assignment, was responsible for conducting an R & D program entitled "Investigation of Switching Requirements for Future Combat Systems".

1968 to 1972 — Grumman Aerospace Corporation, Bethpage, N.Y. - Electrical Engineer, Lunar Module (LM): As a member of the LM Crew Systems Group, was responsible for nominal and malfunction procedures used by the astronauts, for coordination of related groups within Grumman and with my counterparts in NASA and for support of Apollo missions. Support of Apollo missions consisted of system level problem solving constrained by a three hour turn-around time.

1967 to 1969 — New York University, Language Laboratory, Bronx, N.Y. - Consulting Engineer. Successively became technician, Chief Technician and Consulting Engineer during which time was responsible for management of a solid-state, sixty position, remote tape recorder system including the supervision of twenty technicians. Was able to formally increase the scope of my function as contact with the installing company to the extent of substantially reducing their need and cost to the University.

INTERESTS: I am primarily interested in photography, sports cars and reading.

PROFESSIONAL MEMBERSHIPS: The American Society of Naval Engineers.

APPENDIX 2

6 Running Brook Lane
Sterling, Virginia 22170

25 October 1977
T-002

Engineering Extension Representative,
Northern Virginia
400 West Service Road
Dulles International Airport
P.O. Box 17186
Washington, D.C. 20041

ATTN: Dr. D. L. Michelsen

Subj: "The Simulation and Optimization at the Terraset School Heating System Equipped with Solar Assist", Unsolicited Proposal -- Task Descriptions; submittal of.

Ref: (a) Telephone conversation between D. L. Michelsen and W. J. O'Neil, 17 October 1977.

(b) W. J. O'Neil letter dated 30 September 1977.

Encl: (1) "The Simulation and Optimization of the Terraset School Heating System Equipped with Solar Assist", Task Descriptions.

1. Enclosure (1) is the development of Task Descriptions based on the proposed Statement of Work in Ref(b).

2. For any additional information please contact the undersigned.

William J. O'Neil

cc: Dr. D. R. Drew
Prof. E. Peterson
Mr. Alton Hlavin
File - 2 copies

Task Descriptions

Systems engineering of the Terraset School heating system requires the development of a program management structure capable of directing the program from design development, construction, testing, operations, maintenance and disposal.

The individual work packages will be ultimately combined and integrated with the project work breakdown structure (WBS) which was specified as the second item of "technical and engineering assistance" in the SOW, Ref (b). The WBS links objectives and activities with resources and will be the management tool for program planning, monitoring and control since it is iterative and will continue to evolve as the program evolves. Following the development of the preliminary WBS, the individual task descriptions will be formulated.

Therefore, a preliminary WBS for levels 1, 2 and 3, based on MIL-STD-881 and the draft proposal, is offered as follows:

1A0.0

TERRASET SOLAR HEATING SYSTEM

- 2A1000 System/Project Management
  - 3A1100 Systems Engineering Management
  - 3A1200 Integrated Logistics Support
  - 3A1300 Human Factors
  - 3A1400 Public Relations
  - 3A1500 System Test and Evaluation
  - 3A1600 Data Depository
  - 3A1700 Operating Procedures
  - 3A1800 Maintenance Procedures
- 2A2000 Electrical Engineering
  - 3A2100 Sunkeeper System Hardware.
  - 3A2200 Mini Computer Hardware
  - 3A2300 Simulator Hardware
  - 3A2400 Accurex System Hardware
  - 3A2500 New electronic measurement and control system hardware
- 2A3000 Mechanical/Chemical Engineering
  - 3A3100 Honeywell System Hardware
  - 3A3200 Design Data
  - 3A3300 Reliability
  - 3A3400 New thermal energy alternatives
  - 3A3500 Maintainability
- 2A4000 Computer/Software Engineering
  - 3A4100 Simulator Software
  - 3A4200 Mini Computer Software
  - 3A4300 Software evaluation of thermal performance
- 2A5000 Thermal Instrumentation and Control Engineering
  - 3A5100 Energy Balance
  - 3A5200 Simulator Hardware
  - 3A5300 Testing
  - 3A5400 Data Collection
  - 3A5500 NDA - Interface

TASK NO.	TITLE/DESCRIPTION
3A1100	Systems Engineering Management.

This element refers to the systems engineering management effort of directing and controlling a totally integrated engineering effort including systems engineering, design engineering and specialty fields (e.g. human factors). Specifically, this includes the system engineering effort to:

a. Transform the primitive statement of need of the Terraset Foundation of simulating and optimizing the Terraset School heating system into an appropriate functional description and systems delineation through the use of an iterative process of definition, needs analysis, functional analysis, synthesis, design, test and evaluation.

b. Integrate the Honeywell HVAC system, Sunkeeper System, the new system hardware, the mini-computer and the Accurex system to optimize the total system definition and design.

c. Develop integrated logistic support, human factors, community relations, reliability, maintainability, intersystem compatibility analysis, and prepare subsystem performance specifications.

3A1200 Integrated Logistics Support.

The integrated logistics support element refers to all the support considerations necessary to assure the effective and economical support of the Terraset School for its life cycle. This element specifically includes:

TASK NO.	TITLE/DESCRIPTION
	a. Maintenance planning for all hardware sub-systems. b. Specification of test and support equipment. c. Supply support. d. Technical data. e. Personnel and training.
3A1300	Human Factors. This element refers to the compatibility between the system physical and functional design features and the operators in the operation, maintenance and support of the Terraset School.
3A1400	Public Relations. The public relations element refers to: a. Fairfax County's five-year responsibilities. b. Reports and publications required for architects, engineers and the general public. c. Workshops, training courses and seminars for domestic and foreign scholars, professionals in the field, government officials and other interested persons. d. Liaison between the Terraset Foundation, VPI&SU, NDAS and hardware manufacturers.
3A1500	System Test and Evaluation. This element refers to the use of the existing hardware as well as the required hardware to obtain as well as validate engineering data on the performance

TASK NO.	TITLE/DESCRIPTION
	of the heating system. This element includes the detailed planning, conduct, support, data reduction and reports from: a. The energy balances. b. Calibration of monitoring and control equipment. c. Installation of new hardware. d. Integration of the entire system. e. Simulation runs. It also includes all effort associated with the design and construction of special equipment in support of the test program.
3A1600	Data Depository. The data depository element refers to VPI&SU to act as custodian in establishing and maintaining a master engineering specification and drawing depository service for approval documents that are the property of the Terraset Foundation.
3A1700	Operating Procedures This element refers to the construction of a system level document that would detail the optimum procedural steps to follow under varying conditions to insure economic operation of the Terraset School.
3A1800	Maintenance Procedures. The maintenance procedures element refers to the required maintenance actions to be performed to insure

TASK NO.	TITLE/DESCRIPTION
	economic and reliable operation of the Terraset School. Maintenance procedures will cover:

a. All significant repairable items.

b. All maintenance requirements (i.e., trouble shooting, remove and replace, repair, servicing, alignment and adjustment, functional test and check-out, inspection, calibration, overhaul and the like).

3A2100 Sunkeeper System Hardware.

This element refers to familiarization with the Sunkeeper monitoring and control system. This element carries with it the responsibility of integrating the Sunkeeper to all new and existing hardware and software.

3A2200 Mini Computer Hardware.

The mini computer hardware element refers to the probable need of a computer to coordinate the automatic functions of the heating system, perform data performance evaluation computations and perform calculations for the proposed system simulator. This element carries with it the responsibility of hardware specification for the computer as well as integration to new and existing hardware.

TASK NO. TITLE/DESCRIPTION

3A2300 Simulator Hardware.

This element refers to the system simulator for the complete HVAC with solar assist process for demonstration, educational and engineering optimization studies. The simulator will be developed to permit study of day-night, winter-summer and change in load conditions without altering the school system when in operation. Considerations must be made for all variables and transients in a total solar-plus energy system. Specifically, it could be used as an educational device to examine alternate control strategies as well as to vary cost parameters. In addition, considerable flexibility on input and output should be included to provide for optimization studies.

3A2400 Accurex System Hardware.

The Accurex system hardware element refers to the system hardware used for data collection and transmission to the Nation Data Acquisition System. This element carries with it the responsibility to interface the Accurex system to new hardware and software.

3A2500 New Electronic Measurement and Control System Hardware.

This element refers to the new system intended to replace the Honeywell pneumatic system. An A and E

TASK NO.	TITLE/DESCRIPTION

firm should be selected to carry out the conversion. This element carries with it the responsibilities of defining the hardware specifications, assisting with acceptance and system level tests and assisting with the energy balances.

3A3100 Honeywell System Hardware.

This element refers to a familiarization with the existing HVAC system installed. This element carries with it the responsibilities for an evaluation of the system measurements needed to complete an energy balance, data collection for calibration and performance evaluation, presentation of results and, finally, recommendations for changes and improvements in measurement and control.

3A3200 Design Data.

The design data element refers to the schematics, drawings, associated lists, specifications and other documentation required for the systems engineering effort. This element includes all plans, procedures, reports and documentation pertaining to systems, subsystems, component engineering and testing.

3A3300 Reliability.

The reliability element refers to the requirement to alter the instrumentation and control to provide for

TASK NO.	TITLE/DESCRIPTION
	reliable operation long into the future. This element will focus on component reliability as well as the backup philosophy.
3A3400	New Thermal Energy Alternatives. This element refers to the formalized procedures of systems engineering that will be utilized to select the most optimum system. Initially, replacement of the Honeywell system will be evaluated. If this is demonstrated to be appropriate, alternate energy alternatives will be examined, such as: a. Heat pumps. b. Solar panels. c. Modifications to existing solar panels.
3A3500	Maintainability. The maintainability element refers to the design for supportability. The Terraset School HVAC system must be designed for ease of maintenance long after the specialists of the systems engineering team have completed their efforts.
3A4100	Simulator Software. This element refers to the development of a computer program design specification, computer program performance specification, math model and software for the simulator. The software will be dedicated to

TASK NO.	TITLE/DESCRIPTION

demonstration, educational and engineering optimization studies.

3A4200 Mini Computer Software.

This element refers to the development of a computer program design specification, computer program performance specification, math model and software for the mini computer. The software will be dedicated to the optimal scheduling of the thermal subsystems data cycle.

3A4300 Software Evaluation of Thermal Performance.

This element refers to the development of a computer program design specification, computer program performance specification, math model and software for the mini computer. The software will perform calculations to determine performance and make the necessary calculations for the energy balance.

3A5100 Energy Balance.

The energy balance element refers to the calculations necessary to evaluate the entire HVAC system now and after it is system engineered under varying climatic heating and cooling load conditions to verify and define key performance and control variables.

3A5200 Simulator Hardware.

The simulator hardware element refers to the specifi-

TASK NO.	TITLE/DESCRIPTION
	cations required for simulation hardware. The hardware will have suitably displayed results so that it can be used in the tour center. It will have the capability to simulate day-night, winter-summer and changes in load. As an educational device alternate control strategies and cost parameters will be inputs which can be varied. In addition, considerable flexibility on input and output will be included to provide for optimization studies.
3A5300	Testing. This element refers to test planning to acquire engineering data and confirm engineering hypotheses.
3A5400	Data Collection. The data collection element refers to the compilation of data regarding the checking and recalibration of the monitoring and control equipment, energy balances, NDAS, and simulations.
3A5500	NDAS Interface. The NDAS interface element refers to the interface required for the transmission of data to NDAS, according to NB SIR 76-1137.

Regarding the author's participating in the Terraset Program, it is strongly felt that the minimum number of elements from the WBS to complete a rigorous and personally satisfying Masters Degree thesis are the following:

1. 3A1100 Systems Engineering Management
2. 3A1200 Integrated Logistics Support
3. 3A1300 Human Factors
4. 3A1500 System Test and Evaluation
5. 3A3300 Reliability
6. 3A3500 Maintainability
7. 3A2200 Mini Computer Hardware
8. 3A2300 Simulator Hardware
9. 3A2500 New Electronic Measurement and Control System Hardware
10. 3A3200 Design Data
11. 3A3400 New Thermal Energy Alternatives

It should be noted that a time restriction on effort has not been set. Therefore, the author anticipates reception of a fee should VPI&SU, in conjunction with the Terraset Foundation, concur that more than the equivalent of 15 credits work is involved with the program, at a minimum.

APPENDIX 3

6 Running Brook Lane
Sterling, Virginia 22170
home no. (703)430-6918
work no. (301)779-6240

28 November 1977
T-003

Director, Educational Facilities Planning
and Construction
Fairfax County Public Schools
10700 Page Avenue
Fairfax, Virginia 22030

ATTN: Mr. A. Hlavin

Subj: Terraset School, Proposed Masters Degree Thesis for

Ref: (a) Luncheon meeting 15 Nov. 1977 with Don Michelsen, Al Hlavin and Bill O'Neil

(b) Terraset Project, Outline for Research and Development Proposal, D.L. Michelsen, 11 Nov. 1977

(c) The Simulation and Optimization of the Terraset School Heating System Equipped with Solar Assist, Task Descriptions, W. J. O'Neil, T-002, 25 October 1977

Encl: (1) VPI Systems Engineering Masters Degree Thesis Proposal for the Terraset Project

1. Enclosure (1) is a Thesis Proposal based on the discussions in Ref (a), the draft proposal in Ref (b) and the work breakdown structure and task descriptions in Ref (c).

2. At this point in the program, the undersigned requests that Mr. A. Hlavin be a member of Mr. W. O'Neil's Thesis Advisory Committee. This would add the flavor of the construction aspect of the program to the committee.

3. For any additional information please contact the undersigned.

W. J. O'Neil

cc: Dr. D. Michelsen
Dr. D. Drew
Prof. E. Peterson
File - 2 copies

Proposed Masters Degree Thesis For The Terraset School

Thesis: Systems Engineering Applied to School Construction

1. Definition of Systems Engineering.
2. Definition of Systems Engineering with respect to construction and the Terraset School application.
3. A literature search on the subject of total energy balance and systems management of similar applications.
4. Perform a Needs Analysis resulting in a system model and system constraints (a performance specification).
5. Perform a Functional Analysis to determine system requirements.
6. Outline system level test requirements.
7. Serve as a design monitor for all disciplines.
8. Determine the Critical Path and Necessary Path for the entire construction process.
9. Calculate estimates for all stochastic parameters.

Note: The anticipated effort for the thesis is the first year of the five year program.

APPENDIX 4

6 Running Brook Lane
Sterling, Virginia 22170
Home No. (703) 430-6918
Work No. (301) 779-6240

12 January 1978
T-004

Dr. Donald L. Michelsen, Director
Engineering Program in Northern Virginia
Dulles International Airport
Gateway One Building
P.O. Box 17186
Washington, D.C. 20041

Attn: Dr. D. L. Michelsen

Subj: "The Terraset School, Expanded Masters Degree Thesis Proposal for".

Ref: (a) The Simulation and Optimization of the Terraset School Heating System Equipped wiht Solar Assist, Unsolicited Proposal - - Task Descriptions; submittal of, W. J. O'Neil

(b) Terraset School, Proposed Masters Degree Thesis for, W. J. O'Neil, T-003 28 November 1977.

(c) Telephone conversation between D. L. Michelsen and W. J. O'Neil, 2 December 1977.

Encl: (1) VPI Systems Engineering Masters Degree Expanded Thesis Proposal for the Terraset Project

1. Enclosure (1) is an Expanded Thesis Proposal based on the descriptions in Ref (a) and Ref (b) as well as the discussion in Ref (c).

2. For any additional information please contact the undersigned.

William J. O'Neil

cc: Dr. D. R. Drew
Prof. E. Peterson
Mr. Alton Hlavin
File - 2 copies

Expanded Masters Degree Thesis Proposal
For the Terraset School

Thesis: Systems Engineering Applied to the Terraset School Construction

1. Definition of Systems Engineering.

   The Systems engineering process and the systems approach will be defined. This will be a very complete but general definition. The VPI & SU originated concept of the S-T-E-P Process will serve as the overall backbone of the definition. In addition, the thesis effort will be traced and documented from time T=0. This unique, approach will serve to demonstrate both the iterative process involved in systems engineering as well as to demonstrate the real world problems of starting a systems engineering effort.

2. Definition of Systems Engineering with respect to construction and the Terraset School application.

   Traditionally systems engineering has been the tool of production. Therefore, any changes to the previously stated definition necessary will be called out and highlighted. In particular, the new facets of the definition that have particular impact upon the Terraset School application will be pointed out.

3. Perform a Needs Analysis resulting in a system model and system constraints (a performance specification).

   The Needs Analysis will take the statement of need for the program as provided by Fairfax County or VPI. The statement of need will then be transformed, via the systems engineering process, into a system model. The model will contain:

   a. The set of inputs to the system
   b. The set of desired outputs
   c. The set of un-desired outputs
   d. The set of Figures of Merit

The model will then be used to produce the system constraints:

a. Constraints on the input

b. Constraints on the output

C. Constraints on the system

The model and its constraints will then be the performance specification for the system.

5. Perform a Functional Analysis to determine system requirements. The results of the Needs Analysis will be translated into Functional Flow Diagrams. The Functional Flow Diagrams will be developed for the primary purpose of structuring system requirements into functional terms, with the main emphasis on accuracy and completeness. The functional diagrams will be a block diagram portrayal of the functions which must be met to satisfy the total system needs. The functional diagrams will, in turn, be used to develop an operational requirements matrix and a maintenance function matrix. The requirements matrices results will then be used, in an iterative manner, to close the loop back to the operational need.

6. Outline system level test requirements. Test requirements will be determined from an analysis of the performance specification. In other words, the testing requirements will ensure that the previously defined performance parameters can be achieved. This is also an iterative process in that design parameter magnitudes may have to be changed to reflect testing results.

7. Serve as a design monitor for all disciplines. The construction process will be monitored for completeness using the previously developed (William O'Neil letter, 25 October 1977, T-002) Work Breakdown Structure and Task Descriptions.

8. Determine the Critical Path and Necessary Path for the entire construction process.

A PERT Flow plan will be utilized to determine the scheduling structure of the construction effort as well as to identify the critical activities that would effect project completion the most (Critical Path). In addition, Necessary Paths will be identified so that simultaneous construction activity can take place.

9. Calculate estimates for all stochastic parameters.

The stochastic type system parameters will be identified. Then the probability of each one, followed by a system probability will be estimated.

APPENDIX 5

6 Running Brook Lane
Sterling, Virginia 22170
Home No. (703) 430-6918
Work No. (301) 779-6240

1 March, 1978
T-005

Dr. Donald L. Michelsen, Director
Engineering Program in Northern Virginia
Dulles International Airport
Gateway One Building
P.O. Box 17186
Washington, D.C. 20041

Attn: Dr. D. L. Michelsen

Subj: "The Terraset School, Expanded Masters Degree Thesis Proposal for"

Ref: (a) Meeting between D. L. Michelsen, E. Peterson, B. Blanchard and W. J. O'Neil, 22 February 1978.

Encl: (1) VPI Systems Engineering Masters Degree Expanded Thesis proposal for the Terraset Project (Revision A)

1. Enclosure (1) is an Expanded Thesis Proposal based on the discussion in Ref (a).

2. For any additional information please contact the undersigned.

William J. O'Neil

WO'N/drb

cc: Dr. D. R. Drew
Prof. E. Peterson
Mr. Alton Hlavin
Mr. Anthony Martin
File - 2 copies

Expanded Masters Degree Thesis Proposal
For the Terraset School
Revision A

Thesis: Systems Engineering Applied to the Terraset School

1. Definition of Systems Engineering.

   The Systems engineering process and the systems approach will be defined. This will be a very complete but general definition. The VPI & SU originated concept of the S-T-E-P Process will serve as the overall backbone of the definition. In addition, the thesis effort will be traced and documented from time T=0. This unique, approach will serve to demonstrate both the iterative process involved in systems engineering as well as to demonstrate the real world problems of starting a systems engineering effort.

2. Application of Systems Engineering to Terraset.

   The application of the S-T-E-P process to Terraset will be performed. This will consist of also applying the standard techniques of problem identification etc. to the design process. At this point, the preliminary design configuration will be defined.

3. Perform a Needs Analysis resulting in a system model and system constraints (a performance specification).

   The Needs Analysis will take the statement of need for the program as provided by Fairfax County or VPI. The statement of need will then be transformed, via the systems engineering process, into a system model. The model will contain:

   a. The set of inputs to the system
   b. The set of desired outputs
   c. The set of un-desired outputs
   d. The set of Figures of Merit

The model will then be used to produce the system constraints:

a. Constraints on the input

b. Constraints on the output

c. Constraints on the system

The model and its constraints will then be the performance specification for the system.

i. Perform a Functional Analysis to determine system requirements.

The results of the Needs Analysis will be translated into Functional Flow Diagrams. The functional Flow Diagrams will be developed for the primary purpose of structuring system requirements into functional terms, with the main emphasis on accuracy and completeness. The functional diagrams will be a block diagram portrayal of the functions which must be met to satisfy the total system needs. The functional diagrams will, in turn, be used to develop an operational requirements matrix and a maintenance function matrix. The requirements matrices results will then be used, in an interative manner, to close the loop back to the operational need.

. Outline system level test requirements.

Test requirements will be determined from an analysis of the performance specification cost, time and availability. In other words, the testing requirements will ensure that the previously defined performance parameters can be achieved. This is also an iterative process in that design parameters magnitudes may have to be changed to reflect testing results.

. Serve as a design monitor for all disciplines.

The construction process will be monitored for completeness using the previously developed (William O'Neil letter, 25 October 1977, T-002) Work Breakdown Structure and Task Descriptions. This acitivity will also be interative and result in change analysis of the initial design.

. Determine the Critical Path and Necessary Path for the entire construction process.

A PERT Flow plan will be utilized to determine the scheduling structure of the construction effort as well as to identify the critical activities that would effect project completion the most (Critical Path). In addition, Necessary Paths will be identified so that simultaneous activity can take place.

. Calculate estimates for all stochastic parameters.

The stochastic type system parameters (e.g. electrical power and thermal requirements) will be identified. Then the probability of each one, followed by a system probability will be estimated.

. Expected Products

a. Statement of Need
b. Performance Specification
c. Maintenance Concept
d. Test Requirements
e. Design Configuration/Change Analysis
f. PERT Charts
g. Data Format and Analysis for Transmission to NSDAS

APPENDIX 6

6 Running Brook Lane
Sterling Virginia 22170
Work No. (301) 779-6240
Home No. (703) 430-6918

30 March 1978
T-006

Dr. Donald L. Michelsen, Director
Engineering Program in Northern Virginia
Dulles International Airport
Gateway One Building
P.O. Box 17186
Washington, D.C. 20041

Attn: Dr. D. L. Michelsen

Subj: "Practical Utilization of the 'Expected Products' of a VPI & SU Masters Degree Thesis Entitled: Systems Engineering Applied to the Terraset School".

Ref: (a) Telephone conversation between D. L. Michelsen and W. J. O'Neil, 6 March 1978.

1. Enclosure (1) is a suggested description of the practical use of the results of W. J. O'Neil's Masters Degree Thesis entitled: Systems Engineering Applied to the Terraset School.

2. Enclosure (2) is the costing breakdown for the Thesis and Expected Products.

3. For any additional information please contact the undersigned.

William J. O'Neil

WO'N/drb

cc:
Dr. D. R. Drew
Prof. E. Peterson
Mr. Alton Hlavin
Mr. Anthony Martin
File - 2 copies

PRACTICAL UTILIZATION OF THE "EXPECTED PRODUCTS" OF A VPI & SU MASTERS DEGREE THESIS ENTITLED: SYSTEMS ENGINEERING APPLIED TO THE TERRASET SCHOOL

Since the Terraset Foundation will have to purchase hardware,the optimum decision must rest on the functions that have been assigned the anticipated new Terraset School configuration to satisfy the objectives of its educational role. This should start with prestated performance and operational requirements in order to judge the design effectiveness of the new design. This is the purpose of first Expected Product, the Statement of Need.

In addition, design effectiveness can only be appraised in terms of the system requirements, not general design specifications. This performance specification will permit deriving and evaluating alternate design deisions. Unless the new hardware satifies the functions for which it is designed and can operate within specified performance and design constraints it will be nonfunctional. This is the purpose of the second Expected Product, the performance specification.

Additionally the maintenance concept must be defined so that initial design requirements and support criteria can evolve. This is the purpose of the third Expected Product, the Maintenance Concept.

In like manner, test criteria are required to accomplish both the operational and maintenance funtions that have been previously defined. This is the purpose of the fourth Expected Product, the Test Requirements.

The system design process is not a one-way street from (1) specification of functions to (2) performance standards and to (3) final design configuration. The system designer must go through a continuous and repeated process of progressive comparison between (1) stated functions (2) performance standards and (3) proposed design criteria. This system of check, compare, readjust, recheck, recompare and readjust is embeded in the fifth Expected Product, the Design Configuration/Change Analysis item.

In order to determine the probability of meeting specified deadlines, to identify the activities which are most likely to be bottlenecks and to evaluate the effect of changes in the program the sixth Expected Product, PERT charts were established.

Finally, an analysis of the data requirements for NSDAS will be made. This is the purpose of the seventh Expected Product, Data Format and Analysis for Transmission to NSDAS.

Costing for Expected Products
of Thesis Entitled:
Systems Engineering Applied to the Terraset School

March 1978 - March 1979

1. Statement of Need
2. Performance Specification
3. Maintnnance Concept
4. Test Requirements
5. Design Configuration/Change Analysis
6. PERT Charts
7. Data Format and Analysis for Transmission to NSDAS
8. Typing
9. Reproduction
10. Travel from Sterling to Reston

14 Months @ 8 hrs/week	
@ $10/hr	$4,480.00
Typing	$ 600.00
Reproduction	$ 60.00
Travel	$ 25.00
	$5,165.00

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the scanned document

SYSTEMS ENGINEERING APPLIED TO
THE TERRASET SCHOOL

by

William John O'Neil

(ABSTRACT)

Systems Engineering was applied to Terraset, a school underground, heated and cooled via the sun. The Systems Engineering process (since it occurred after design) consisted of Needs Analysis, Functional Analysis, Test Requirements Analysis and System Life Cycle Cost Analysis. The school had never been Systems Engineered and the processes revealed a long list of requirements still lacking. The results of the thesis are applicable to a new design taking place at the Burke Center Elementary School.