MRI/SOL--0800-05

DE86 001273

Solar Controlled Environment Agriculture Project

FINAL REPORT

Volume 5
Science Applications, Incorporated System Requirements Definition

Published for the
United States - Saudi Arabian Joint Program
for Cooperation in the Field of Solar Energy
SOLERAS

by the Program Operating Agent
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110 USA

Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A07

Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

FOREWORD

THE SOLERAS PROGRAM: A UNIQUE EFFORT IN COOPERATIVE SOLAR ENERGY RESEARCH

In October 1977, Saudi Arabia and the United States signed a Program Agreement for Cooperation in the Field of Solar Energy The Program, named SOLERAS, is the first of its kind in purpose, funding organization, and results It is based on the respective commitments of the United States and Saudi Arabia to advance the development of solar energy as a viable cost-competitive energy alternative by combining the technical and other unique resources of each country SOLERAS has made significant progress in demonstrating the effectiveness of solar energy—progress that would have been difficult for either country to achieve on its own

SOLERAS is sponsored by the government agencies responsible for energy research and development in each country the Saudi Arabian National Center for Science and Technology (SANCST) and the United States Department of Energy The Program is under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation, formed in 1974 by the Saudi Arabian Ministry of Finance and National Economy and the United States Department of the Treasury

Although SOLERAS is only one of more than 30 such projects under the direction of the Joint Commission, it is the only one that is funded by both countries All other projects are funded completely by Saudi Arabia This jointly funded program is evidence, therefore, that both countries recognize the mutually beneficial results expected to be generated by the cooperative research projects undertaken by SOLERAS

The administration of SOLERAS also reflects the philosophy of cooperation underlying this unique Program Senior officials from SANCST, the Ministry of Finance and National Economy, the U S Department of Energy, and the U S Department of the Treasury comprise an eight-member Executive Board which governs all aspects of the SOLERAS Program The Board establishes the goals objectives, and policies of SOLERAS and oversees the technical and financial management of the projects undertaken to implement those goals and objectives

A four-member Project Selection Committee, with two members from each government, assists the Executive Board in selecting and evaluating projects Its members combine their technical expertise and experience in renewable energy technologies and demonstration projects to review proposals, designs, plans, reports, operations, and data for the various projects

The daily technical and administrative management of the SOLERAS projects is the responsibility of Midwest Research Institute, an independent, not-for-profit research organization, which has been designated as the SOLERAS Operating Agent MRI utilizes technical and managerial personnel from both countries in fulfilling its responsibility for implementing the decisions of the Executive Board and in managing the individual technical projects This includes contracting with various companies and research organizations in both countries to design and install state-of-the-art solar systems SOLERAS program offices are located at MRI's Kansas City, Missouri, headquarters, and in Riyadh and Yanbu, Saudi Arabia

SOLERAS has initiated several major research projects converting solar energy into electricity for everyday use by the inhabitants of several rural villages, testing solar energy as a source for space cooling and water treatment, developing agricultural systems using solar energy to control the entire growing environment, undertaking fundamental photovoltaic and solar thermal research, establishing high technology laboratories for advanced solar research at Saudi Arabian universities, and sponsoring basic solar energy research in universities in the United States

In addition, SOLERAS has contributed to the dissemination of scientific and technical solar information through its sponsorship of technology workshops, short courses, and the publication of technical reports These have provided an important means of informing the scientific research community about the solar energy technologies developed under SOLERAS and other relevant projects throughout the world

تقديم

«البرنامج السعودي الامريكي المشترك»
للتعاون في ميدان أبحاث الطاقة الشمسية

وقّعت المملكة العربية السعودية والولايات المتحدة الأمريكية في عام ١٩٧٧م اتفاقية برنامج التعاون في ميدان أبحاث الطاقة الشمسية . وكان هذا البرنامج الذي سُمّي «سوليراس» الاوّل من نوعه من حيث الغرض والتمويل والتنظيم والنتائج . وهو معتمد على الالتزام المتبادل بين الولايات المتحدة الأمريكية والمملكة العربية السعودية بالعمل على تنمية الطاقة الشمسية ، بوصفها طاقة بديلة متجدّدة وذات كلفة منافسة ، عن طريق الجمع للموارد الفنية وغيرها من المصادر الطبيعية لكل من البلدين . ولقد حقّق برنامج «سوليراس» تقدّما ملحوظا ببيان فعالية الطاقة الشمسية ، وهو تقدّم قد يكون من الصعب تحقيقه على أي من البلدين منفردا .

يتم انجاز برنامج «سوليراس» تحت رعاية الهيئات الحكومية المسؤولة عن أبحاث وتنمية الطاقة في كل من البلدين ، أي المركز الوطني السعودي للعلوم والتكنولوجيا ووزارة الطاقة الأمريكية . وتشرف على البرنامج اللجنة الأمريكية السعودية المشتركة للتعاون الاقتصادي المكوّنة عام ١٩٧٤م من قبل وزارة المالية والاقتصاد الوطني في المملكة العربية السعودية ووزارة المالية في الولايات المتحدة الأمريكية .

بالرغم من أن برنامج «سوليراس» هو واحد من بين ما يزيد عن ٣٠ مشروعا تديرها اللجنة المشتركة فانه البرنامج الوحيد الذي يموّله البلدان ، في حين أن جميع البرامج الأخرى تموّلها المملكة العربية السعودية كليا . فيبرهن هذا البرنامج ، المشترك التمويل ، على أن كلا البلدين يعترفان بالفوائد المتبادلة المتوقّع تحقيقها من خلال مشاريع البحث التعاوني التي يتداولها برنامج «سوليراس» .

وتعكس إدارة «سوليراس» أيضا فلسفة التعاون التي يستند عليها هذا البرنامج . فيشكّل مسؤولون من المركز الوطني السعودي للعلوم والتكنولوجيا ومن وزارة المالية والاقتصاد الوطني ومن وزارة الطاقة الأمريكية ووزارة المالية الأمريكية مجلسا تنفيذيا يضمّ ثمانية أعضاء ويدير جميع جوانب برنامج «سوليراس» . فيحدّد هذا المجلس أهداف وغايات وسياسة «سوليراس» كما يشرف على الادارة الفنية والمالية للمشاريع المباشَرة لتحقيق هذه الأهداف والغايات .

تقوم لجنة اختيار المشاريع المتكوّنة من أربعة أعضاء ، اثنان من كل جانب بمساعدة المجلس التنفيذي في اختيار وتقييم المشاريع . فيجمع أعضاء هذه اللجنة خبرتهم الفنية وتجربتهم في مجال تكنولوجيا الطاقة المتجدّدة والمشاريع النموذجية لمراجعة المقترحات والتصاميم والمخططات والتقارير والعمليات والبيانات المتعلقة بالمشاريع المتنوّعة .

أمّا الادارة الفنيّة والادارية اليوميّة لمشاريع «سوليراس» فهي تحت مسؤوولية «مدوست ريسيرتش انستيتيوت» (معهد «مدوست» للابحاث) . وهو معهد أبحاث مستقل ليس ذا صبغة تجارية ، تم تعيينه كوكيل تشغيل لبرنامج «سوليراس» . ويستخدم معهد «مدوست للأبحاث» فنييّن واداريين من كلا البلدين للقيام بمسؤولية تنفيذ قرارات المجلس التنفيذي وإدارة المشاريع الفنية الفردية . ويشمل ذلك التعاقد مع مختلف الشركات ومعاهد الابحاث في كلا البلدين لتصميم وتركيب أنظمة طاقة شمسية من أحدث تكنولوجيا . وتقع مكاتب برنامج «سوليراس» في المقرّ الرئيسي لمعهد «مدوست للأبحاث» بمدينة كنساس سيتي بولاية ميسوري وكذلك في الرياض وينبع بالمملكة العربية السعودية .

انبعث من برنامج «سوليراس» العديد من مشاريع الابحاث الكبرى ، منها تحويل الطاقة الشمسية الى كهرباء للاستعمال اليومي لسكّان العديد من القرى الريفية واختبار الطاقة الشمسية كمصدر طاقة للتبريد والتدفئة وتحلية المياه وتطوير أنظمة زراعية باستعمال الطاقة الشمسية للتحكّم في كامل بيئة الانماء ، والقيام بأبحاث نظرية حول الخلايا الكهروضوئية والحرارة الشمسية وانشاء مختبرات تكنولوجيا عالية للابحاث الشمسية المتقدّمة في الجامعات السعودية ورعاية أبحاث أساسية في الطاقة الشمسية في جامعات بالولايات المتحدة الأمريكية .

كما أن برنامج « سوليراس» ساهم في نشر المعلومات العلمية والفنية المتعلقة بالطاقة الشمسية من خلال رعايته للندوات العلمية والدورات القصيرة ونشر التقارير الفنية . ولقد كان ذلك وسيلة لنقل معلومات هامّة لمجموعة الباحثين العلميين حول تكنولوجيا الطاقة الشمسية المطوّرة من خلال برنامج «سوليراس» والمشاريع الأخرى المرتبطة به عبر بلدان العالم .

ACKNOWLEDGEMENTS

Many people cooperated closely during the work under Phase 1 of this project and the preparation of all documents. An effort such as this is truly a team effort. Each principal contributing organization and key personnel who provided inputs to the project is listed below.

Science Applications, Inc.

Mr. R. C. Edwards
Dr. M.D. Fraser
Dr. Y. P. Gupta (Project Director)
Mr. A. J. Houghton (Task 4 Leader)
Dr. H. S. Liers (Project Manager, Task 2 Leader)
Mr. E.V. Lofgren
Dr. G.D. Mehta
Dr. W.G. Scholten
Mr. F.D. Varcolik
Mr. P. L. Versteegen (Task 5 Leader)
Dr. S. K. Young (Task 3 Leader)

Texas A&M Agricultural Experiment Station

Dr. J. Larsen
Dr. D. Paterson
Dr. A. J. Turgeon
Dr. C. H. M. van Bavel

University of Texas at Dallas/McCormack Corporation

Dr. W.T. Eriksen
Dr. W.M. Glaze
Mr. L. P. Lee
Mr. A. F. McCormack

Geiger Berger Associates

Mr. P. A. Gossen
Mr. M. Antonson

Robert E. McKee, Inc.

Mr. J. Lunardon
Mr. C. Bailey

Zumwalt & Vinther

Mr. R.L. Rome
Mr. R.E. Wilson
Mr. D.L. Wilson
Mr. H.V. Ratliff

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

System Requirement Definition

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

SECTION 1
INTRODUCTION

BACKGROUND

Saudi Arabia and the United States have signed a project agreement for cooperation in the field of Solar Energy (SOLERAS) under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation. The objectives of the agreement are:

- to cooperate in the field of solar energy technology for the mutual benefit of the two countries, including the development and stimulation of solar industries within the two countries,
- to advance the development of solar energy technology in the two countries, and
- to facilitate the transfer between the two countries of technology developed under this agreement.

The Midwest Research Institute (MRI),* as the Operating Agent, is responsible for implementing SOLERAS in accordance with directives of the SOLERAS Executive Board.

A five-year technical program plan for SOLERAS was approved by the Executive Board. As a part of this technical program plan various industrial applications were identified for solar technology. The objectives of the Industrial Solar Applications program are to introduce solar energy technologies into industrial applications and to foster the establishment of domestic industries using renewable energy sources. This would then lessen industrial dependence on fossil fuels and minimize deleterious effects on the environment.

Anticipated future demands for food production, coupled with rapidly depleting fossil fuel reserves, point to the need for food production that utilizes renewable energy sources. Many regions have large areas of land that are suitable for

---

* The responsibilities of managing the SOLERAS program used to be with the Solar Energy Research Institute (SERI) operated by Midwest Research Institute (MRI).

agricultural use, but whose development are constrainted by the lack of irrigation water and the presence of hot arid environmental conditions. These conditions exist in most of Saudi Arabia and in portions of the Southwestern United States. Even in some areas of the United States, where water is available for irrigation, the rising cost of fossil fuel used for pumping this water is making the cost of irrigation farming prohibitive. In such regions, Controlled Environment Agriculture (CEA) offers an attractive means of increasing food production by controlling adverse environmental conditions with minimum water inputs.

Conventionally powered controlled-environment agriculture facilities have been in operation for years. In 1977, there were approximately 92,000 hectares of CEA facilities throughout the world powered by the electric grid and/or fossil fuel. Benefits of CEA include: reduced fresh water consumption, protection from harmful external conditions (e.g., insects, sandstorms, cold weather), and higher quality and larger yields of produce. As demonstrated at some of the CEA facilities in the Middle East and Southwest United States, the ratio of yield per hectare of CEA to open field agriculture may range from 4:1 to 21:1 depending on the type of crop grown.

Conventionally powered controlled-environment agriculture is a worldwide activity that has been proven successful in many different climates. Much effort has been put forth by the United States to use solar energy in support of agriculture; however, the objectives of these efforts have been directed toward one specific aspect of farm support; e.g., crop drying, heating of greenhouses or livestock shelters, or providing solar energy to power irrigation pumps. In Saudi Arabia, small research controlled-environment agriculture facilities powered by fossil fuel generators are being supported by the Ministry of Agriculture and Water. Even though CEA activity is worldwide, no real significant effort is being made to replace conventionally powered controlled-environment agriculture with completely integrated Solar Controlled Environment Agriculture systems. "Integrated" in this context means a total energy self-sufficient system as opposed to separate interfacing subsystems.

OBJECTIVES

The overall objective of this project is to design and cost a commercial solar controlled-environment agriculture system and to construct and operate a smaller Engineering Test Facility that exhibits the same characteristics as the commercial design. The work to be performed on this project has been divided into three phases:

Phase 1. Preliminary system design and cost analysis

Phase 2. Detailed design and construction of an engineering field test.

Phase 3. Operation and evaluation of the engineering field test.

One important goal of this study is to design a system with broad applicability to other sites in terms of system performance as well as high reliability using proven or state-of-the-art technology so that the operation of the system does not require a large number of highly skilled personnel.

PROJECT ORGANIZATION

Science Applications, Inc. (SAI) was awarded a contract for the Phase 1 Activity. The project roles of SAI and each of the participating subcontractors are shown below.

Project Participant	Project Role
Science Applications, Inc. (SAI)	Overall Project Management, Systems Analyses, Energy Systems Design, Planning for Phase 2
Texas A&M Agricultural Experiment Station (TAES)	Agricultural Design Greenhouse Systems Design
Geiger Berger and Associates (GBA)	Architectural and Structural Design
University of Texas at Dallas (UTD)/McCormack Corporation	Environmental Analysis and Desalination System Design
Robert E. McKee, Inc. (REM)	Cost Estimation and Construction Planning.

The overall goal of the Phase 1 activity is to carry out the preliminary system design and cost analysis of a commercial sized solar controlled agriculture environment system, and to complete a preliminary design and cost estimate of an Engineering Test Facility approximately 1/10th the size of the commercial one. The system under study by SAI utilizes a novel fluid-roof/roof-filter concept for the greenhouse and is generally configured and designed for an environment comparable to that in the El Paso, TX area. The corresponding Engineering Test Facility would be located on a 160 acre experimental farm, owned and operated by the Texas A&M Agricultural Experiment Station at El Paso, Texas. All the water requirements for this system will be provided by a brackish water well on the farm. A reverse osmosis desalination subsystem is used to produce fresh water for irrigation and deionized water for cooling the greenhouse. The original concept would have photovoltaics and wind turbines in combination with batteries and diesel back-up power providing all the energy requirements of the proposed system including controls and support facilities. The system analysis effort resulting in the definition of the commercial facility eliminated the wind turbines FOR THE El Paso, Texas site analyzed. CO_2 enrichment will be provided to enhance crop growth. Crop residue will be tilled into the land surrounding the greenhouse and offer the possibility of growing limited outside crops. Humidity control of the greenhouse air will be provided by means of a ground water cooled condenser in conjunction with outside air mixing which will result in reduction of water usage. Heating or cooling (depending upon the season) of the greenhouse will be provided by means of heat exchange with the well water and with thermal storage tanks. The effluents from this system will be appropriately discharged if environmentally acceptable; otherwise they would be stored in a lined evaporation pond.

The work under Phase 1 of this project was divided into one management and four technical tasks. The first task dealt with all management, operational and reporting activities. In Task 2, the requirements were defined for the 5-hectare commercial unit and the engineering field test system of 0.4 to 1.0 hectare. Systems analyses of a commercial size system were carried out under Task 3 which included detailed sub-system trade-off studies and optimization of the integrated system. Based upon the results of that task, the size of an engineering field test for El Paso, Texas was recommended. Preliminary design of an Engineering Test Facility with process flow diagrams and top level drawings were completed in Task 4. Work plans to carry out the detailed design, construction, operation and training of personnel under Phase 2 were developed in Task 5. Levelized produce cost for sites in U.S. and the Kingdom of Saudi Arabia were estimated in Task 5 taking into account the changes in system design and cost that resulted from accomplishment of Task 4.

REPORT ORGANIZATION

Work completed under Phase 1 was reported and reviewed on a task-by-task basis. As discussed above Phase 1 was comprised of five tasks. Task 1 dealt with all management and reporting aspects and included all monthly status reports. No separate discussion is provided on this task. The results of Task 2, dealing with the definition of the requirements, design criteria, and environmental impacts, are described in detail in Volume 2 of this report. Systems Analysis and the definition of the commercial sized system are the result of Task 3 and are described in Volume 3. The preliminary design of the Engineering Test Facility, ETF, was the subject matter of Task 4 and the results are described in detail in Volumes 4 and 5. The first of these two volumes describes the system and subsystem features and contains, in Appendix A, 50 drawings describing various aspects of the ETF. Volume 5 contains the preliminary specifications as they relate to the system and drawings. The Task 5 results are described in Volume 6 of this report and deal with the definition of Phase 2 involving plans for the detailed design and construction of the ETF.

This is Volume 1 of the final report. It gives a brief overview of all the accomplishments reported in the remaining volumes. Section 2 of this volume describes the system as it evolved from the Phase 1 effort, while Section 3 summarizes briefly the work performed under Tasks 2 through 5.

SECTION 2
DESCRIPTION OF CONCEPT

This section summarizes briefly the features of the Solar Controlled Environment System concept as it evolved during the Phase 1 effort. It has changed little from the originally proposed concept. The changes that were made will be summarized later in this section.

GENERAL DESCRIPTION

The greenhouse complex is based on a novel roof concept, a photovoltaic power system, and CO_2 enrichment, all designed to enhance the growth of vegetables. The fresh water needs of the facility are provided by a reverse osmosis (RO) desalination system using brackish aquifer water with 3500 mg/l total dissolved solids (TDS). All power needs of the greenhouse and desalination facility are provided by solar energy.

The greenhouse employs an innovative roof-filter/fluid-roof concept that utilizes an inner roof glazing which selectively allows sunlight in the 400-700nm range to pass into the greenhouse but strongly absorbs sunlight outside this range . The absorbed infrared radiation heats the inner glazing. This heat is removed by water flowing along the upper portion of the glazing and collected by a gutter system at its lower edges. In order to isolate the roof water from the environment, and to provide some insulation to the greenhouse, an air inflated durable clear plastic film with a high transmissivity is used to cover the inner glazing. The heated roof water is returned to an underground storage tank. In the summertime, when the roof must be cooled, water from the storage tanks is pumped through heat exchangers where its temperature is reduced by 18°C ground water. In wintertime, the excess energy is collected in the storage tanks and is used to provide nighttime heating of the greenhouse, if required. The 18°C ground water source can be used to augment the heating requirement. The primary function of the fluid-roof/roof-filter is to prevent harmful infrared radiation from entering the greenhouse and from being absorbed by the plant foliage. In this manner plant foliage and greenhouse air temperatures are nearly identical, plant evapotranspiration losses are minimized, and plant foliage is more nearly at its optimum growth temperature. Because of the lower evapotranspiration losses, fan power requirements to control humidity are significantly reduced.

Greenhouse dehumidification is accomplished by means of cool aquifer water and activated during the daylight hours only. Water condensed in this process is recycled back into the greenhouse. The greenhouse envelope has been designed in such a way as to minimize air infiltration. Such tight construction maximizes the water recovered from the dehumidification process, and makes feasible carbon dioxide (CO_2) enrichment. It has been estimated that a sustained greenhouse CO_2 level of 1000 ppm during daylight hours enhances the productivity by at least a factor of two over ambient air CO_2 levels (325 ppm). Therefore, a liquid CO_2 storage facility has been included in the design so that CO_2 levels of approximately 1000 ppm can be maintained during the daylight hours. There are times when the greenhouse air temperature is too low to effectively control humidity (such as during wintertime or early morning hours). In these circumstances, outside air in just the needed proportion is allowed into the greenhouse. If the air exchange rate is not too great the CO_2 injection is continued, otherwise it is inhibited.

The layout of the commercial greenhouse complex is shown in Figure 1. The greenhouse itself is basically square with four square growing compartments separated by two corridors, one running North-South, the other running East-West. Outside the East side and West side of the greenhouse are large storage tanks which contain the roof cooling/heating water. This water must be purified by a demineralizer to a TDS of no more than 5 ppm to prevent scale build up on the glass. The main corridor is used for access to all growing sections and houses materials needed for direct support of the growing operations as well as other growing area mechanical/electrical equipment. A support facility, housing such items as fertilizer, fresh produce, RO system, office space, control room, batteries, etc., is located at the North end of the greenhouse.

The greenhouse growing media is a 30 cm layer of porous sand on top of a sloped floor, covered with a plastic liner. Embedded in the sand are drainage pipes which allow fertigation water to reach the plant roots and which are used for periodic purging of the soil to prevent salt buildup. The leachate is collected in a holding pond along with a portion of the rainwater and is subsequently used to

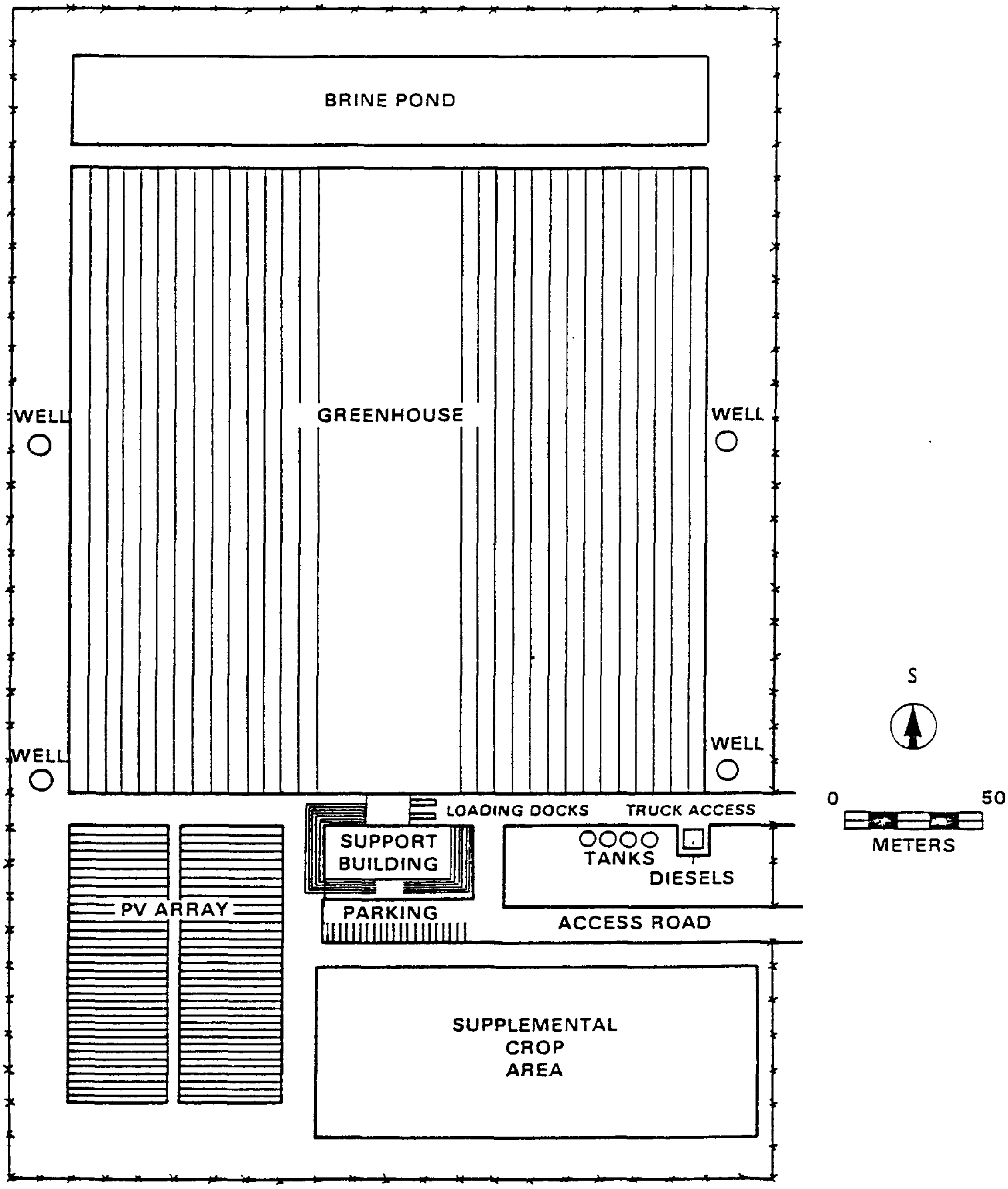


Figure 1. Overall Facility Layout

irrigate outside vegetation. Crop residue is taken outside, tilled into the soil, and allowed to compost, thereby improving the quality of the soil and allowing for the possibility of growing marketable products outside the greenhouse.

The desalination system consists of pretreatment and RO subsystems. Fresh water produced by the RO system will have a TDS of less than 250 ppm and is stored in a fresh water tank. During plant startup, water from the fresh water tanks is sent through a demineralizer reducing the TDS to no more than 5 ppm before entering roof water storage. During greenhouse operation, the demineralizer will be used to maintain the roof water at less than 5 ppm purity. Waste water from the RO and demineralizer systems will be sent to an evaporation pond.

The energy system consists of photovoltaic modules, electric battery storage, and a power conditioning unit. Backup power is provided by diesel generators.

A fully automatic control system, with the capability for manual override, controls the entire facility from a centrally located point in the support building. In many cases, however, individual subsystems have their own integral controls in which case the central control system is only used to monitor these systems, to sound alarms, and to activate or deactivate the system. An uninterruptable power supply (UPS) system has been included to serve all control functions.

Each of the four growing areas will be operated and controlled individually. This procedure provides for increased facility reliability as well as for maintaining separate environmental conditions.

The support building is a typical prefabricated structure that houses equipment and facilities required to operate the greenhouse.

THE COMMERCIAL FACILITY

The subsystem sizes and characteristics of the commercial system were the result of comprehensive analyses performed under Task 3. They can be summarized as follows:

ENERGY SUBSYSTEM

PV ARRAY

- Sized at 340 kWp (modules at 28°C, 1 kW/m^2)
- Block V module specs
- Modules tilted at 20°
- Electrical protection (diodes, lightning protection, breakers, etc.)

ARRAY REGULATOR

- Buck boost DC-DC converter, 94% efficiency
- Peak power tracking
- Multiple parallel units

BATTERY STORAGE

- Rated capacity 2700 kWh, 256 kW
- Lead-calcium grid for 10 year life
- Allowable depth of discharge 80% of rated capacity

WIND ENERGY CONVERSION

- Not included in optimized El Paso design

POWER CONDITIONING UNIT

- 250 kVA DC to AC inverter, over 90% efficient
- Multiple parallel units for high part load efficiency and high reliability
- Built-in protection (overload, overvoltage, under voltage, etc.)

BACKUP

- 2-200 kW diesel generators
- UPS for key control functions

GREENHOUSE SUBSYSTEM

- 4.7 Ha growing area in 4 compartments
- Roof-filter/fluid-roof cooling
  - ridge and furrow configuration
  - single glazing with air supported film roof
- Cool water dehumidification with water recovery
- CO_2 enrichment
- Central access corridor
- Sand growing medium

DESALINATION SUBSYSTEM

- Pretreatment
- Reverse osmosis desalination
  - 75% recovery ratio
  - 3.04 m^3/h (73 m^3/d) capacity
  - spiral wound membrane
  - automatic operation
- Product water storage
- Demineralizer and storage tanks for fluid roof circulating water
- Evaporation pond (7320 m^2) for brine discharge

CONTROL SUBSYSTEM

- Leaf temperature control
- Direct control from central control station (CCS)
  - roof water circulation subsystem
  - greenhouse ventilation
  - greenhouse dehumidification
  - CO_2 supplementation
  - independent controls for each growing compartment

- Integral control modules
  - fertigation
  - ground water pumps
  - desalination and demineralization
  - fresh water distribution
  - brackish water low-volume distribution
  - PV subsystem
  - support facility environmental control
  - enable-inhibit from CCS status and alarms to CCS

THE ENGINEERING TEST FACILITY

The purpose of the Engineering Test Facility (ETF) is to demonstrate the feasibility of the system analyzed in Task 3 by constructing and operating a smaller scale version. The ETF must meet the same basic requirements and design criteria as the commercial system and must be representative in the most fundamental way, especially the stand-alone power requirement. It must be sized in such a way that results obtained with it can be reliably extrapolated to a larger facility. It, furthermore, must be constructed at the lowest possible cost to the SOLERAS program.

The principal equipment sizes and capacities for the ETF are given in Table 1. To be responsive to the cost consideration stated above, slight differences were introduced between the commercial facility and the Engineering Test Facility, none of which impacting in any way the satisfaction of the basic system requirements. These differences can be summarized as follows:

- No evaporation pond - Wastes retained in a holding pond
- No diesel generators - Local electric utility backup used instead.
- Not all electric loads met by PV systems - The support facility uses entirely local electric utility power in order to limit the cost of the system (The support facility loads do not scale readily with the size of the greenhouse therefore distorting the load profiles severely when reducing greenhouse size).
- The East-West corridor was eliminated but four growing compartments were retained - The removal of the corridor provided additional growing area and more readily approximated the fraction of roof covered area not actively used for growing.

Table 1. Major ETF Subsystem Sizes/Capacities

SUBSYSTEM	RATING
Photovoltaic array	38 kWp
Array Regulator	37 kW
Battery	89 kWh
Power Conditioner	37 kVA
Desalination	10 m^3/d
Well Pumps	2-25 HP, 1-5 HP
Greenhouse	.36 hectare total area .32 hectare growing area

CHANGES FROM THE ORIGINAL CONCEPT

The original proposed concept was slightly different than the final one in only a few respects. A comparison of the before and after concept is summarized in Table 2. The most important difference is the elimination of wind machines from the power production subsystem. Wind machines contributed only marginally for the El Paso, Texas site. It was thus decided to eliminate it from the concept for reasons of simplicity. This is not to say that a combined PV-wind energy system is not economical, but rather that the El Paso, Texas, meteorological environment was not suited for inclusion of wind power.

Table 2. System Concept Development*

SYSTEM FEATURE	ORIGINALLY PROPOSED*	AFTER PHASE I EFFORT*
Size of Greenhouse	4 HA/0.96 HA	5 HA/0.36 HA
Number of Compartments	4	4
Roof-Filter/Fluid-Roof Concept	YES	YES
Roof Structure	Double Glazing	Single Glazing and Film
Photovoltaic Power	YES	YES
Wind Power	YES	NO
Evaporation Pond	YES/NO	YES/NO
Crop Residue Drying and Burning	YES	NO
CO_2 Enrichment	YES	YES
Humidity Control	Cooled inside air mixed with outside air	Inside air cooled and reheated
Backup Diesel Generator	YES/NO	YES/NO
Reverse Osmosis Desalination	YES	YES
Water Storage Tanks	YES	YES
Electric Storage Batteries	YES	YES
Central Control System	YES	YES
Aquifer Water	YES	YES
Support Facilities	YES	YES
Location in El Paso, Texas	YES	YES

* When two items are separated by a slash (/), first item refers to the commercial system and the second to the Engineering Test Facility. A single answer applies to both.

SECTION 3
TASK SUMMARIES

The task summaries given below describe briefly the purpose of the task and summarize either the context of the appropriate task report or give certain relevant facts of the effort conducted under that task. These summaries are not intended to be totally inclusive, but provide only highlights of the effort that was conducted under Phase 1. Details on each of the task results are reported in separate volumes of this report.

TASK 2 - SYSTEM REQUIREMENTS DEFINITION

The purpose of Task 2 was three-fold:

- to define the requirements relevant to the configuration and sizing of equipments for the design of the SCEAS;
- to define design criteria based on these requirements;
- to determine environmental impacts.

The system requirements pertain to the overall objectives and goals of the project and are generally specified in the contract. They deal with aspects of system performance, site constraints, and economic factors. The key system requirements are summarized in Table 3.

In addition, the El Paso, Texas, site was proposed for the location of the SCEAS, and becomes therefore a requirement that has to be met in terms of climate. These requirements can be summarized as follows:

- Abundance of sunshine; typical of southwestern U.S. and the KSA.
- Low humidity.
- Little rainfall; mostly during July through September.
- Mild winter season; virtually no snowfall.
- Dust storms occur with greatest frequency during March and April.

Table 3. System Requirements

- 5 Ha for the commercial size greenhouse (0.4 to 1 Ha for the test facility)
- Stand-alone solar power/energy system
- Fossil fuel backup for emergency only
- Desalinated brackish water with TDS less than 500 MG/L
- Irrigation water storage for 20 days
- Backup power system fuel storage for 7 days
- Support facilities for personnel, storage of supplies, equipment, and produce
- Environmentally acceptable waste disposal facilities
- Reliable and safe operation
- Design life of 20 years

In defining the economies of the system, the economic analysis methodology and values of basic economic factors were specified as a requirement.

Design criteria result from these requirements, and provide guidelines and limits that the overall system and the various subsystems must satisfy. The design criteria are summarized in Table 4. The design criteria for the major subsystems were developed in some detail and are reported in Volume 2 of this report in the following format:

1. Identification/Name
2. Scope
3. Design Philosophy
4. Features
5. Technical Constraints
6. Environmental Constraints
7. O&M Requirements.

TASK 3 - SYSTEMS ANALYSIS

The purpose of this task was to define a viable 5 ha commercial greenhouse system that satisfies the requirements and criteria defined and developed under Task 2. This included tradeoff studies and the determination of the sizes and/or capacities of all of the major subsystems, and to evaluate overall system performance both from a technical and cost point of view. Once the commercial system was defined, scaling criteria were to be derived to define a smaller scale engineering field test for which the preliminary design was to be developed during the next task.

The approach taken in Task 3 is best summarized by Figure 2. It shows the basic steps that were taken starting with a refinement of the original proposed concept, using additional information gathered since the original submittal of the idea and preliminary comments from reviewers. As a result the following key system features were defined:

- Five hectare greenhouse providing leaf temperature control via an energy-efficient fluid-roof/roof-filter concept, humidity control via groundwater cooling including condensate recovery, CO_2 enrichment for increased plant productivity, and loads closely matched to the solar energy resource.

Table 4. Design Criteria

SYSTEM DESIGN CRITERIA

- Lowest possible energy consumption
- Lowest possible water use rate
- Suitable working environment for personnel
- Use of commercially available equipment
- Maximum possible technology transfer functions

SITE DESIGN CRITERIA

- SOLMET TMY hourly meteorlogical data for El Paso, Texas
  - direct normal radiation
  - total radiation on horizontal surface
  - wind speed
  - wind direction
  - dry bulb temperature
  - wet bulb temperature
  - barometric pressure

- Maximum solar intensity of 1,050 W/m^2
- Maximum wind speed of 35.8 m/s (at 10 m above ground)

- Water from aquifer
  - Rio Grande alluvium aquifer
  - on the average the aquifer is full
  - water level averages 3 to 6 m below land level
  - water temperature is virtually constant at 18°C
  - TDS in water is approximately 3,500 PPM

- Seismic zone no. 1

ECONOMIC DESIGN CRITERIA

- Minimum levelized life-cycle cost per kilogram of produce based on the requirements that
  - methodology used is "the cost of energy from utility-owned solar electric systems - a required revenue methodology for ERDA/EPRI evaluations", ERDA/JPL-11012-76-3, June 1976
  - basic economic factors be used that are specified in the contract

- 1986 DOE cost goals for solar energy subsystems.

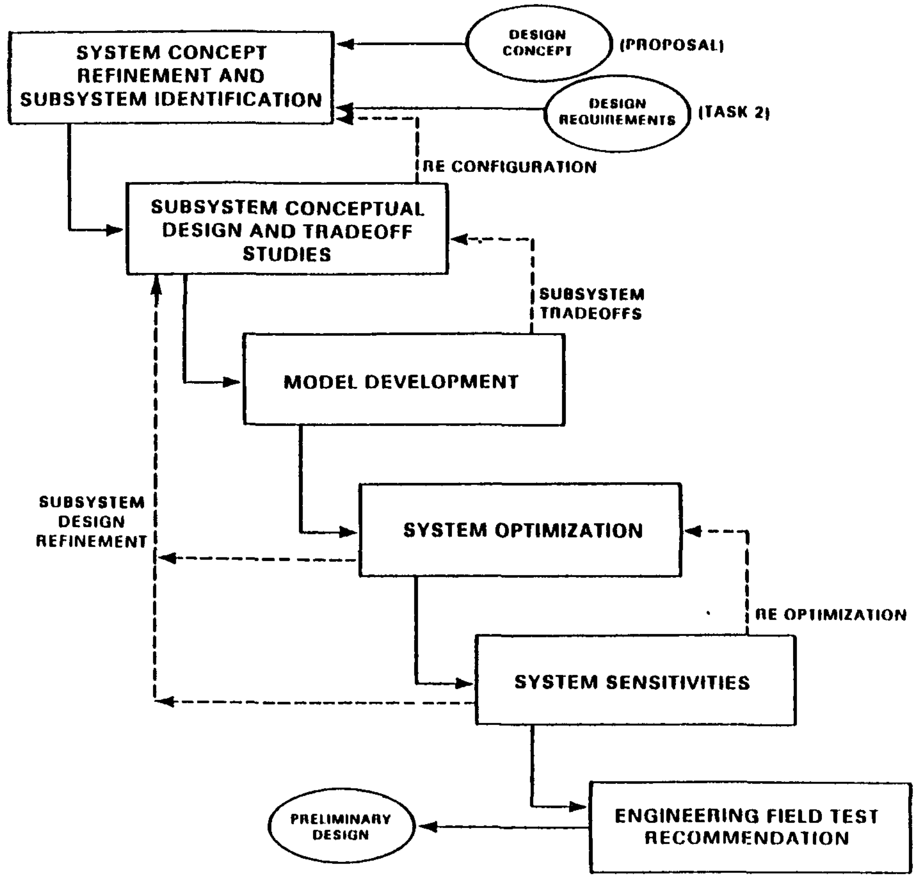


Figure 2. System Analysis Approach

- Stand-alone solar power system incorporating a photovoltaic array, wind machines, battery storage, a dc-ac inverter and power conditioning unit (PCU), and diesel generator backup for emergency conditions.

- Self-contained fresh water supply provided by a reverse osmosis (RO) desalination unit with 75 percent recovery ratio and an evaporation pond for brine disposal.

- Automatic control system with redundant alarms and provision for manual control.

- Energy-efficient support facility providing necessary work areas, produce storage, equipment storage, and office space.

- Supplementary crop area with enrichment using crop residues and irrigation using leachate and excess desalinated water.

Following this subsystem tradeoff studies were conducted to determine the most appropriate form of the subsystem. The next three steps are concerned with analytical work that define the optimum system configuration, from model development, to detailed performance analyses and optimization, to sensitivity studies. Lastly the engineering field test scaling was performed. All of these individual steps are highly interactive as shown by the dotted lines in Figure 2. Detailed subsystem tradeoff studies were conducted on:

- the greenhouse roof structure,
- the fluid-roof filter,
- greenhouse dehumidification,
- greenhouse cooling,
- CO_2 supply,
- water desalination.

Following the definition of all of the major subsystem types mathematical models were derived for each of these compatible with the optimization methodology used in this project. System optimization was based on the following criteria:

- minimum levelized produce cost,

- economic assumptions specified by the contract,

- DOE cost goal projections for 1986 for the energy subsystems.

A schematic diagram of the optimization methodology used is shown in Figure 3. It is based on a linear programming formulation of the hourly performance characteristics of the subsystems. Hourly weather data for a year was analyzed and reduced to a representative week from each of the four seasons. Unit greenhouse electrical and water loads, and energy system electrical output were determined from hourly TRNSYS simulations. Models were derived for all other pertinent subsystems and made part of the SYSOPT computer program. The SYSOPT program generated the appropriate equations which were subsequently solved with the commercially available APEX III LP solver. The results from the latter program were then processed and cast into a form more suitable for analysis and evaluation. The system schematic diagram for optimization is shown in Figure 4, where nodes define the balance of DC power, AC power, brackish water flow, fresh water flow, thermal energy and CO_2. Of particular importance in this methodology is the model for the greenhouse. The loads imposed by the greenhouse on the system were determined from detailed simulations with TRNSYS. The TRNSYS model (Fortran based) was indentical to the SG79 (CSMP-III based) computer model developed by C. van Bavel at Texas A&M University and used and verified in several studies dealing with greenhouse performance.

The results of these analyses are summarized in Table 5 and Figure 5. Table 5 gives the major optimization results and annual performance, while Figure 5 shows the annual balances. A typical result of some of the details available is shown in Figure 6. System economics are summarized in Table 6 and Figures 7 and 8. These results are described and discussed in detail in Volume 3 of this report.

TASK 4 - PRELIMINARY SYSTEM DESIGN AND COST ANALYSIS

The purpose of Task 4 was to develop a preliminary design of an Engineering Test Facility (ETF) to be located on the Texas A&M Agricultural Experiment Station Farm in El Paso, Texas. The preliminary design was to consist of top-level drawings and component specifications. This information was then used to determine the cost of construction and operation, Phase 2 and Phase 3, respectively, of the ETF.

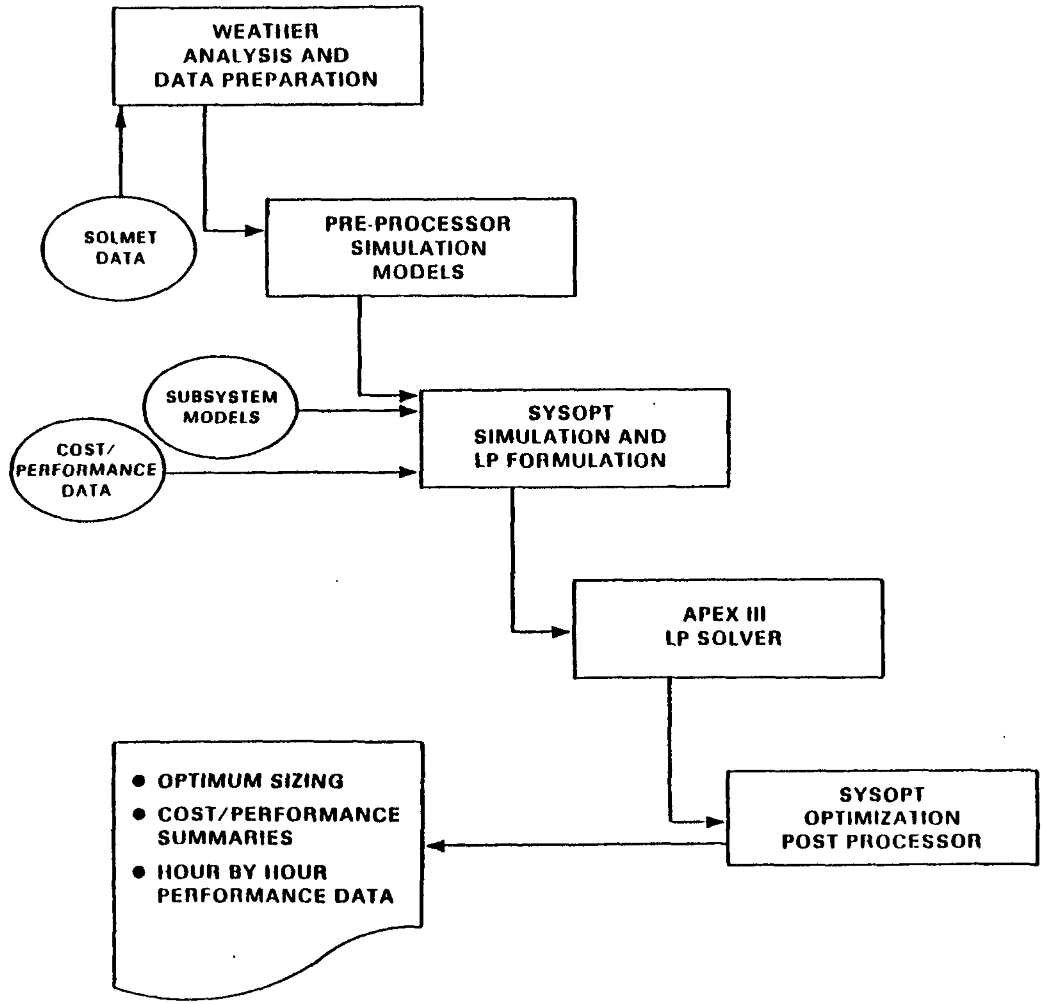


Figure 3. SYSOPT - System Optimization Methodology

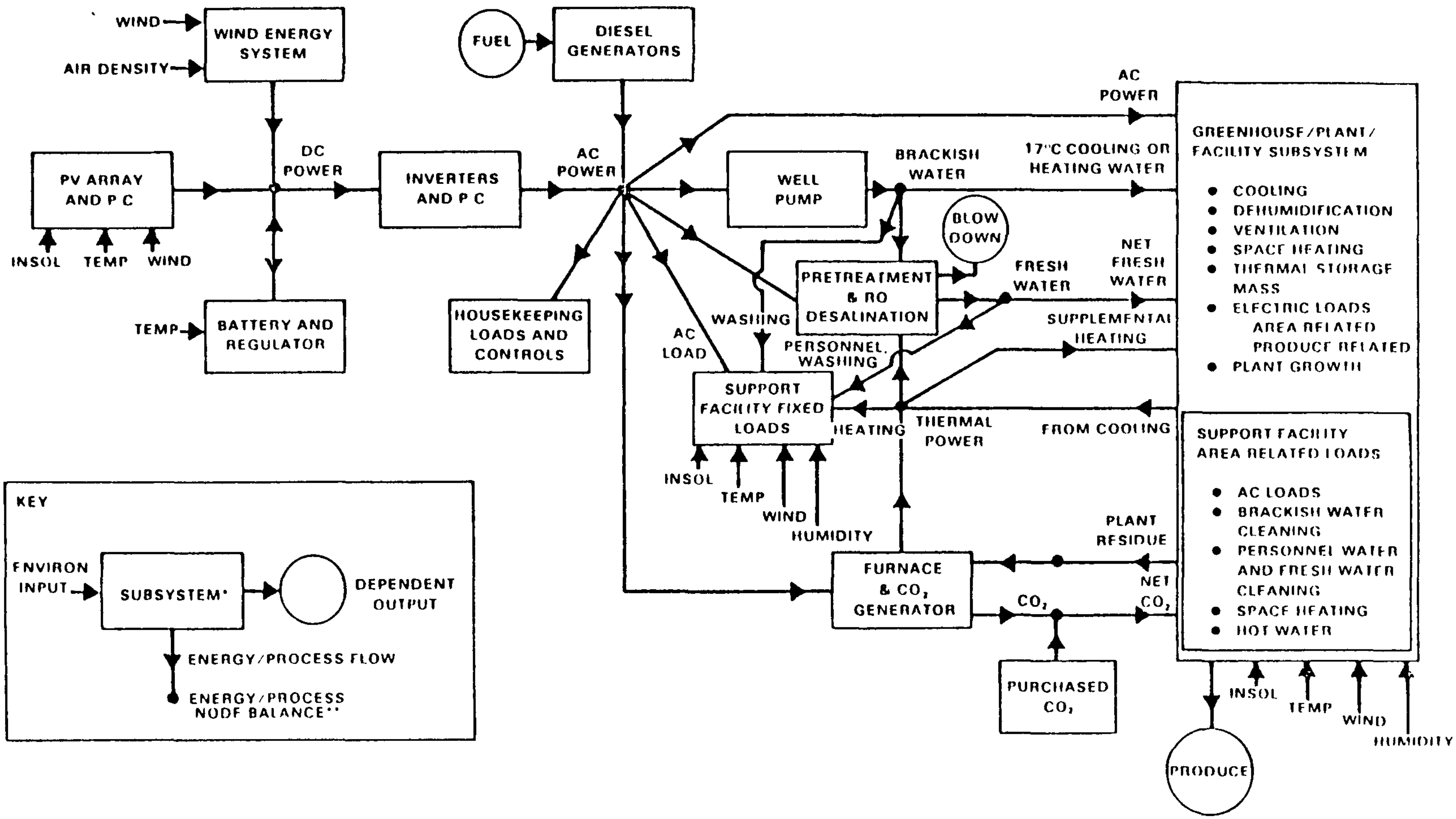


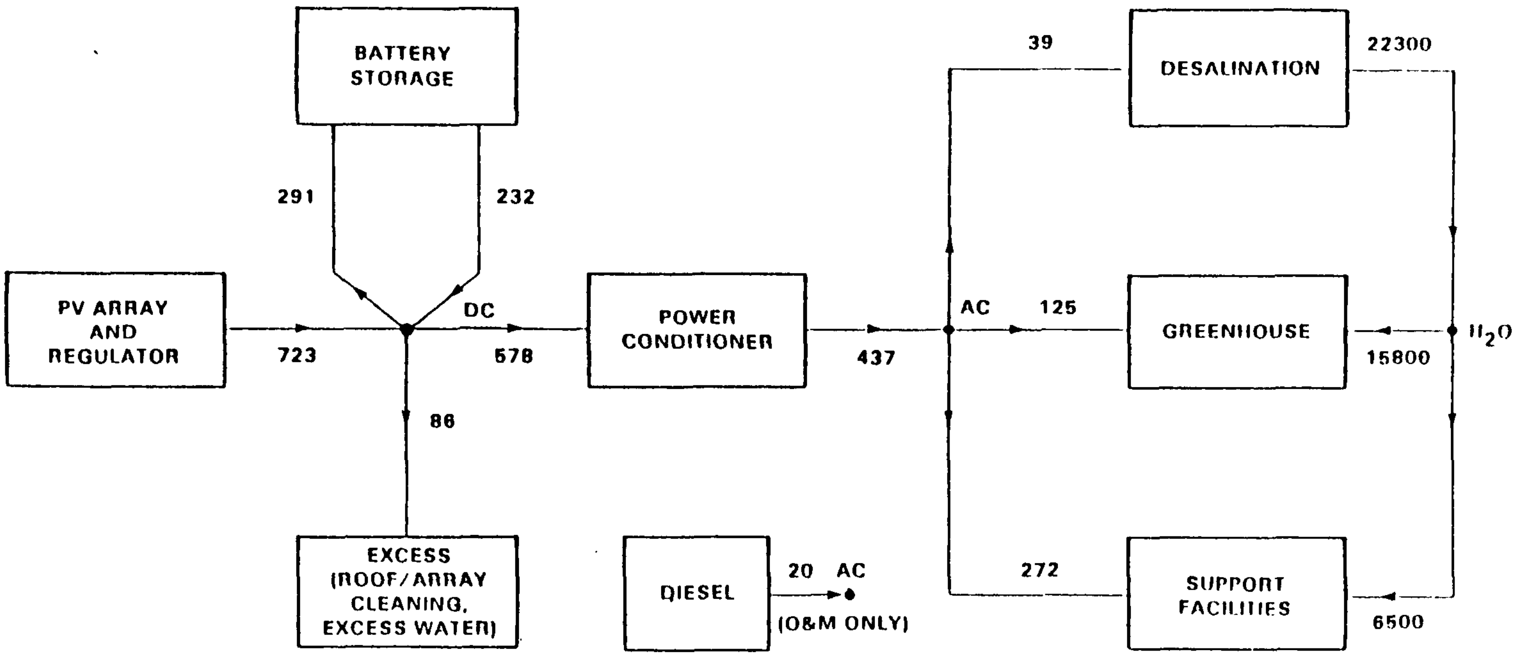
Figure 4. SCEAS Optimization Schematic

Table 5. SCEAS System Optimization Results

SUBSYSTEM	RATED CAPACITY	ANNUAL PERFORMANCE
PV System*	344 kWp	723 MWh DC
Wind Subsystem	0 kW	0 MWh
Battery Charging	256 kW, 2740 kWh**	291 MWh DC
Battery Discharging	256 kW, 2740 kWh**	232 MWh DC
Power Conditioner	250 kVA	437 MWh AC
RO Desalination	3.04 m^3/h	22,300 m^3
Total AC Loads	250 kVA	437 MWh AC

* Includes array regulator

** Nominal capacity (usable capacity is 2,190 kWh at 80% allowable depth of discharge)



UNITS

DC FLOWS IN MWh/y

AC FLOWS IN MWh/y

H2O FLOWS IN m^3/y

Figure 5. Optimized Annual Energy/Mass Balances

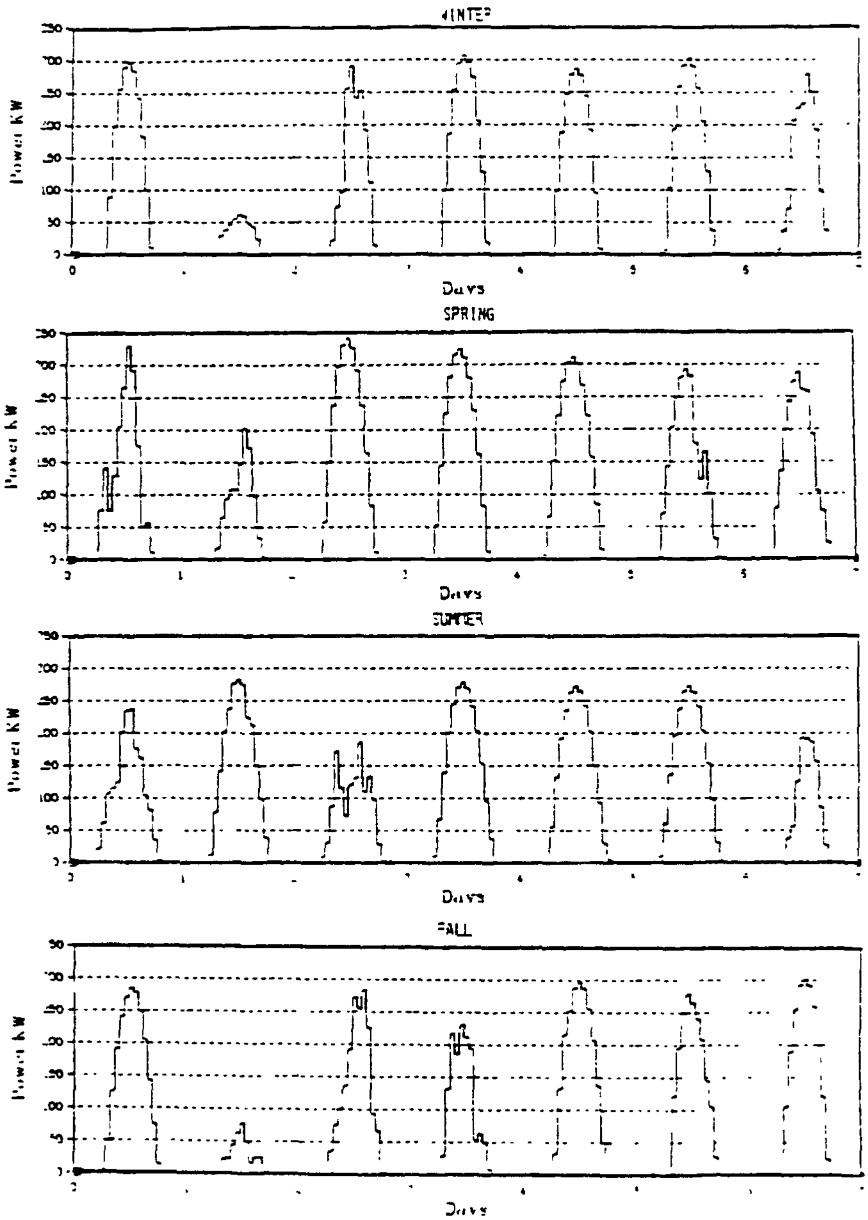


Figure 6. Typical Result - Photovoltaic Power

Table 6. SCEAS Subsystem Cost Breakdown (1981 k$)

SUBSYSTEM	CAPITAL COST	ANNUAL COST	REPLACEMENT COST
PV, 344 kW	642	10	356 @ 10y
Battery, 2740 kWh	478	11	
PCU, 250 kVA	48	1	
Diesel, 2-200 kW	62	4	
Controls, UPS, Data	440	7	
Desalination	240	5	15.3 @ 3y
Evaporation Pond	183	3	
Greenhouse, 5 Ha	11916	89	
Support Facilities and personnel	366	403	
CO_2	2	242	
Capital Cost Adders	3595	0	
TOTAL	17972	775	439 (NPV)

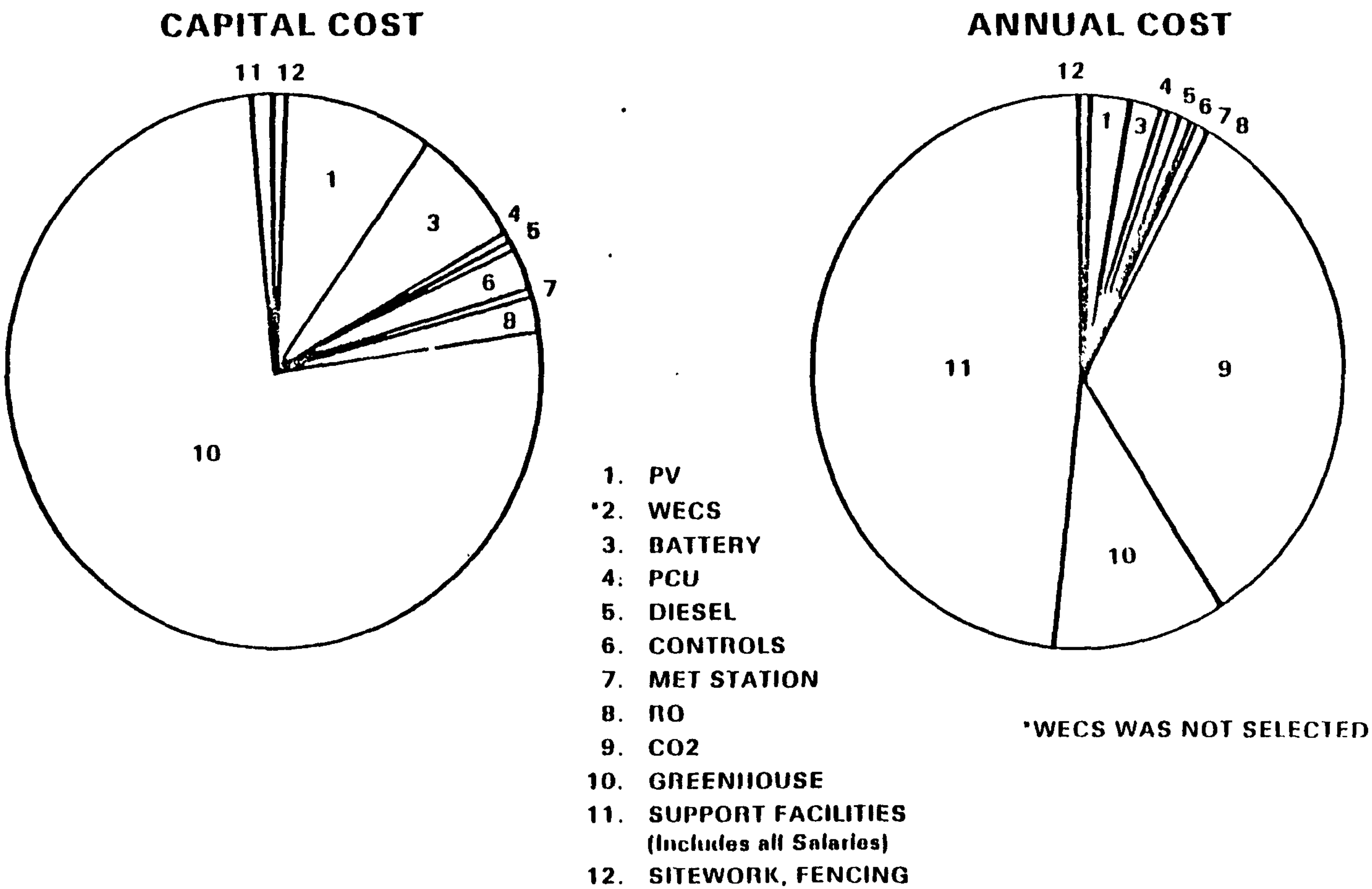


Figure 7. Relative Contribution of Subsystem Costs

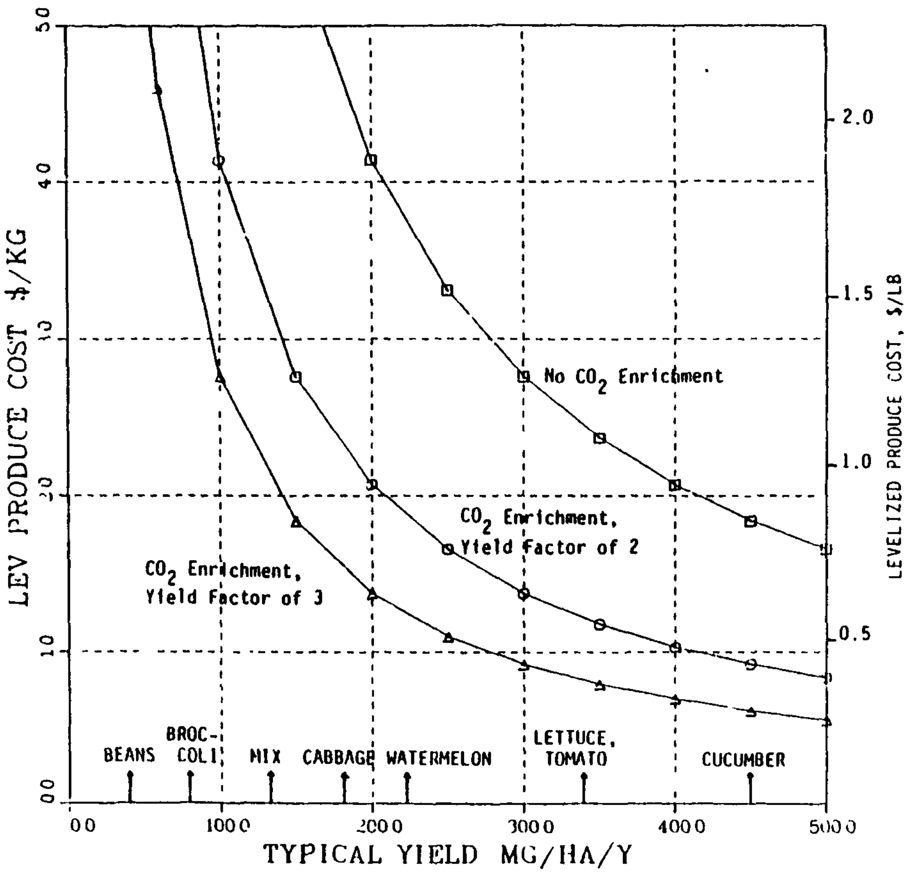


Figure 8. Levelized Produce Cost

The objective of the design was the faithful scaling of the commercial facility to ensure that the ETF results could be extrapolated to a commercial facility of any size. Therefore, all major features, including the photovoltaic power system, an integral water desalination system and even the basic structural module have been retained.

The design is described in Volume 4 of this report, with details in appendices in Volumes 4 and 5, giving the drawings and specifications, respectively. A computer simulation of the performance of the Engineering Test Facility in El Paso, Texas, was made to verify the adequacy of the design.

The Task 4 results represent an effort substantially greater than a typical preliminary engineering design study would provide. The added effort was deemed necessary in order to develop realistic implementation schedules and high confidence cost estimates for the definition of Phase 2 (Task 5).

The Engineering Test Facility design emulates the commercial size facility in all important aspects except size. The enclosed greenhouse area is 3,600 m^2 with 3,150 m^2 of growing area. There are four equal size growing compartments and a 7.5 m wide corridor thru the center that provides access to the compartments and work space. The size and compartmentation are adequate for all experimental objectives. The ETF roof structure consists of water cooled glass covered by an inflated plastic film roof to maintain a clean environment for the fluid roof and to protect the inner glazing from hail and other small missiles.

The only significant departure from the commercial system design is the powering of non-agricultural loads from the local utility. The housekeeping functions for the ETF do not scale linearly and their inclusion in the power requirement for the photovoltaic system would have resulted in a substantial cost increase without any experimental purpose. The utility is also used as a backup power source for the agricultural loads in lieu of diesel generators.

The performance analysis indicates a remarkably small energy requirement for operation of the facility. Prudent design dictates a slight oversizing of the solar energy system to account for reduced efficiencies resulting from smaller motors and a 4:1 increase in the ratio of unfiltered side walls to filter glass roof.

TASK 5 - PHASE 2 DEFINITION

The purpose of Task 5 was to develop a plan for implementing the Engineering Test Facility developed under Task 4. This plan constitutes a proposed Phase 2. Furthermore, Task 5 was to determine the cost of Phase 2 based on the preliminary drawings and specifications for the El Paso, Texas, site and prepare an estimate for an equivalent facility in Saudi Arabia. An additional item to be considered under Task 5 was the estimation of the cost of operation during Phase 3.

In order to accomplish the above, a detailed work breakdown structure was developed accounting for all activities required under Phase 2. This information was used to determine the project design and management costs and the overall implementation schedule. The preliminary drawings and specifications were used to generate material take-offs to determine equipment, material, and construction costs. Cost quotations were solicited for all items to be purchased or constructed and tallied to obtain the total system construction cost. Details of these costs have been presented in a separate document.

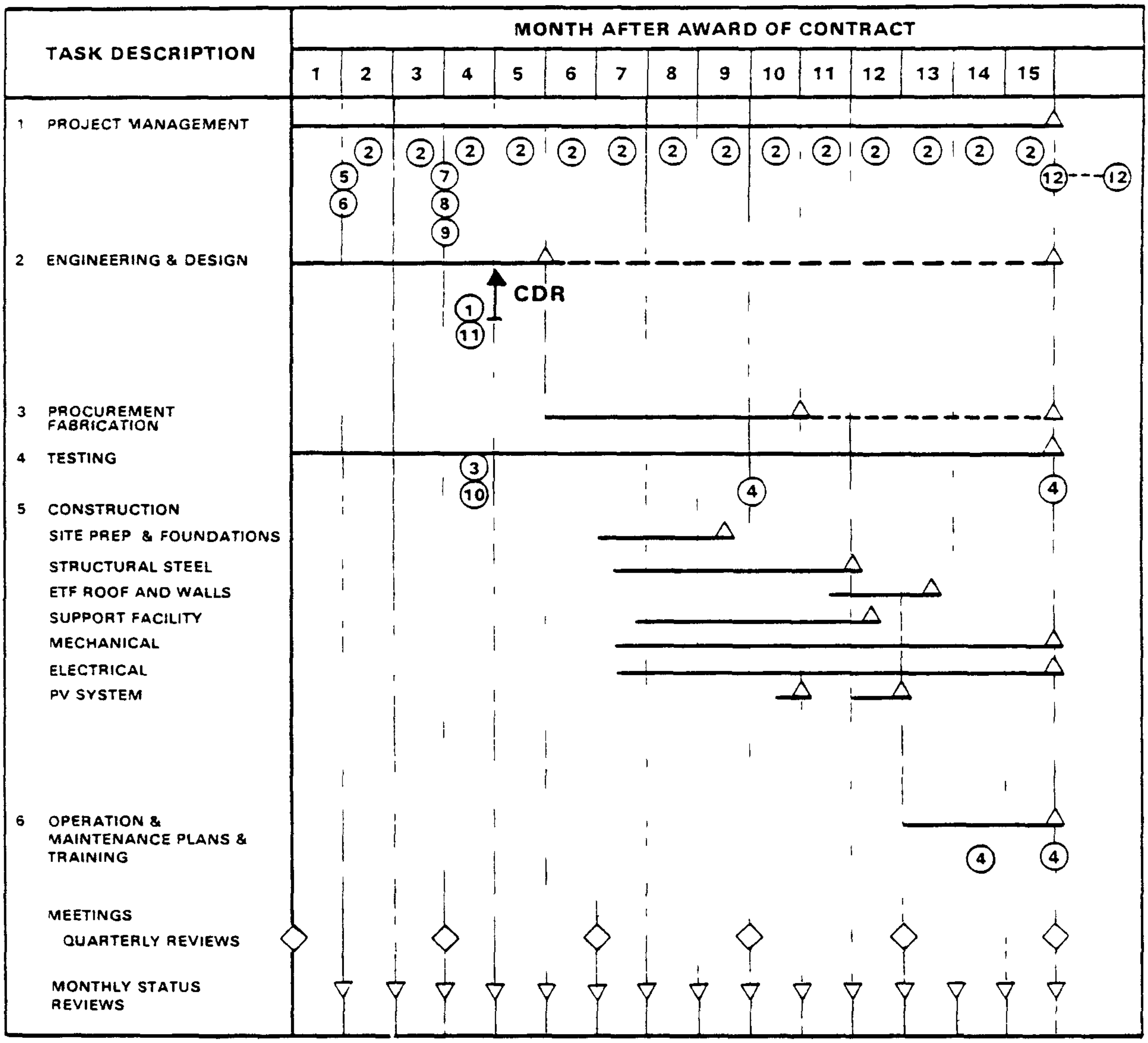
The WBS allowed the development of the Phase 2 schedule shown in Figure 9. The overall schedule for completion of Phase 2 is 15 months, of which approximately 10 months are associated with construction and checkout. No long lead items have been identified that could seriously impact the schedule.

In addition to the cost of the ETF for the El Paso, Texas, site, a cost multiplier has been estimated for construction of an ETF in Riyadh, Saudi Arabia. Cost differences between the two sites are principally due to the following factors:

- Construction costs - Due to limited availabilities of required materials of construction and skilled technicians and engineers, the cost increase for this element of the ETF is estimated at 29% of the total project cost

- Shipping costs - Most of the high technology elements of the system will come from the US, incurring handling and shipping costs estimated at an additional 1% of the total project cost

- Site differences - Because the Saudi Arabia and US sites are not identical certain design changes are required to the ETF in order to make it functional in Saudi Arabia. The specific



LEGEND

Ⓧ — DOCUMENTATION REQUIRED AS PER ITEM X SEE TABLE 4-1

CDR — CRITICAL DESIGN REVIEW

Figure 9. Phase 2 Schedule

items requiring modifications are the result of greater well depth and higher acquifer temperatures, requiring additional pumping power and an alternative cooling system. These changes are estimated to add an additional 33% to the project cost.

- Project Management - Both construction and project management represent additional cost items when conducted from the U.S. These cannot be estimated at this time until further details are available as to the required structure of the project.

The overall cost multiplier for an ETF in Saudi Arabia is thus estimated at around 1.63, or 63% higher than the El Paso, Texas site.

The operation of the ETF, or Phase 3 of the project, is currently planned for a 2 year period following construction. To estimate the cost of Phase 3 required a consideration of the following items:

- Routine Operation and Maintenance
  - O&M of equipment, structures, mechanical, electrical, and electronic systems (including replenishment of spare parts inventory)
  - Planting, growing, harvesting, and disposition of crops
- Conducting a Test and Evaluation Program
  - Collection and organization of experimental data
  - Analysis of data
  - Dissemination of data
- Training/Educating Visiting Personnel

These considerations resulted in a first year operating cost estimate of $950,000 and a second year estimate of $900,000. For the operation of the ETF at El Paso, Texas, the estimated costs are $950,000 for the first year of operation and $900,000 for the second year of operation.

ABSTRACT

This report sets forth the system requirements for a Solar Controlled-Environment Agriculture System (SCEAS) Project. In the report a conceptual baseline system description for an engineering test facility is given. This baseline system employs a fluid roof/roof filter in combination with a large storage tank and a ground water heat exchanger in order to provide cooling and heating as needed. Desalination is accomplished by pretreatment followed by reverse osmosis. Energy is provided by means of photovoltaics and wind machines in conjunction with storage batteries. Site and climatic data needed in the design process are given. System performance specifications and integrated system design criteria are set forth. Detailed subsystem design criteria are presented and appropriate references documented.

SECTION 1
INTRODUCTION

This report presents the results of Task 2 entitled "System Requirements Definition." The principal activities under Task 2 include the collection of standard climatic and site data, the generation of engineering field test system and subsystem performance specifications and the generation of integrated system design criteria. This Task 2 report summarizes the results of these activities and provides a guide for subsequent activities under Task 3 "Systems Analysis", Task 4 "Preliminary Design of Pilot Plant of an Engineering Field Test" and Task 5 "Phase 2 Definition Study". As these subsequent tasks are undertaken the Task 2 report will be used as a guide to insure that all of the requirements are being met. It is possible that some of the system or subsystem requirements may have to be modified as the project progresses, based on more complete information and ideas generated. However, in such cases a detailed rationale for the change will be provided.

The report is organized in such a way as to first provide an overview of the initial baseline design, followed by site and climatic data, system performance specifications, integrated system design criteria, subsystem design criteria, a list of references and finally a preliminary environmental assessment.

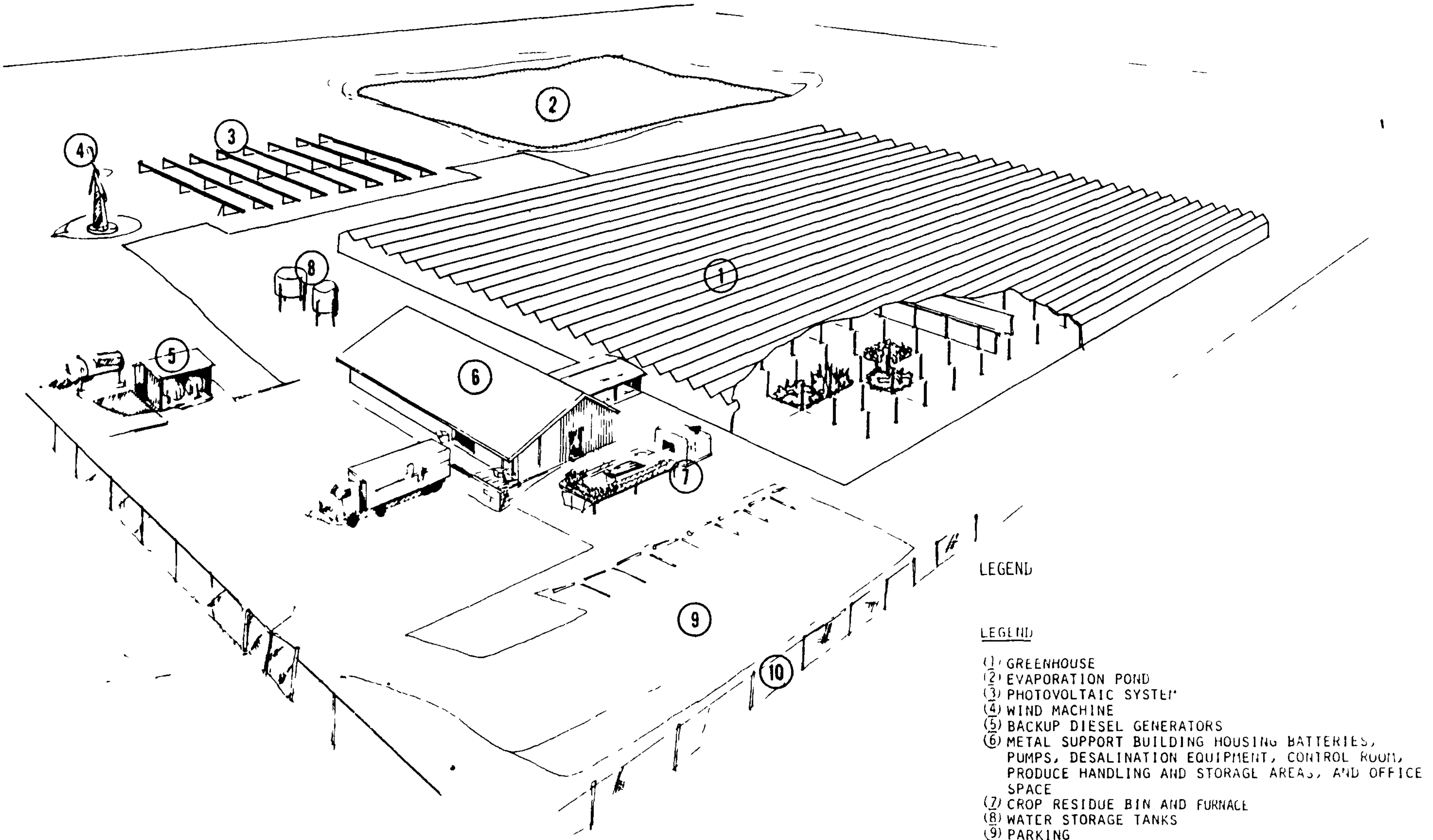
SECTION 2

ENGINEERING TEST FACILITY BASELINE SYSTEM DESCRIPTION

2.1 OVERVIEW OF THE DESIGN

The site location has been selected to be the Texas A&M Agricultural Experiment Station Farm in El Paso, Texas. An overall view of the SCEAS concept is shown in Figure 1. The basic elements of the system consist of a 0.96 hectare greenhouse; an evaporation pond; a photovoltaic system; a wind machine; a metal support building housing batteries, pumps, desalination equipment, controls and instrumentation, office space, product processing and handling areas, product and material storage areas as well as other greenhouse support operations; crop residue drying and burning operation; a CO_2 supplementation facility, backup diesel generators and water storage tanks. The entire facility will be surrounded by a fence.

The system block diagram shown in Figure 2 indicates key features of the system. The 0.96 hectare greenhouse is divided into four 0.2 hectare crop growth sections with a North-South dividing corridor. The greenhouse is cooled by water flowing between the double glass layers comprising the ridged roof. The inner glass pane is tinted to pass most of the photosynthetically active light (400-700 nm) and block the infrared radiation (greater than 700 nm) from passing through. This feature allows leaf temperatures only a few degrees centigrade above greenhouse air temperatures to be maintained. Heat collected by the flowing roof water is rejected through a heat exchanger to a cool water supply from an underground aquifer at $18^{o}C$. This same cool water supply is used to recover some of the water transpired by the plants in a condenser and thereby conserves on water usage. Cool air from the condenser is mixed with greenhouse air and small amounts of outside air and helps maintain relative humidity levels at about 85 percent. By re-injecting the cooled greenhouse air which has been enriched with CO_2, the amounts of CO_2 needed for enrichment are reduced as compared to a system which uses only outside air for humidity control. CO_2 enrichment is accomplished at least in part by burning the crop residues in a furnace. The hot gases from the



LEGEND

LEGEND

(1) GREENHOUSE
(2) EVAPORATION POND
(3) PHOTOVOLTAIC SYSTEM
(4) WIND MACHINE
(5) BACKUP DIESEL GENERATORS
(6) METAL SUPPORT BUILDING HOUSING BATTERIES, PUMPS, DESALINATION EQUIPMENT, CONTROL ROOM, PRODUCE HANDLING AND STORAGE AREAS, AND OFFICE SPACE
(7) CROP RESIDUE BIN AND FURNACE
(8) WATER STORAGE TANKS
(9) PARKING
(10) SECURITY FENCE

FIGURE 1 OVERALL VIEW OF PROPOSED CONCEPT

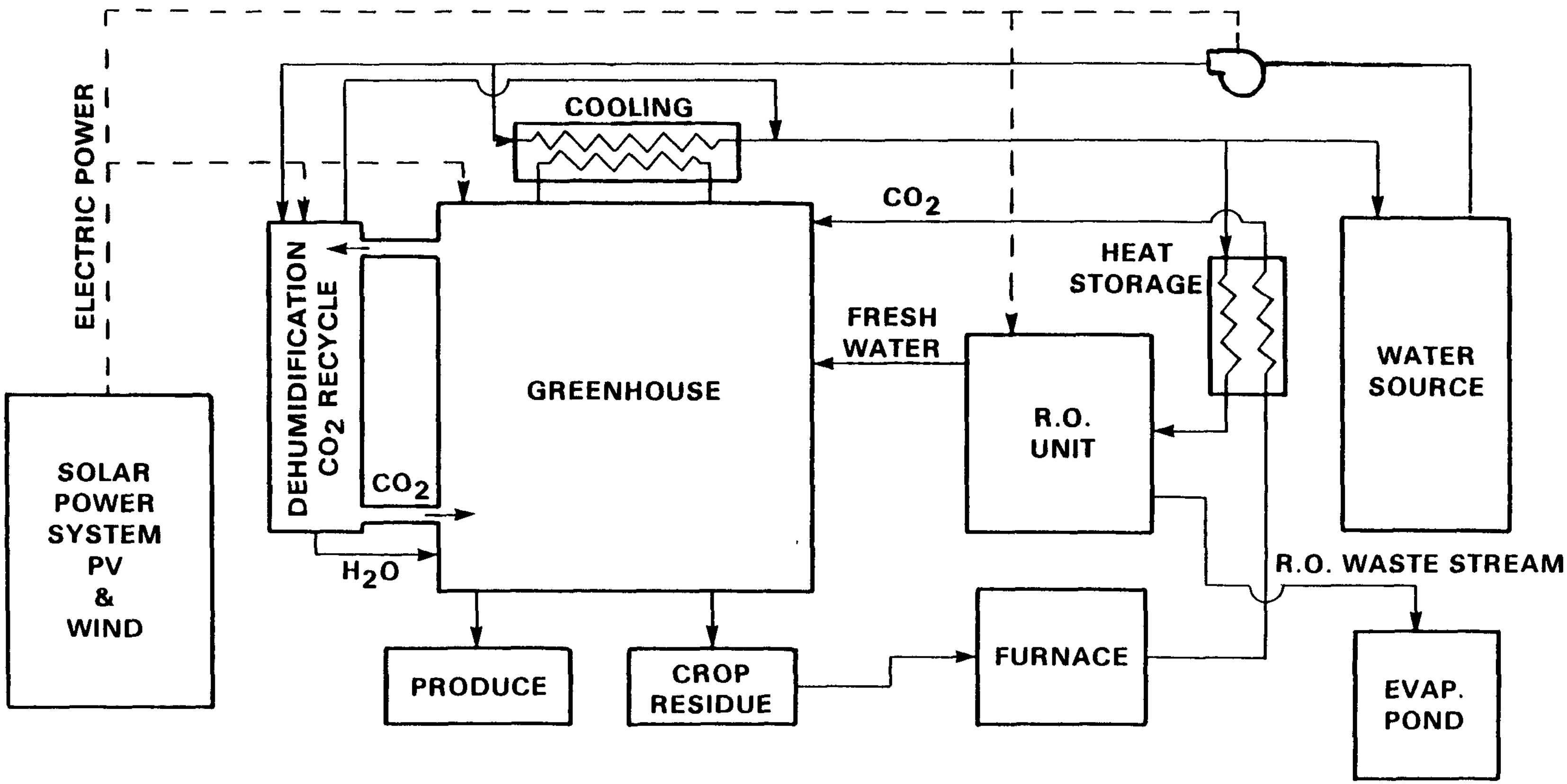


FIGURE 2. OVERALL SYSTEM BLOCK DIAGRAM

furnace, enriched in CO_2, are passed through a heat exchanger before entering the greenhouse. In this manner, heat is stored in an insulated water or oil filled storage tank and subsequently used for other facility needs.

The reverse osmosis process is used for desalination. Feedwater for the reverse osmosis unit is brackish water from the aquifer after it has been heated to about 45°C, using waste heat from the roof cooling system or from the above mentioned storage tank, and chemically treated. The rejected brine from the desalination equipment is sent to an evaporation pond.

Power is provided by means of a photovoltaic system which provides power in proportion to the greenhouse power needs. A wind energy conversion system has been incorporated into the power system in order to reduce battery storage, increase electrical system availability and take advantage of available resources.

Not shown in Figure 2 is the large underground concrete storage tank. Normal roof coolant flow is from the storage tank, up through the roof, to the heat exchanger if required, and back to the storage tank. This storage system can be used for heat and "coolness" storage depending upon the time of the year. The hydroponic crop production system allows growth of selected vegetables in a sand medium. These vegetables are rotated on a seasonal basis in consonance with greenhouse temperature variations.

2.2 INNOVATIVE FEATURES OF THE SYSTEM

We believe that the fluid roof/roof filter concept for greenhouse cooling is truly unique and innovative. Although this concept is not widely known, a 400 m^2 demonstration greenhouse using this concept has been built and is operating successfully in Hyeres, France. Much of the original design work for this facility was carried out by Dr. Cornelius van Bavel, a world renowned greenhouse expert. Dr. van Bavel, who is a key member of our team, has developed a detailed dynamic computer simulation code incorporating plant growth models for the proposed concept as well as for other more conventional greenhouses. This code is being incorporated into TRNSYS by SAI for use on this project.

The potential for innovation within the proposed concept and the options identified for later study is truly far reaching. Among these innovations are the following:

- A unique fluid roof/roof filter radiation control system
- An integrated, energy self-sufficient system
- A crop growth system with flexibility for crop selection and rotation
- An active/passive storage system for greenhouse cooling and heating
- Combined usage of both solar radiation and wind energy resources
- State-of-the-art desalination technology with broad applicability to other sites and water qualities
- Usage of crop residue carbon for CO_2 generation recycling
- Reduction of water usage by humidity control with ground water condensor
- A system with broad applicability to a range of site conditions.

SECTION 3
SITE AND CLIMATIC CHARACTERISTICS

The site chosen for detailed analysis is located in Texas in the lower El Paso Valley. In this section, a background description of the El Paso area is given, specific information on the proposed site is provided and detailed information on the climate is presented. Specific sources used to compile data for this section include references 1-10, 22 and 23.

3.1 BACKGROUND DESCRIPTION OF EL PASO AREA

El Paso is a city at the extreme western tip of Texas, on the Rio Grande River, opposite Ciudad Juarez in Mexico, is the seat of El Paso County and is the port of entry. The city lies at the foot of Mt. Franklin, below a pass where the Rio Grande issues from southernmost spurs of the Rockies. The altitude is 1,147 m (3,762 ft); the climate is sunny, mild, and dry, with annual precipitation averaging about 216 mm (8.5 in). Municipal deep wells supply the city with adequate water. It is the largest city on the Mexican border. Pop. (1970) 322,261; standard metropolitan statistical area (El Paso County) 359,291. The city and county together with Ciudad Juarez create an international community of more than 500,000 inhabitants, a metropolitan oasis hundreds of miles from any equal concentration of population and commerce. The Spanish language and the Latin heritage are important to the city's personality. Old adobe buildings in the city are distinctly Mexican, yet in general appearance El Paso is a modern U.S. city.

Both its original establishment and its growth are attributed essentially to a strategic site upon a transcontinental crossroad. It is an important foreign trade and transportation center on several federal highways and is served by both U.S. and Mexican railroads. Trucking systems augment these facilities, and commercial airlines operate from a municipal airport.

El Paso is a tourist gateway to Ciudad Juarez and the interior of Mexico on the Pan-American Highway and to attractions in a scenic area of the

United States, which include Carlsbad Caverns National Park and Big Bend National Park.

It is the commercial and financial center for a widespread trade territory where livestock ranching, irrigated cotton farming, and mineral production are chief resources. Located in El Paso are a copper-lead custom smelter and an electrolytic copper refinery, both among the world's largest. There are petroleum refineries, a cement plant, extensive carshops, and home offices of the world's largest natural-gas distributor. El Paso is a center of distributors and jobbers of manufactured products and goods. Many diversified small industries are components of the city's economy. A needle-goods industry, mainly the manufacture of cotton outdoor clothes, employs several thousand workers. El Paso stockyards and meat-packing plants process cattle and sheep from ranges in the southwestern U.S. and northern Mexico. El Paso is the centre of a reclamation area comprising 71,200 hectare (178,000 acres) of Rio Grande Valley farmlands irrigated from Elephant Butte and Caballo reservoirs. Two-thirds of annual production is cotton, much of it high quality long-staple. It is processed by the valley's ginning and cottonseed milling industries.

Military installations are important. Fort Bliss, established as a frontier post at El Paso in 1849, is a U.S. Army air defense missile test center and missile school. The Army's William Beaumont General Hospital adjoins Fort Bliss.

A scenic driveway around Mt. Franklin affords a fine view of the city and valley. El Paso has public, parochial, and private schools and is the seat of the University of Texas at El Paso (established 1913). A symphony orchestra is supported by El Paso's citizenry. The public library, built in 1954, houses over 340,000 volumes and is of outstanding architectural merit. A museum of art built in 1960 holds a collection of old masters and exhibits contemporary works. Beginning in late December each year the city celebrates a sun carnival, which includes art shows, bullfights, polo matches and horse races and which ends with a football game on January 1.

3.2 SITE DESCRIPTION

3.2.1 General Area Terrain

Physiographically the area includes three distinct divisions. These are (1) the rugged and prominent Franklin Mountains which reach 2186 m (7172 ft) above mean sea level, (2) the benchlands adjacent to the river valley which are locally referred to as the "Mesa" and average 1219 m (4000 ft) above mean sea level and, (3) the river valley which consists of the recent flood plain of the Rio Grande and is relatively level with a slight gradient of 0.53 m per kilometer (2.8 ft per mile) to the southeast. The river valley in the vicinity of the site is approximately 1128 m (3700 ft) above sea level.

Soils in the area are of the blue-point, loamy, fine-sand type which are favorable for structures of less than 3 stories and traffic ways. This soil is subject to blowing and requires special consideration for foundations and sub-level structures.

3.2.2 Water Source and Characteristics

The source of water for the SCEAS located on the Texas A&M Experimental Farm is the Rio Grande alluvium aquifer. Recharge to the aquifer comes from four sources:

1. Infiltration of precipitation which falls directly on the surface and runoff from the Mesa areas.
2. Upward leakage from the underlying Hueco and Messila Bolson deposits.
3. Leakage from the Rio Grande river and numerous canals which traverse the heavily cultivated and irrigated flood plain.
4. Excess irrigation water applied to the cultivated land.

Prior to the development of the surface water irrigation system, recharge was very small and the water level was below the bottom of the Rio

Grande. However, due primarily to recharge from irrigation the water level began rising and it was necessary to construct a system of drainage canals to keep the land from becoming waterlogged. On the average the aquifer is full and a large part of the recharge water is rejected and becomes drain flow. In years of subnormal surface water availability, there may be some reduction of the water level because of heavy pumping from the aquifer, which is recovered in years of good surface water availability. The water level at the site averages 3 m (10 ft) to 6 m (20 ft) below land level.

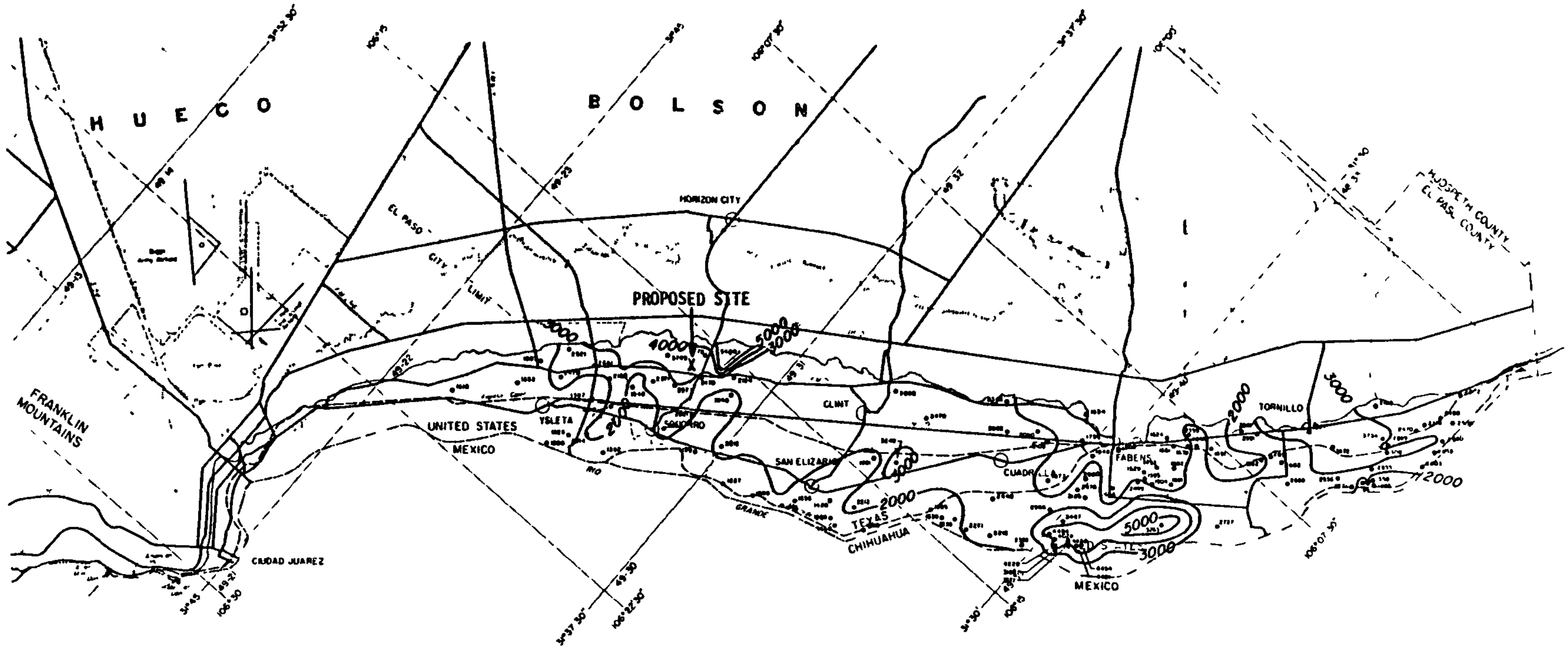
It appears therefore that the source of water for the SCEAS is renewable and that no significant reduction in water level will be experienced from its water useage.

3.2.3 Area Water Quality

Figure 3 shows the areal chemical quality of water in the Rio Grande alluvium aquifer. The quality varies considerably through the region. Most of the recharge to the alluvium is from infiltration of applied irrigation water. The use of partial recycling of this water has had the effect of increasing the salinity of the groundwater particularly in the upper water bearing sands of the alluvium. Table 1 shows analyses of water from selected wells on the Mesa and in the Valley to give an indication of the variable quality of water in the neighborhood of the selected site. The data show that water quality in the Mesa area is considerably better than in the valley and that the wells to reach the water table are approximately 61 m (200 ft) deeper than in the valley. These two factors resulted in elimination of a site in the Mesa area.

3.2.4 Specific Site

The site for the SCEAS is located on a 64 hectare (160 acre) experimental farm, owned and operated by the Texas A&M Experimental Station at El Paso. The farm is located in the Rio Grande Valley about 24 kilometers (15 miles) from El Paso airport and approximately 4.8 kilometers (3 miles) from route 10, the main East West interstate highway. Figure 3 shows the site location. Although irrigation water for the farm is obtained from the El Paso

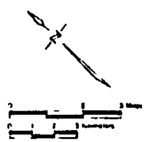


EXPLANATION

Sampled well
Number indicates the concentration of dissolved solids in the water, in milligrams per liter
Sampled wells are from 100-200 feet deep
Date of sampling is in the period 1964-74

—2000—
Line showing approximate concentration of dissolved solids, in milligrams per liter
Interval 1000 milligrams per liter

Approximate edge of the Rio Grande alluvium (from Van Horn-El Paso geologic atlas sheet)



Base adapted from county highway maps by the Texas Department of Highways and Public Transportation, topographic maps by the U.S. Geological Survey and maps of the El Paso County and Hudspeth County Water Improvement Districts

Figure 3.
Areal Distribution of Ground-Water Quality in the Rio Grande Alluvium, Lower El Paso Valley, Within the Depth Interval 0-200 Feet

Source: Texas Department of Water Resources, "Ground-Water Development in the El Paso Region, Texas with Emphasis on the Lower El Paso Valley", June 1980.

TABLE 1

ANALYSIS OF IRRIGATION WELLS
IN VICINITY OF TEXAS A & M EXPERIMENT STATION

MESA WELLS

From Fig 17: Well # 49-22:	Aquifer	Sample Depth ft.	Date	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	B	DS	Total Hardness as $CaCO_3$	Specific Conductance Micromhos at 25°C	pH
102	Qtal 6	323	8/1/66	29	.45	21	6.3	178	6.6	145	77	198	0.9	1.8	0.09	591	80	1050	7.6
103	Qtal 6	386	7/22/70	-	.01	34	6.0	254	-	-	106	320	0.8	-	-	747	110	-	8.2
201	Qtal 6	219	11/9/50	28	.13	40	9.8	200	-	130	84	269	-	1.0	-	704	140	1220	7.8
205	Qal Rg	87	7/27/56	-	-	-	-	-	-	298	-	358	-	-	-	-	470	2230	8.1
206	Qal Rg	110*	7/11/55	-	-	46	15.	194	-	-	130	249	0.5	-	-	778	178	-	8.2
601	Qal Rg	50	3/18/68	-	-	26	8.9	-	-	228	620	282	-	-	-	-	102	2520	7.4
613	Qtal 6	312	1/17/76	19	-	45	17.	312	-	82	775	366	0.6	<0.4	-	1080	182	1850	7.7
616	Qtal 6	220	5/15/74	31	-	43	13.	305	-	155	385	218	1.5	0.6	-	1070	161	1610	6.9
617	Qtal 6	307*	11/5/69	18	.05	-	-	340	-	96	482	295	-	-	-	1394	419	-	7.9
$\bar{X}$ MESA WELLS		223.7		25	.16	36.4	11.125	254.7		162	332.7	283.8	0.86	0.95		909.1	204.6	1746.6	7.75
VALLEY WELLS 49-22																			
118	Qal Rg	100	8/7/56	36	-	163	31	364	-	356	591	288	.8	1.5	-	1650	534	-	-
401	Qal Rg	103	9/24/57	30	-	85	25	200	7.6	247	274	193	.4	-	0.16	936	315	1500	7.7
506	Qal Rg	128	7/12/72	36	-	236	44	275	-	417	620	275	1.0	<0.4	-	1690	770	2220	7.5
512	Qal Rg	160	3/28/51	29	-	78	34	295	-	182	238	414	.8	2.5	.29	1180	334	2020	7.9
530	Qal Rg	93	1/17/76	11	-	109	37	347	-	397	444	298	1.1	<0.4	-	1440	426	2290	7.9
818	Qal Rg	173*	4/3/57	36	-	570	99	705	15	100	358	2050	0.1	-	0.15	3880	1830	6630	7.5
907	Qal Rg	111	9/5/56	-	-	-	-	-	-	386	-	880	-	-	-	-	845	4390	7.6
908	Qal Rg	145	3/28/51	32	-	353	108	965	-	162	938	1650	-	.5	0.3	4130	1320	6460	7.7
911	Qal Rg	138	do	36	-	219	71	855	-	154	844	1230	0.9	2.0	0.4	3330	838	5200	7.9
939	Qal Rg	90*	1/30/74	-	<0.1	120	61	654	-	-	950	600	1.1	-	-	1860	550	-	8.3
930	Qal Rg	126	1/15/76	23	-	286	61	700	-	228	1120	780	0.5	0.7	-	-	960	4160	8.0
$\bar{X}$ VALLEY WELLS		124.27		29.88	-	221.9	57.1	536		262.9	637.7	787	0.74	1.14	0.26	2232.8	793	3874.4	7.8
$\bar{X}$ ALL WELLS		169.0		28.14	.12	145.5	38.0	420		221.3	502	560.6	.785	1.07	0.23	1653.75	528.2	3023.3	7.778
STD. DEV.		94		7.7	.18	143.1	31.9	251.3		111.5	326.3	518.2	.35	0.75	0.116	1127.9	43[illegible].4	1863.7	.33

*average

Source of data: Texas Department of Water Resources, Report 246, "Ground-Water Development in the El Paso Region, with Emphasis on the Lower El Paso Valley", June 1980.

water district, there is a well on the farm which would be a suitable source of brackish water for the SCEAS. This well was run at 157 l/s (2500 gpm) for 2 hours on August 7, 1981. A sample taken after 2 hours showed 3488 ppm TDS and a water temperature of 18^{o}C (64^{o}F). A detailed water analysis is shown in Table 2. An approximately 2 hectare (5 acre) tract in the immediate vicinity of the well could be made available for the SCEAS.

3.3 CLIMATIC DATA

3.3.1 Climatological Summary

The El Paso National Weather Service station is located on a mesa at about 1189 m (3900 ft) elevation. The climate of the region is characterized by the abundance of sunshine throughout the year, high but no extreme daytime summer temperatures, with very low humidity, scanty rainfall, and a relatively mild winter season typical of arid areas at low latitudes.

Rainfall throughout the year is light, insufficient for any growth except desert vegetation, and irrigation is necessary for crops, gardens, and lawns. Dry periods of several months' duration without appreciable rainfall are not unusual. Almost half of the precipitation occurs in the three-month period, July-September, from brief, but at times heavy, thunderstorms. Small amounts of snow fall nearly every winter, but snow cover rarely amounts to more than a few cm and seldom remains on the ground for more than a few hours.

Daytime summer temperatures are high, frequently above 32^{o}C (90^{o} F) and occasionally above 38^{o}C (100^{o}F), but summer nights usually are comfortable, with minimum temperatures usually around 15-20^{o}C. The highest temperature on record is 45^{o}C (112^{o}F) in July 1981. It should be noted that when temperatures are high the relative humidity is generally quite low. A 20-year tabulation of observations with temperatures above 32^{o}C (90^{o}F) shows that in April, May, and June the humidity averaged from 10 to 14 percent, while in July, August, and September it averaged 22 to 24 percent. This low humidity aids the efficiency of evaporative air coolers, which are widely used in homes and public buildings and are quite effective in cooling the air to comfortable temperatures.

TABLE 2

RESULTS OF ANALYSIS ON UNIVERSITY FARM WELL WATER

McCORMACK CORPORATION

ESTIMATED OPERATING RESULTS

Name University Farm Well . . . Address East of El Paso, Texas

1. Raw water sample collected after two hours pumping at 2,500 gpm, as substance

2. 1 - converted to $CaCO_3$ 6.

3. 7.

4. 8.

Analysis of treated waters are typical of results anticipated. Any guarantees with reference to specific constituents are covered separately.

	Substance	Symbol	1	2	3	4	5	6	7	8
			mg/L (PPM) As $CaCO_3$							
Cations	Calcium	Ca^{++}	108	270						
	Magnesium	Mg^{++}	83.3	343						
	Sodium	Na^{+}	781	1702						
	Potassium	K^{+}	66.7	85						
	Hydrogen Acidity	H^{+}	-	-						
	Total Cations		-	2400						
Anions	Bicarbonate (Alkalinity)	HCO_3^-	416	416						
	Carbonate (Alkalinity)	CO_3^{-}	0	0						
	Hydroxide (Alkalinity)	OH^-	0	0						
	Phosphate (Alkalinity)	PO_4^-	1.5	2.4						
	Chloride	Cl^-	719	1014						
	Sulfate	SO_4^{--}	920	957						
	Nitrate	NO_3^-	1.5	1.2						
	Total Anions		-	2391						
	Total Hardness $CaCO_3$		615	613						
	Alkalinity A (Methyl Orange) $CaCO_3$		416	416						
	Alkalinity B (Phenophthalein)		0	0						
			mg/L (PPM) As Substance Or In Units Indicated							
	Free Carbon Dioxide	CO_2	CALC.	26						
	Silica – Total	SiO_2	16.4	16.4						
	2. Silica – Dissolved	SiO_2	15.6	15.6						
	1. Iron – Total	Fe	0.59	0.59						
	Iron – Dissolved	Fe	0.40	0.40						
	Manganese – Total	Mn	0.66	0.66						
	Manganese – Dissolved	Mn	0.56	0.56						
	Fluoride	F	1.15	1.15						
	Oxygen Demand	$KMnO_4$	-	5.6						
	Suspended Solids		24	24						
	1. Turbidity (NTU)		1.7	1.7						
	Silt Density Index		-	-						
	Color Apparent		-	-						
	Color True (APHA)		50	50						
	Total Organic Carbon	C	2.2	2.2						
	Conductivity mmho/cm		5166	5166						
	Total Ions		-							
	TDS (By Evaporation)		3488	3488						
	pH Field		-	-						
	Laboratory		7.5	7.5						
	Calculated		-	-						

Barium <0.01

Strontium 9.0

1. Haze in sample cleared when acidified
2. Sample thru 0.45U filter.

Winter daytime temperatures are mild, rising to 12.8°C (55°F) to 15.6°C (60°F) on the average. At night they drop below freezing about half the time in December and January. The flat, irrigated land of the Rio Grande Valley in the vicinity of El Paso is noticeably cooler, particularly at night, than the airport or the City proper, both in summer and winter. This result is more comfortable temperatures in summer but increased severity of freezes in winter. The cooler air in the Valley also causes marked short-period fluctuations of temperature and dewpoint at the airport with changes in wind direction, especially during the early morning hours.

The Franklin Mountains begin within the City limits and extend northward for about 25.8 kilometers (16 miles); peaks of these mountains range from 1429 m (4,687 ft) to 2180 m (7,152 ft) above sea level. They add noticeably to the gustiness of the winds during high velocities, and cause changes in direction during periods of light winds.

Dust and sandstorms are the most unpleasant features of the weather in El Paso. While wind velocities are not excessively high, the soil surface is dry and loose and natural vegetation is sparse, so moderately strong winds raise considerable dust and sand. A tabulation of duststorms, for a period of 20 years, shows that they are most frequent in March and April, and comparatively rare in the period July through December. The highest monthly average is in March - nearly 40 hours a month with visibility reduced to 9.6 kilometers (6 miles) or less by dust.

Prevailing winds are from the north in winter and south in summer, with the prevailing direction for the year north by a small margin.

3.3.2 Meteorological Data Base

The various meteorological data required to analyze the solar controlled environment agriculture system will be derived from historical data. The various data requirements are listed in Table 3. Hourly weather data will be used to determine plant performance, extremes will be used to set reliability and safety requirements. The source of data is the National

TABLE 3 METEOROLOGICAL DATA REQUIREMENTS BY SUBSYSTEM

PARAMETER \ SUBSYSTEM	PV COLLECTORS	WECS	ELECTRICAL STORAGE	EVAPORATION POND	GREENHOUSE
DIRECT NORMAL RADIATION	●				
TOTAL RADIATION ON A HORIZONTAL SURFACE	●			●	●
WIND SPEED	●	●		●	●
WIND DIRECTION		●			
DRY BULB TEMPERATURE	●	●	●	●	●
HUMIDITY				●	●
GROUND TEMPERATURE				●	●
RAINFALL RATE				●	
BAROMETRIC PRESSURE		●			
SNOW AND ICE	●	●			●

Climatic Center and their supporting agencies, either in the form of magnetic data tapes or printed summaries.

Tables 4a-g provide specific monthly data for 1980; historical normals, means and extremes; and other relevant monthly data for selected years. These are issued by the NOAA National Climatic Center in Ashville, N.C. Several of these data along with average lake-surface evaporation rates are plotted in Figure 4.

The meteorological data for the performance calculations will be obtained from the hourly records of the Typical Meteorological Year (TMY) data base for El Paso, Texas. This data set is part of a larger data set, (1, 2, 3, 7) and represents the best available hourly meteorological data that can be used to simulate mathematically the performance of solar energy systems.

The TMY data were derived from a larger data base, encompassing a twenty-three year historical record of hourly measured solar radiation data and surface weather observations ending in 1975. This "SOLMET" data base was prepared by NOAA for DOE, Division of Solar Technology, in 1977. The Typical Meteorological Year was developed by Sandia Laboratories in 1979.

Alternative choices of data include the TRY (Test Reference Year) data base, used extensively by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), This data base contains solar radiation data in the form of cloud cover specifications, so that a model is required to convert these data to solar radiation (direct normal and/or global). Extreme values were eliminated. Another choice might be the Liu-Jordan probabilistic model for solar radiation, but its drawbacks are that daily sequences are not accounted for and that wind is not included in this procedure.

For systems utilizing solar radiation the TMY data are the best available. However, great care has to be exercised in using the wind information. During the history of a weather station the location of the measuring equipment may have changed several times. Of special importance is the location and height of the anemometer. The TMY data are a concatenation

TABLE 4a

Meteorological Data For The Current Year

Station EL PASO, TEXAS # 23044 INTERNATIONAL AIRPORT Standard time used: MOUNTAIN Latitude 31° 48' N Longitude 106° 24' W Elevation (ground) 3918 feet Year 1980

Month	Temperature °F: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Total	Greatest in 24 hrs.	Date	Snow, ice pellets: Total	Greatest in 24 hrs.	Date	Relative humidity, pct.: Hour 05	Hour 11	Hour 17	Hour 23 (Local time)	Wind: Resultant: Direction	Speed m.p.h.	Average speed m.p.h.	Fastest mile: Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F: Maximum (b) 90° and above	32° and below	Minimum 32° and below	0° and below	Average station pressure mb Elev 3916 feet m.s.l.
JAN	59.9	33.7	46.8	71	14	17	24	565	0	0.54	0.27	30-31	T	T	22	67	49	37	59	24	2.2	7.6	33	30	15	67	5.5	12	7	12	5	0	1	0	0	0	31	0	881.8
FEB	64.0	37.2	50.6	80	26	16	9	410	0	0.73	0.24	8-9	3.6	3.6	8-9	68	49	35	54	28	3.0	8.0	29	30	29	81	4.6	11	13	5	6	1	0	1	0	0	7	0	882.4
MAR	69.1	39.1	54.1	78	22	24	2	331	0	0.25	0.29	10-11	0.0	0.0		43	27	19	34	28	4.8	10.3	39	31	31	82	4.8	17	6	8	3	0	0	0	0	0	6	0	879.1
APR	77.8	43.4	60.6	92	20	28	13	157	34	0.31	0.29	12	2.8	2.0	12	30	21	16	26	28	2.2	8.6	30	28	23	87	3.2	20	5	5	2	1	1	0	1	0	3	0	880.8
MAY	86.9	54.1	70.5	98	31	42	4	19	190	0.08	0.08	2-3	0.0	0.0		30	21	15	25	27	4.6	9.0	26	27	11	92	3.2	21	7	3	2	0	3	0	11	0	0	0	878.8
JUN	103.9	66.6	86.3	109	28	62	2	0	646	T	T	20	0.0	0.0		27	15	10	16	19	2.1	7.4	29	28	1	94	3.1	18	12	0	0	0	4	0	30	0	0	0	880.5
JUL	101.8	72.5	87.2	106	26	67	24	0	693	0.21	0.19	8-9	0.0	0.0		39	22	18	28	15	1.9	6.6	35	11	27	92	3.5	15	15	1	3	0	6	0	31	0	0	0	882.7
AUG	94.9	69.0	82.4	108	2	63	28	0	546	1.76	1.30	12-13	0.0	0.0		53	33	27	43	21	1.9	6.3	21	27	2	88	4.7	12	13	6	8	0	3	0	25	0	0	0	881.1
SEP	87.3	63.8	75.6	98	21	50	26	2	329	1.90	0.84	25-26	0.0	0.0		64	42	37	54	05	1.3	5.4	24	15	2	73	5.3	13	5	12	8	0	5	0	19	0	0	0	882.5
OCT	74.9	46.1	60.3	93	1	20	29	203	63	0.95	0.59	26	1.0	1.0	26	71	40	35	66	04	0.6	5.8	25	29	26	88	2.5	23	4	4	4	1	1	0	1	0	2	0	884.5
NOV	64.8	34.3	49.2	82	7	18	26	467	0	0.54	0.53	15-16	4.0	4.0	15-16	88	46	39	62	08	0.8	4.9	25	32	24	84	3.5	18	4	8	3	2	0	0	0	0	12	0	885.2
DEC	65.3	31.6	48.5	79	10	20	31	503	0	0.04	0.04	13	0.0	0.0		79	48	39	69	05	1.0	4.9	17	12	29	85	3.6	15	10	6	1	0	0	0	0	0	20	0	886.6
YEAR	79.1	49.5	64.3	109	JUN 28	16	FEB 9	2647	2509	7.31	1.30	AUG 12-13	10.6	4.0	NOV 15-16	56	34	27	44	26	1.2	7.1	39	31	MAR 31	85	3.9	195	101	70	45	5	24	1	113	0	61	0	882.2

TABLE 4b

Normals, Means, And Extremes

Month	Temperatures °F: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct.: Hour 05	Hour 11	Hour 17	Hour 23 (Local time)	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F: Max (b) 90° and above	32° and below	Min 32° and below	0° and below	Average station pressure mb Elev 3916 feet m.s.l.
(a)				41		41					41		41		41		41		41		20	20	20	20	38	15	5	5		38	38	38	38	38	41	41	41	41	20	20	20	20	8
J	57.0	30.2	43.6	80	1970	-8	1962	663	0	0.39	1.84	1949	0.00	1967	0.61	1960	8.3	1949	4.6	1973	63	44	34	54	8.9	N	40	28	1976	77	4.6	14	7	10	4	1	*	1	0	*	19	*	883.2
F	62.5	34.1	48.4	83	1972	8	1956	465	0	0.42	1.69	1973	0.00	1943	0.83	1956	8.9	1956	7.2	1956	53	36	26	43	9.8	N	46	26	1977	82	4.1	14	7	7	3	*	*	*	0	*	12	0	883.0
M	68.9	40.3	54.6	88	1971	14	1971	328	6	0.39	2.26	1958	T	1979	1.72	1941	7.3	1958	7.3	1958	44	28	20	33	11.7	WSW	48	30	1977	85	4.3	15	8	8	2	*	*	*	0	0	5	0	879.6
A	78.5	49.3	63.9	98	1965	24	1973	89	56	0.24	1.23	1942	0.00	1978	1.06	1966	2.0	1980	2.0	1980	36	22	15	26	11.7	WSW	42	30	1975	88	3.6	17	8	5	2	*	1	*	2	0	1	0	879.7
M	87.2	57.2	72.2	104	1951	31	1967	0	223	0.32	1.92	1941	0.00	1962	1.23	1942	0.0		0.0		39	22	15	27	10.9	WSW	35	25	1979	89	3.3	18	9	4	2	0	5	*	13	0	*	0	879.3
J	94.9	65.7	80.3	111	1978	40	1979	0	459	0.60	2.67	1966	T	1980	1.49	1966	0.0		0.0		42	24	17	30	9.9	S	40	22	1976	89	2.8	20	7	3	3	0	5	0	26	0	0	0	880.7
J	94.6	69.9	82.3	112	1979	57	1979	0	536	1.53	5.53	1968	0.04	1970	2.63	1968	0.0		0.0		63	39	29	45	8.8	SSE	35	11	1980	80	4.6	12	13	6	8	0	10	0	27	0	0	0	882.4
A	92.8	68.2	80.5	108	1980	56	1973	0	481	1.12	4.11	1957	T	1962	2.00	1957	0.0		0.0		62	40	31	48	8.3	S	35	13	1979	81	4.2	14	12	5	7	0	10	0	24	0	0	0	882.6
S	87.4	61.0	74.2	103	1948	41	1945	0	274	1.16	6.68	1974	T	1959	2.52	1958	0.0		0.0		66	44	34	53	8.1	S	29	08	1979	82	3.4	18	7	5	5	0	4	*	11	0	0	0	882.8
O	78.5	49.5	64.0	96	1979	25	1970	92	61	0.70	4.31	1945	0.00	1952	1.77	1945	1.0	1980	1.0	1980	61	36	29	50	8.0	N	35	27	1973	84	3.0	19	7	5	4	*	2	*	2	0	*	0	883.7
N	66.1	37.0	51.6	84	1973	1	1976	402	0	0.32	1.63	1961	0.00	1969	1.19	1943	12.7	1976	7.8	1961	61	39	33	52	8.3	N	40	24	1975	83	3.5	18	6	6	4	*	*	*	0	*	8	0	883.8
D	57.8	30.9	44.4	80	1973	5	1953	639	0	0.50	1.73	1960	0.00	1955	1.09	1946	10.1	1967	7.1	1951	63	44	36	54	8.3	N	42	24	1975	79	4.2	15	8	8	4	*	*	1	0	*	19	0	884.2
YR	77.2	49.5	63.4	112	JUL 1979	-8	JAN 1962	2670	2098	7.77	6.68	SEP 1974	0.00	APR 1978	2.63	JUL 1968	12.7	NOV 1976	7.8	NOV 1961	56	35	27	43	9.4	N	48	30	MAR 1977	83	3.8	194	99	72	46	2	35	2	105	1	64	*	882.1

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Maximum monthly precipitation 8.10 in July 1881; maximum precipitation in 24 hours 6.50 in July 1881; maximum snowfall in 24 hours 8 4 in November 1906.

(a) Length of record, years, through the current year unless otherwise noted, based on January data
(b) 70° and above at Alaskan stations
* Less than one half
T Trace

NORMALS - Based on record for the 1941-1970 period
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees

c February 1975 to Date.

CONVERSION TABLE
1 in. = 25.4 mm
°C = (°F-32) x 0.555
1 mph = 1.61 km/h
= 0.45 m/s

Table 4c

Average Temperature

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1941	46.7	53.0	53.8	60.2	73.7	78.6	80.9	79.8	74.4	65.2	53.3	48.2	64.0
#1942	47.7	48.2	54.1	63.6	73.5	83.6	83.6	79.4	73.5	64.8	58.1	47.7	64.8
1943	44.4	51.2	55.8	67.2	72.6	79.6	80.7	84.0	73.8	63.8	51.2	43.6	64.0
1944	40.8	49.4	54.0	61.6	71.7	79.4	82.3	80.0	72.6	65.6	51.4	44.7	62.8
1945	45.8	51.5	54.2	61.8	73.2	79.0	81.7	81.5	75.8	63.8	54.9	45.4	64.0
1946	41.0	48.5	55.8	67.8	71.6	82.6	82.0	81.8	76.8	66.2	49.8	47.0	64.2
1947	40.0	49.7	55.4	61.4	73.5	79.4	83.6	80.0	76.4	68.0	49.4	43.0	63.3
1948	40.6	48.8	50.8	67.4	74.6	82.2	83.2	82.2	76.0	64.4	47.9	47.8	63.6
1949	36.1	46.2	57.0	62.1	72.5	80.6	81.6	80.1	74.7	62.7	55.7	44.0	62.9
1950	49.2	53.4	58.0	65.9	72.1	82.5	79.6	80.6	74.4	70.7	54.0	49.5	65.8
1951	44.2	47.6	54.5	61.3	73.1	80.8	85.6	82.5	77.9	67.8	51.0	46.4	64.4
1952	49.2	47.5	50.7	63.0	72.0	82.7	81.3	83.6	76.2	65.4	49.5	44.1	63.8
1953	50.3	48.1	58.7	64.4	68.8	84.1	83.5	82.1	76.3	64.2	53.8	39.5	64.5
1954	47.0	52.6	54.9	68.6	73.2	81.2	83.2	79.3	78.5	67.9	54.5	46.0	65.6
1955	42.3	45.4	55.8	64.8	71.6	79.8	79.7	80.1	76.8	66.3	54.4	49.4	63.9
1956	49.7	44.9	57.5	61.8	75.7	83.9	82.0	79.9	77.4	67.5	48.4	44.6	64.4
1957	49.3	57.6	57.0	62.4	69.5	81.9	83.9	80.5	74.5	62.4	49.0	46.4	64.5
1958	42.9	51.6	51.2	63.3	74.2	83.5	84.5	82.6	74.0	62.5	53.3	47.0	64.2
1959	47.9	49.3	54.0	65.0	73.9	83.0	82.9	81.0	77.9	66.1	50.3	46.3	64.8
#1960	42.4	46.3	59.7	66.3	73.7	85.0	81.9	82.5	75.6	63.5	52.9	38.8	64.0
1961	41.0	47.9	56.3	64.1	74.1	80.8	82.8	80.5	74.5	63.5	47.8	46.3	63.3
1962	40.5	53.5	50.9	67.3	74.1	80.0	81.3	84.0	73.9	64.9	53.7	45.2	64.1
1963	40.5	49.2	56.4	66.5	74.9	81.1	84.9	80.3	76.2	66.4	53.5	42.7	64.4
1964	39.3	40.8	53.6	63.2	73.9	81.5	84.5	82.6	75.2	63.4	51.8	44.0	62.8
1965	48.0	46.7	52.1	65.3	71.8	78.2	84.2	81.1	74.0	63.0	56.8	45.7	63.9
1966	40.1	42.9	56.4	65.1	74.5	79.5	83.6	78.7	73.4	62.1	54.5	42.4	62.8
1967	41.6	48.0	59.6	65.1	70.9	79.1	83.0	78.6	73.3	63.7	53.1	41.5	63.1
1968	42.4	50.4	53.0	61.4	73.0	81.0	79.1	76.5	72.4	65.0	51.0	41.3	62.2
1969	48.6	48.4	49.4	65.8	72.1	81.5	84.9	85.7	77.1	67.7	52.5	49.6	65.2
1970	46.9	52.3	55.6	63.5	72.2	79.7	82.8	81.4	74.2	59.5	51.9	48.0	64.0
1971	44.6	48.4	58.1	62.6	72.1	81.1	82.3	77.0	73.5	62.5	52.1	44.7	63.2
1972	45.2	52.3	61.2	65.2	69.8	78.3	82.2	77.7	72.9	65.7	48.8	46.6	63.8
1973	42.9	47.0	52.4	57.7	68.7	76.6	79.7	79.2	75.9	63.3	53.8	45.7	61.9
1974	44.3	44.8	59.6	65.0	75.6	82.8	79.6	77.0	69.4	63.0	49.9	41.3	62.7
1975	43.1	48.9	55.1	59.7	69.8	80.9	79.8	80.9	72.2	64.0	51.5	44.2	62.5
1976	42.3	52.6	55.9	64.1	69.5	79.4	78.2	78.7	70.5	58.5	44.8	41.9	61.4
1977	40.7	47.3	49.7	61.5	70.7	81.5	82.2	82.5	77.4	64.3	53.7	49.6	63.6
#1978	45.4	48.8	58.6	66.1	73.6	83.4	84.5	80.0	72.3	63.6	55.8	44.6	64.7
1979	41.0	47.1	53.1	63.6	70.1	78.9	85.1	78.8	74.2	66.2	47.9	43.1	62.4
1980	46.8	50.6	54.1	60.6	70.5	86.3	87.2	82.4	75.6	60.3	49.2	48.5	64.3
RECORD MEAN	44.7	49.3	55.6	63.7	72.2	80.8	82.0	80.3	74.8	64.6	52.4	45.2	63.8
MAX	57.2	62.4	69.1	77.6	86.0	94.5	94.0	92.0	86.8	77.8	65.7	57.5	76.7
MIN	32.1	36.1	42.0	49.8	58.3	67.0	69.9	68.5	62.7	51.3	39.1	32.8	50.8

Table 4e

Heating Degree Days

EL PASO, TX

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
#1960-61	0	0	0	86	357	606	775	477	266	97	1	0	2921
1961-62	0	0	0	82	513	575	754	318	433	36	3	0	2714
1962-63	0	0	0	65	333	608	753	438	279	41	0	0	2517
1963-64	0	0	0	17	341	683	789	695	354	99	3	0	2981
1964-65	0	0	0	76	391	647	521	504	397	54	7	2	2595
1965-66	0	0	4	107	240	592	769	612	264	59	4	0	2651
1966-67	0	0	2	126	307	695	718	469	173	56	25	0	2571
1967-68	0	0	2	108	352	720	691	415	377	128	0	0	2791
1968-69	0	0	0	61	414	728	503	464	477	43	24	0	2714
1969-70	0	0	0	67	371	504	556	348	286	94	33	0	2254
1970-71	0	0	34	180	386	519	625	457	254	110	6	0	2578
1971-72	0	0	31	117	381	624	607	364	126	56	3	0	2304
1972-73	0	0	3	97	480	563	679	499	384	218	31	0	2944
1973-74	0	0	7	90	336	592	636	558	178	79	5	0	2481
1974-75	0	0	41	107	445	728	672	445	309	188	13	0	2948
1975-76	0	0	20	66	399	640	696	351	278	91	26	0	2567
1976-77	0	0	7	214	601	709	623	492	469	138	3	0	3256
1977-78	0	0	0	56	328	472	603	449	200	57	22	0	2187
#1978-79	0	0	16	106	272	625	735	494	362	118	26	1	2755
1979-80	0	0	24	56	505	677	555	410	331	157	19	0	2727
1980-81	0	0	2	203	467	503							

Table 4f

Cooling Degree Days

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1969	0	1	1	71	250	501	627	647	372	155	2	0	2626
1970	0	0	2	57	263	448	559	514	321	19	0	0	2183
1971	0	0	45	45	235	492	543	375	293	43	0	0	2071
1972	0	4	15	70	159	404	543	401	247	120	0	0	1963
1973	0	0	0	7	152	355	459	448	340	44	7	0	1812
1974	0	0	19	84	338	540	459	378	181	54	0	0	2053
1975	0	0	9	35	170	482	469	502	241	41	1	0	1950
1976	0	0	4	71	170	441	418	434	179	18	0	0	1735
1977	0	0	0	39	186	500	540	552	380	43	0	0	2240
#1978	0	0	8	98	295	559	612	474	238	70	2	0	2356
1979	0	0	0	84	190	414	630	432	308	99	0	0	2157
1980	0	0	0	34	198	646	693	546	329	63	0	0	2509

Table 4d

Precipitation

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1941	0.59	0.55	1.97	1.18	1.92	0.18	0.77	1.42	5.19	1.55	0.49	0.48	16.29
1942	0.06	0.65	0.01	1.23	T	0.05	1.08	1.86	0.64	1.61	T	1.26	8.45
1943	0.25	0.00	0.07	T	T	1.63	0.92	0.44	1.36	T	1.53	0.82	7.02
1944	0.45	1.42	0.15	T	0.39	1.67	1.52	1.04	0.25	1.30	0.41	0.48	9.08
1945	0.11	0.17	0.64	T	T	0.03	0.47	0.84	0.12	4.31	0.00	0.05	6.74
1946	1.23	T	0.04	0.36	1.23	0.20	0.71	1.19	1.51	0.41	0.03	1.31	8.22
1947	0.67	T	0.66	0.06	0.68	0.53	0.97	1.63	0.02	0.35	0.53	0.82	7.12
1948	0.29	0.63	0.04	0.11	T	0.96	0.82	1.82	0.03	0.18	T	0.86	5.70
1949	1.84	0.22	0.04	0.05	0.39	0.51	1.18	0.43	1.74	1.50	T	0.86	8.76
1950	0.29	0.26	T	T	0.10	0.11	3.57	0.16	1.32	0.94	0.00	0.00	6.75
1951	0.33	0.63	0.89	0.45	T	T	2.48	0.72	0.04	0.43	0.12	0.68	6.47
1952	0.02	0.96	0.92	1.08	0.46	1.14	1.88	1.06	0.07	0.00	0.23	0.15	7.97
1953	0.00	0.34	0.12	0.71	0.27	0.53	0.99	0.42	T	0.65	T	0.39	4.42
1954	0.10	T	0.09	0.19	1.26	0.23	0.88	2.37	0.95	0.30	0.00	0.02	6.39
1955	0.59	0.05	0.18	0.00	0.26	0.10	3.70	0.70	0.16	0.73	0.15	0.00	6.70
1956	0.35	1.06	T	0.05	T	1.19	1.10	0.61	0.43	0.01	T	0.64	5.44
1957	0.24	0.46	0.33	0.09	0.10	0.02	2.64	4.11	0.11	2.34	0.74	0.02	11.20
1958	0.74	1.11	2.26	0.05	0.40	1.66	1.36	1.14	6.29	1.98	0.20	T	17.19
1959	0.21	T	0.07	0.15	0.30	0.46	0.40	2.39	T	0.58	0.14	0.29	4.99
1960	0.72	0.37	0.21	0.02	0.04	0.76	3.61	0.77	0.01	0.77	0.11	1.73	9.12
1961	0.41	T	0.29	0.01	T	0.27	2.18	1.40	0.69	0.18	1.63	0.63	7.69
1962	0.94	0.58	0.24	0.10	0.00	T	1.82	T	3.54	0.55	0.21	0.30	8.28
1963	0.13	0.53	T	T	0.71	0.05	0.52	1.03	0.64	0.55	0.76	T	4.92
1964	T	T	0.99	0.08	0.02	T	0.18	0.76	2.40	0.40	0.00	0.52	5.35
1965	0.19	0.59	0.03	0.01	0.11	0.66	0.17	0.49	2.12	0.18	0.12	0.74	5.41
1966	0.38	0.20	T	1.08	0.04	2.67	1.17	1.85	1.79	0.01	0.01	0.04	9.24
1967	0.00	0.04	0.17	0.03	0.05	1.41	0.84	0.54	1.54	0.09	0.23	0.78	5.72
1968	0.47	1.11	0.85	0.10	T	0.03	5.53	1.71	0.53	0.11	1.35	0.23	12.02
1969	0.05	0.08	0.17	T	0.28	T	1.14	0.28	0.43	0.59	0.63	0.69	4.39
1970	0.03	0.55	0.47	T	0.71	0.73	1.41	0.41	1.01	0.68	T	0.06	6.06
1971	0.17	0.04	0.00	0.42	T	0.01	2.34	1.59	0.96	1.07	0.14	0.50	7.24
1972	0.44	T	T	0.00	0.04	1.62	0.71	2.59	1.60	1.25	0.33	0.42	9.00
1973	1.23	1.69	0.60	0.00	0.29	0.71	2.12	0.73	0.01	0.07	0.08	T	7.53
1974	0.27	T	0.36	0.12	0.05	0.36	2.21	0.63	6.68	1.90	0.50	0.87	13.95
1975	0.70	0.59	0.19	T	0.03	T	1.11	0.45	2.18	0.25	T	0.71	6.21
1976	0.26	0.52	T	0.30	0.74	0.50	3.17	0.23	1.70	1.20	1.20	0.32	10.14
1977	0.57	T	0.17	0.09	0.06	0.04	1.09	1.36	0.16	1.65	0.05	0.26	5.50
1978	0.44	0.47	0.07	0.00	0.57	1.46	0.04	2.18	4.14	2.28	0.45	0.47	12.57
1979	0.77	0.68	T	0.28	0.24	0.03	0.98	2.16	0.41	T	0.04	0.25	5.84
1980	0.54	0.73	0.25	0.31	0.08	T	0.21	1.78	1.90	0.95	0.34	0.04	7.31
RECORD MEAN	0.44	0.41	0.33	0.24	0.34	0.59	1.67	1.43	1.28	0.81	0.43	0.49	8.46

Table 4g

Snowfall

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1941-42	0.0	0.0	0.0	0.0	0.0	T	0.0	T	0.1	0.0	0.0	0.0	0.1
#1942-43	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	1.5
1943-44	0.0	0.0	0.0	0.0	4.2	T	T	T	T	0.0	0.0	0.0	4.2
1944-45	0.0	0.0	0.0	0.0	T	0.0	T	T	T	T	0.0	0.0	T
1945-46	0.0	0.0	0.0	0.0	0.0	T	6.0	T	T	0.0	0.0	0.0	6.0
1946-47	0.0	0.0	0.0	0.0	T	0.8	5.3	0.0	3.8	0.0	0.0	0.0	9.9
1947-48	0.0	0.0	0.0	0.0	0.0	0.6	2.4	0.6	T	0.0	0.0	0.0	3.6
1948-49	0.0	0.0	0.0	0.0	0.0	T	8.3	T	T	T	0.0	0.0	8.3
1949-50	0.0	0.0	0.0	0.0	0.0	T	T	T	T	0.0	0.0	0.0	T
1950-51	0.0	0.0	0.0	0.0	0.0	0.0	3.8	1.8	T	T	0.0	0.0	5.6
1951-52	0.0	0.0	0.0	0.0	0.0	7.1	T	1.0	T	T	0.0	0.0	8.1
1952-53	0.0	0.0	0.0	0.0	T	T	0.0	T	0.0	0.0	0.0	0.0	T
1953-54	0.0	0.0	0.0	0.0	T	2.2	T	0.0	0.0	0.0	0.0	0.0	2.2
1954-55	0.0	0.0	0.0	0.0	0.0	0.6	T	T	0.8	0.0	0.0	0.0	1.4
1955-56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	0.0	T	0.0	0.0	8.9
1956-57	0.0	0.0	0.0	0.0	0.0	2.3	T	0.0	T	0.0	0.0	0.0	2.3
1957-58	0.0	0.0	0.0	0.0	4.1	0.0	2.0	0.0	7.3	T	0.0	0.0	13.4
1958-59	0.0	0.0	0.0	0.0	0.6	0.0	0.0	T	T	0.0	0.0	0.0	0.6
1959-60	0.0	0.0	0.0	0.0	0.0	T	T	2.1	T	T	0.0	0.0	2.1
1960-61	0.0	0.0	0.0	0.0	0.0	10.1	T	0.0	T	0.0	0.0	0.0	10.1
1961-62	0.0	0.0	0.0	0.0	7.8	T	1.6	0.0	T	0.0	0.0	0.0	9.4
1962-63	0.0	0.0	0.0	0.0	0.0	0.0	0.8	5.3	0.0	0.0	0.0	0.0	6.1
1963-64	0.0	0.0	0.0	0.0	0.0	T	0.0	T	T	0.0	0.0	0.0	T
1964-65	0.0	0.0	0.0	0.0	0.0	T	0.0	0.3	T	0.0	0.0	0.0	0.3
1965-66	0.0	0.0	0.0	0.0	0.0	T	0.4	T	T	0.0	0.0	0.0	0.4
1966-67	0.0	0.0	0.0	0.0	0.0	T	0.0	T	0.0	T	0.0	0.0	T
1967-68	0.0	0.0	0.0	0.0	0.0	5.6	2.1	2.3	0.8	0.0	0.0	0.0	10.8
1968-69	0.0	0.0	0.0	0.0	7.0	T	0.0	0.0	T	0.0	0.0	0.0	7.0
1969-70	0.0	0.0	0.0	0.0	6.0	1.9	0.3	1.7	T	0.0	0.0	0.0	9.9
1970-71	0.0	0.0	0.0	0.0	0.0	0.0	3.8	T	0.0	T	0.0	0.0	3.8
1971-72	0.0	0.0	0.0	0.0	0.0	1.0	2.5	0.0	0.0	0.0	0.0	0.0	3.5
1972-73	0.0	0.0	0.0	0.0	0.0	T	5.3	4.6	T	0.0	0.0	0.0	9.9
1973-74	0.0	0.0	0.0	0.0	T	0.0	T	T	0.0	0.0	0.0	0.0	T
1974-75	0.0	0.0	0.0	0.0	0.0	5.3	2.2	0.2	2.0	0.0	0.0	0.0	9.7
1975-76	0.0	0.0	0.0	0.0	0.0	T	1.0	0.0	T	T	0.0	0.0	1.0
1976-77	0.0	0.0	0.0	T	12.7	2.0	T	T	0.0	T	0.0	0.0	14.7
1977-78	0.0	0.0	0.0	0.0	0.0	0.0	T	0.0	0.0	0.0	0.0	0.0	T
1978-79	0.0	0.0	0.0	0.0	T	T	T	1.2	0.0	0.0	0.0	0.0	1.2
1979-80	0.0	0.0	0.0	0.0	0.0	0.0	T	3.6	0.0	2.0	0.0	0.0	5.6
1980-81	0.0	0.0	0.0	1.0	4.0	0.0							
RECORD MEAN	0.0	0.0	0.0	T	1.1	1.0	1.3	0.8	0.4	T	0.0	0.0	4.6

# Indicates a station move or relocation of instruments. See Station Location table.

Record mean values above are means through the current year for the period beginning in 1887 for temperature, 1879 for precipitation and 1940 for snowfall. Temperature, degree days, and snowfall data are from City Office locations through November 1942, precipitation through 1939.

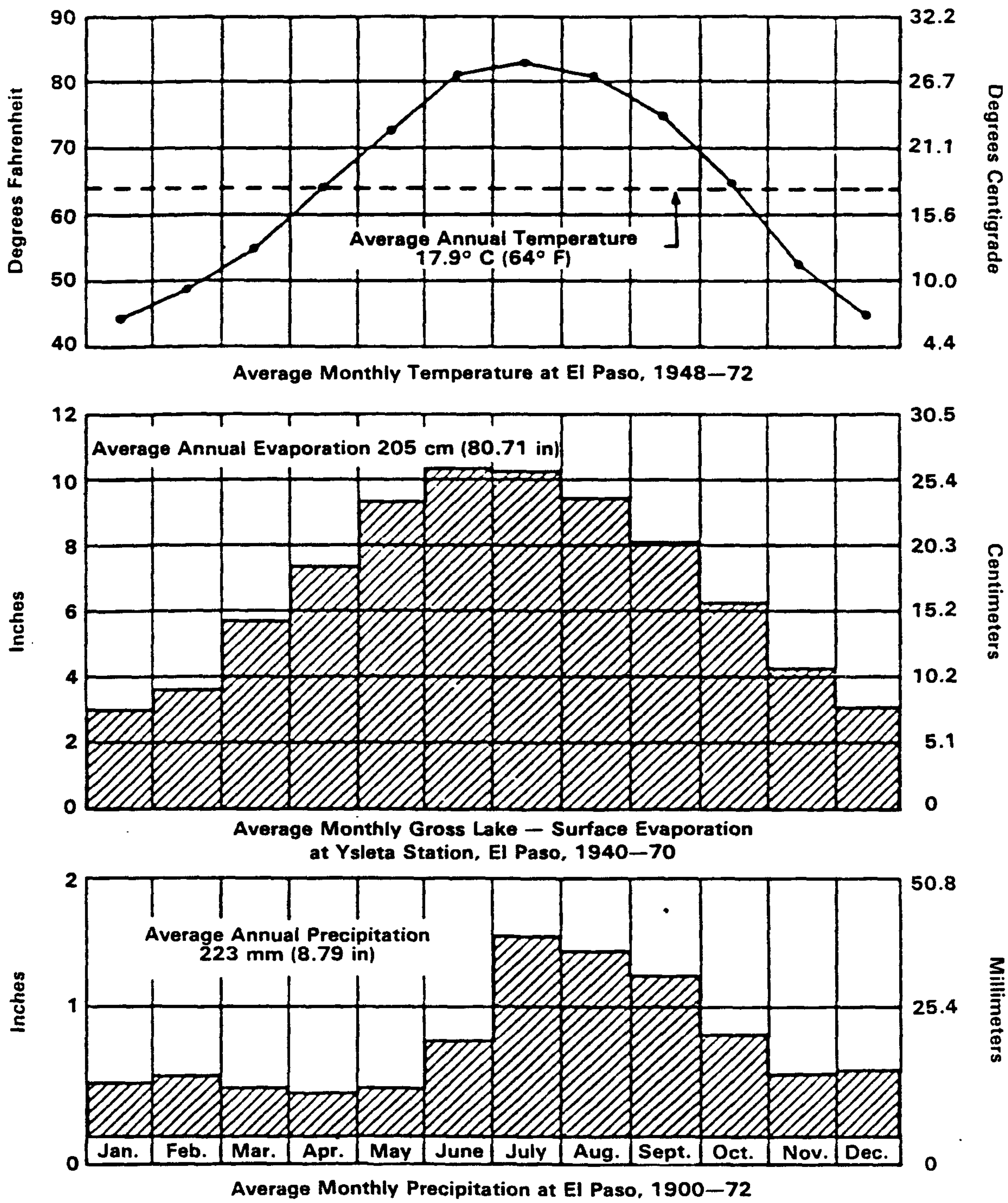


Figure 4 .—Average Monthly Temperature, Evaporation, and Precipitation at El Paso (Temperature and precipitation data from National Weather Service; lake-surface evaporation obtained as described in Kane, 1967)

of typical months selected from a long term data record spanning the years 1952 through 1975. Specifically for El Paso, Texas the months selected are given in Table 5.

Table 5. TMY Months for El Paso, Texas

January	1974	July	1971
February	1967	August	1961
March	1975	September	1971
April	1974	October	1967
May	1954	November	1971
June	1961	December	1956

The wind measurements during the period of record were taken at different heights. The anemometer height histories were obtained of all available wind observations (6). For El Paso, Texas the following was extracted:

14 September 1942: anemometer was moved to roof of building, 25.9m (85 ft) above ground level;

5 January 1961: anemometer was moved to a mast attached directly to the ground, 6.1m (20 ft) above ground level;

11 April 1964: anemometer was moved to a roof of a building 11.3m (37 ft) above ground level.

The windspeed for each hour of the year will be adjusted to a reference height of 10m (33 ft) using the convential 1/7 power law.

When computing windpower, using the corrected windspeed at the hubheight of the wind machine and the power/windspeed curves supplied by the manufacturer, an additional correction factor will be made for air density. This is especially important since El Paso is located approximately 1200 m (3940 ft) above sea level. Thus, for a given windspeed the power obtained from the performance curve will be multiplied by f_d the density correction factor, defined as

$$f_d = \frac{\rho}{\rho_{ref}}$$

where $\rho = \frac{0.0012930}{1+0.00367T} \left[\frac{B-0.378e}{760}\right]$, g/cm^3

ρ ref = 1.24×10^{-3} gm/cm^3 or 1.24 kg/m^3

T = ambient air temperature, ^{o}C

e = partial pressure of water vapor in the air, mm of mercury

B = barometric pressure, mm of mercury

The partial pressure of water vapor, e, will be computed using the procedures given in References 4 and 5.

The following quantities will be extracted from the TMY data tape:

- direct normal radiation
- total radiation on a horizontal surface
- wind speed
- wind direction
- dry bulb temperature
- barometric pressure

The humidity of the air can be expressed in various terms, such as absolute humidity, relative humidity, partial pressure of water vapor, all of which can be determined from the dry bulb temperature, wet bulb temperature, and barometric pressure using appropriate thermodynamic relationships. Relationships (4, 5) exist to derive any moist air variable desired. The parameters to be computed are:

- wet bulb temperature
- absolute humidity
- relative humidity
- humidity ratio
- enthalpy of moist air
- partial pressure of water vapor in moist air
- volume of moist air

In order to obtain a visual picture of the relationships between solar radiation and windspeed, the hourly quantities for each month of total solar radiation on a horizontal surface and windspeed at 10m height were sorted and placed in bins and the results displayed in a 3-dimensional plot. These plots were generated for each month of the year using the TMY data set. The results are shown in Tables 6a, b, and Figure 5. As may be noted this form of representation is dominated by the hours of no solar radiation (night time hours). Ideally one would like to see a band extend horizontally from left to right, implying a perfect complementarity of solar and wind, ranging from no wind - plenty of sunshine to no sunshine - plenty of wind.

A different display of the local meteorology with respect to solar radiation and wind is shown in Figures 6a and b where the average solar radiation and windspeed is plotted for each month of the year.

3.4 CLIMATIC DESIGN CRITERIA

The following design criteria will be used in the analysis and design of the SCEAS.

- Maximum Solar Intensity - 1000W/m^2
- Maximum Wind Speed (10m above ground) - 35.8 m/s (80mph)
- Seismic - Zone No. 1
- Live Loads - 0.72 kPa (15 psf) vertical load or 144kgm (250 lbs) manload on a member in its most critical position (SBC 2304 (a, b).
- Wind Load - 1.77 kPa (37 psf) velocity pressure as set forth in Table 23B (SBC 2306.2 (a))

TABLE 6 a. MONTHLY RESULTS OF EL PASO TMY RADIATION/WIND CORRELATION STUDIES

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 1

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	154	113	119	43	52	22	13	17	4	1	0	538
.200	13	12	8	5	6	1	0	0	3	0	0	48
.300	5	3	2	1	1	0	2	0	1	1	0	16
.400	11	11	8	3	3	3	1	0	2	0	0	42
.500	12	9	10	5	3	2	1	0	1	1	0	44
.600	7	12	12	9	5	2	1	2	1	0	0	51
.700	1	2	0	0	0	1	0	0	0	0	0	4
.800	1	0	0	0	0	0	0	0	0	0	0	1
.900	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	0	0	0	0	0	0	0	0	0	0
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	204	162	159	66	70	31	18	19	12	3	0	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 2

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	161	91	65	43	54	16	4	7	2	3	1	447
.200	4	5	1	3	3	0	0	0	0	0	0	16
.300	11	3	9	4	4	2	0	0	1	0	0	34
.400	4	8	3	4	3	3	0	0	0	0	0	25
.500	10	6	7	9	10	2	1	1	0	0	0	46
.600	9	10	6	5	9	1	1	0	0	1	0	42
.700	9	8	7	5	10	2	0	2	0	0	0	43
.800	6	5	2	3	3	0	0	0	0	0	0	19
.900	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	0	0	0	0	0	0	0	0	0	0
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	214	136	100	76	96	26	6	10	3	4	1	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 3

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	102	76	90	54	39	30	16	19	4	4	17	455
.200	6	6	5	6	2	6	3	3	1	0	2	40
.300	9	1	4	2	3	4	4	1	0	0	0	28
.400	6	6	4	4	5	0	2	0	1	1	1	30
.500	6	7	1	2	3	4	3	3	3	1	1	34
.600	4	7	6	1	4	2	2	1	1	2	1	31
.700	6	7	3	0	3	2	3	4	2	4	3	37
.800	8	8	6	3	8	1	1	4	2	5	4	50
.900	3	6	7	3	4	1	2	2	3	2	4	35
1.000	0	1	0	0	1	0	1	1	0	0	0	4
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	152	127	126	75	72	46	39	38	17	19	33	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 4

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	71	72	57	50	53	40	25	26	17	8	7	426
.200	0	2	1	3	1	1	3	1	1	3	1	17
.300	6	6	5	5	2	3	2	2	1	1	1	34
.400	0	4	4	8	3	0	1	0	2	1	0	23
.500	1	2	4	1	3	0	0	3	1	0	0	15
.600	2	7	6	11	7	2	2	4	5	0	1	47
.700	2	1	1	4	5	1	2	1	2	3	1	23
.800	1	6	7	6	10	3	4	1	2	0	1	41
.900	3	5	5	6	10	7	6	0	2	0	0	44
1.000	3	4	6	6	9	16	2	2	0	0	0	48
1.100	0	0	0	0	0	2	0	0	0	0	0	2
TOTAL	89	109	96	100	103	75	47	40	33	16	12	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 5

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	84	31	75	54	35	25	47	13	9	10	7	390
.200	7	5	13	15	2	4	3	0	0	1	0	50
.300	1	0	1	0	0	2	1	1	0	0	0	6
.400	10	9	12	11	3	6	3	0	1	1	0	56
.500	1	0	2	3	1	1	0	1	1	0	0	10
.600	5	8	14	5	2	4	1	0	0	0	1	40
.700	3	2	7	5	6	2	5	1	0	0	0	31
.800	4	4	16	10	6	3	6	1	1	1	0	52
.900	2	2	6	2	3	0	2	2	0	0	0	19
1.000	20	2	19	14	13	9	10	0	0	0	0	87
1.100	0	0	0	0	1	2	0	0	0	0	0	3
TOTAL	137	63	165	119	72	58	76	19	12	13	8	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 6

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	105	99	50	31	26	21	18	18	6	0	7	381
.200	8	15	8	4	3	0	3	0	2	2	0	45
.300	1	3	1	3	2	0	1	1	0	1	0	13
.400	5	4	4	4	1	2	4	0	0	1	0	25
.500	8	6	7	5	1	3	2	1	0	0	0	33
.600	3	4	4	2	0	2	4	0	0	0	0	19
.700	9	12	11	5	2	1	1	1	0	0	0	42
.800	5	7	8	7	3	3	0	1	0	0	0	34
.900	7	12	8	3	6	1	4	1	1	0	0	39
1.000	14	15	23	12	11	6	2	4	0	0	0	87
1.100	0	1	1	0	0	0	0	0	0	0	0	2
TOTAL	165	176	121	76	55	39	39	27	9	4	7	

NOTE===THE LAST ROW AND LAST COLUMN ALSO CONTAIN VALUES GREATER THAN THE INDICATED BIN SIZE

TABLE 6 b. MONTHLY RESULTS OF EL PASO TMY RADIATION/WIND CORRELATION STUDIES

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 7

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	86	90	105	53	24	28	12	4	2	0	2	406
.200	8	13	13	3	3	3	2	0	0	0	0	45
.300	3	1	0	1	4	1	2	1	0	0	0	13
.400	4	15	9	8	2	3	3	0	0	0	0	44
.500	1	0	1	0	2	1	0	0	0	0	0	5
.600	4	12	16	9	6	2	6	2	0	0	0	57
.700	0	3	5	0	5	0	1	1	0	0	0	15
.800	2	11	26	6	5	2	1	2	0	0	0	55
.900	3	14	15	6	7	5	1	0	0	0	0	51
1.000	0	14	21	7	6	2	1	0	0	0	0	51
1.100	0	0	1	1	0	0	0	0	0	0	0	2
TOTAL	111	173	212	94	64	47	29	10	2	0	2	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 10

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	203	115	53	33	31	16	11	5	5	1	2	475
.200	8	11	8	3	0	2	0	0	1	0	0	33
.300	5	6	7	4	0	2	1	0	1	1	1	28
.400	7	13	3	6	3	0	1	1	0	0	1	35
.500	3	11	4	4	4	1	0	0	0	1	0	28
.600	9	13	15	5	2	2	1	1	0	0	0	48
.700	5	17	10	10	6	2	1	0	0	0	0	51
.800	7	15	15	3	4	0	1	0	0	0	0	45
.900	0	0	0	0	1	0	0	0	0	0	0	1
1.000	0	0	0	0	0	0	0	0	0	0	0	0
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	247	201	115	68	51	25	16	7	7	3	4	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 8

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	149	108	63	37	26	20	13	11	4	1	0	432
.200	4	7	10	2	1	3	4	2	0	0	0	33
.300	8	5	6	2	2	1	0	0	0	0	1	25
.400	8	8	10	8	1	2	2	1	0	0	0	40
.500	3	3	5	1	3	0	0	1	0	0	0	16
.600	10	12	9	7	2	0	1	1	0	0	0	42
.700	4	5	3	4	1	0	0	0	0	0	0	17
.800	5	18	7	7	2	0	4	0	0	0	0	43
.900	14	19	12	9	5	4	0	0	0	0	0	63
1.000	5	9	8	7	1	3	0	0	0	0	0	33
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	210	199	133	84	44	33	24	16	4	1	1	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 11

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	107	156	127	50	31	11	9	6	4	2	0	503
.200	5	10	8	3	2	2	1	0	0	0	0	31
.300	3	10	7	8	3	1	0	1	0	0	0	33
.400	4	13	5	9	2	1	0	0	0	0	0	34
.500	9	10	6	8	4	3	1	1	0	0	0	40
.600	9	22	14	9	6	1	0	0	0	0	0	61
.700	3	8	4	1	2	0	0	0	0	0	0	18
.800	0	0	0	0	0	0	0	0	0	0	0	0
.900	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	0	0	0	0	0	0	0	0	0	0
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	140	229	171	88	50	19	11	8	4	2	0	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 9

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	86	114	87	69	45	24	21	2	0	1	0	449
.200	5	5	6	6	6	2	0	0	0	0	0	30
.300	4	10	5	7	3	1	1	0	1	0	0	32
.400	2	2	3	2	3	0	0	0	0	0	1	13
.500	3	9	11	9	8	0	0	1	0	1	0	42
.600	3	2	4	3	6	0	0	0	0	0	0	18
.700	2	15	10	4	7	4	1	1	0	0	0	44
.800	6	9	7	6	3	4	2	0	0	0	0	37
.900	6	12	14	6	7	0	2	1	0	0	0	48
1.000	0	0	1	5	1	0	0	0	0	0	0	7
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	117	178	148	117	69	35	27	5	1	2	1	

SOLAR POWER VS. WIND SPEED BINS FOR MONTH = 12

EACH BIN IS NUMBER OF HOURS

SOLAR KW/MSQ	WIND SPEED, M/S 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	TOTAL
.100	89	82	104	104	49	31	18	29	10	2	8	526
.200	9	9	7	7	7	4	3	6	1	0	0	53
.300	4	4	3	6	1	0	0	0	1	2	1	22
.400	8	9	9	13	1	4	2	6	0	1	0	53
.500	18	9	12	8	6	3	1	5	0	0	0	64
.600	5	4	2	1	2	3	3	6	0	0	0	26
.700	0	0	0	0	0	0	0	0	0	0	0	0
.800	0	0	0	0	0	0	0	0	0	0	0	0
.900	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	0	0	0	0	0	0	0	0	0	0
1.100	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	133	117	137	139	66	45	27	52	12	5	9	

NOTE--THE LAST ROW AND LAST COLUMN ALSO CONTAIN VALUES GREATER THAN THE INDICATED BIN SIZE

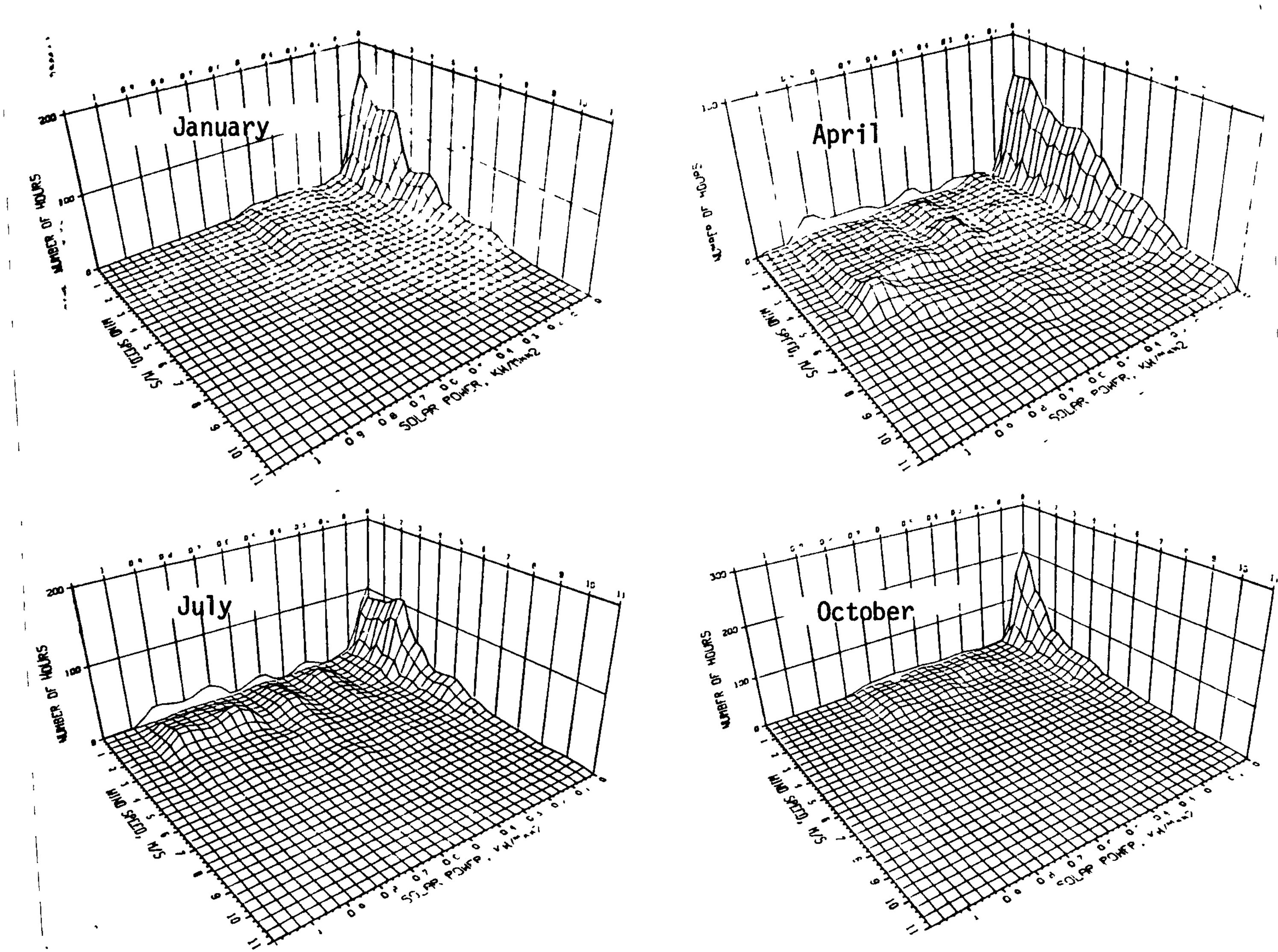


FIGURE 5 . RESULTS OF EL PASO TMY RADIATION/WIND CORRELATION STUDIES FOR SELECTED MONTHS

FIGURE 6a SOLAR RADIATION

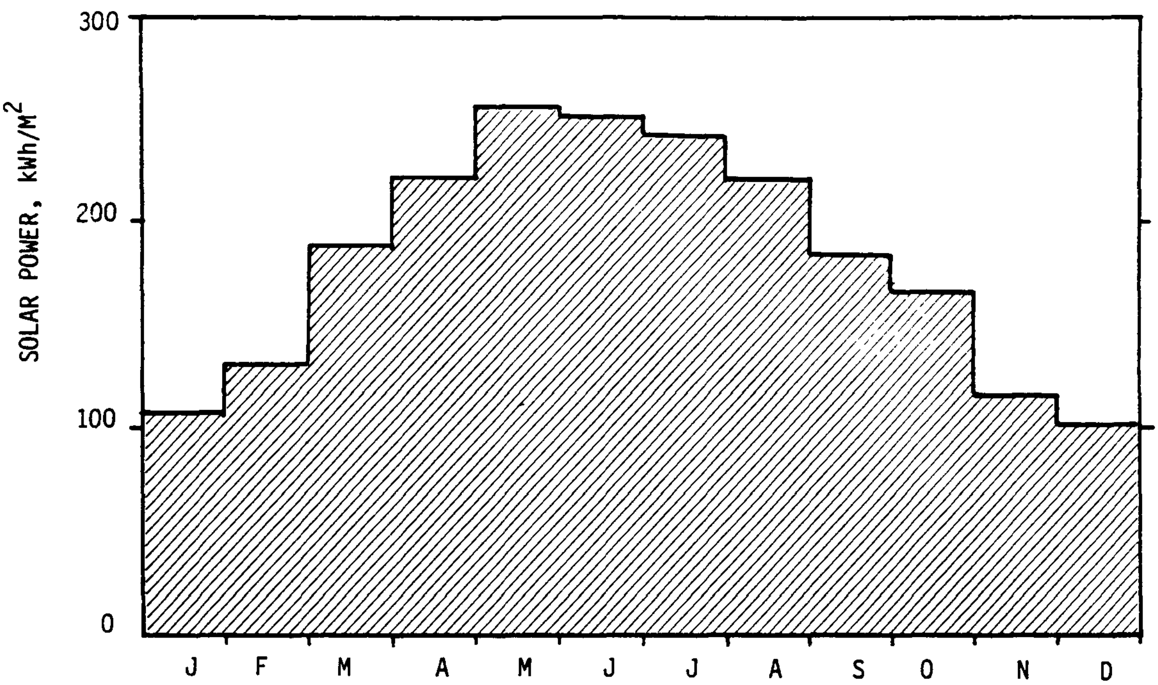
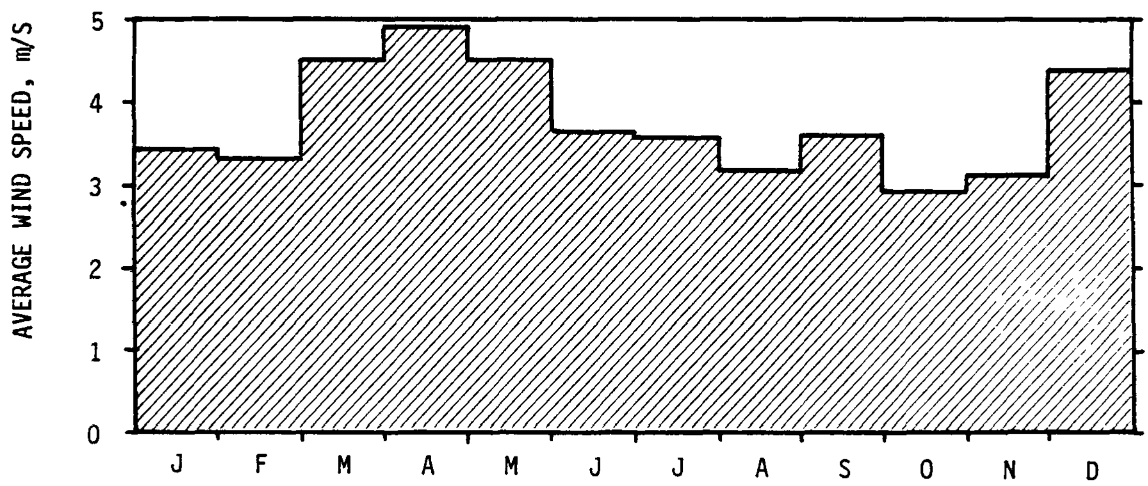


FIGURE 6b AVERAGE HOURLY WIND SPEED



FIGURES 6a&b SOLAR RADIATION AND AVERAGE HOURLY WIND SPEED FOR EL PASO AREA, SOURCE - EL PASO SOLMET TAPE BY MONTH

SECTION 4

SYSTEM PERFORMANCE SPECIFICATIONS

In this section performance specifications and constraints to which the system must conform are given.

4.1 TECHNICAL PERFORMANCE SPECIFICATIONS

Each of the technical performance specificiations prescribed in the contract are given below.

Design Life - the overall system design life shall be 20 years.

Feedwater Type - feedwater to be used for the desalination system shall be from a brackish water aquifer.

Desalinated Water Quality - the total dissolved solids content of the desalinated water shall be less than 500 mg/l.

Climatic Conditions - the SCEAS shall be designed to operate in hot arid regions of the United States and the Kingdom of Saudi Arabia.

Power Generation - all power to be used normally by the integrated SCEAS shall be generated on site by direct or indirect solar sources.

Methods of Cooling/Heating - active and/or passive cooling shall be used to maintain the greenhouse and plant leaf temperatures within acceptable limits.

Economy of Water Usage - the SCEAS design shall economize the use of water owing to its scarcity.

Disposal of Desalination System Waste - the system shall provide an acceptable means for the disposal of wastes from the desalination process.

Usage or Disposal of Agricultural Waste - the system shall provide an environmentally acceptable means for usage or disposal of agricultural waste materials (vines, leaves, etc.).

Backup Power System - a backup power system shall be provided to protect the overall system and crops during emergencies, engineering repairs, and maintenance work.

Energy Storage - adequate energy storage shall be provided (thermal, electrical, etc.) to maintain appropriate system functions at all times of the day, month and year.

Greenhouse Temperature - the SCEAS shall be designed to maintain greenhouse temperatures within the limits required for crop protection and economically optimum growth.

Greenhouse Humidity - the SCEAS shall be designed to maintain greenhouse humidity levels within limits acceptable for economically optimum plant growth and productivity.

Greenhouse CO_2 Levels - the SCEAS shall be designed to provide greenhouse CO_2 levels appropriate for economically optimum plant growth.

Greenhouse Size - the greenhouse for the engineering test facility shall range in size from 0.4-1.0 hectare.

Support Facilities - the SCEAS shall be designed to provide the support facilities required to effectively operate the entire facility as a commercial business. These shall include such items as heated, cooled and ventilated working areas for personnel as required, storage areas for supplies and produce, and environmental protection of SCEAS hardware (pumps, batteries, controls etc.)

Roads and Fence - the entire facility shall have adequate roads for necessary equipment/personnel access and shall be surrounded by a fence.

Irrigation Water Storage - a minimum supply of 20 days storage for irrigation water shall be provided.

Backup Power Fuel System - a 7 day storage of backup power fuel shall be provided.

4.2 ECONOMIC PERFORMANCE SPECIFICATIONS

In performing economic analyses on the system in order to arrive at the minimum levelized life cycle cost per kilogram of product produced the methodology shown in Table 7 will be employed. Specific values to be utilized with this methodology are given in Table 8.

4.3 CODES AND STANDARDS

The codes and standards listed below will be applied in the design and specification of the various system/subsystems/components. The latest addition and the latest addenda in effect at the time of contract will be applied.

a. 1976 Southern Standard Building Code - With the 1977 through 1980 addenda.

b. The local addenda to the Southern Standard Building code as applicable to this project.

c. All references to standards and specifications in the Southern Standard Building Code.

d. Uniform Building Code issued 1979 for seismic design parameters.

e Where the local code does not cover items of design sufficiently to establish clear criteria, the local building official will be consulted. (Chief inspector: Mr. Rios)

f. The National Electric Code including all references to standards and specifications therein.

g. Occupational Safety and Health Administration Documents.

Table 7. Applicable Equations

(From Reference 1)

$$CI_{pv} = (1 + g_c)^p \sum_t CI_t \left(\frac{1 + g_c}{1 + k}\right)^j \quad (B.38)$$

$$X_{pv} = \begin{cases} (1 + g_x)^p X_o \dfrac{1 + g_x}{k - g_x}\left[1 - \left(\dfrac{1 + g_x}{1 + k}\right)^N\right] & \text{if } k \neq g_x \quad (B.39) \\ (1 + g_x)^p \quad X_o \cdot N & \end{cases}$$

where $p=y_{co}-y_p$, $j=y_t-y_{co}+1$,

and g_x is the escalation rate for OP_t, MNT_t, FL_t, as appropriate.

$$\overline{AC}=(1+g)^{-d}\left[FCR \cdot CI_{pv} + CRF_{k,N} \cdot (OP_{pv} + MNT_{pv} + FL_{pv})\right] \quad (B.20)$$

where $d = y_{co} - y_b$

$$\overline{LPC}=\overline{AC}/kg_A \quad (B.22)$$

$$DPF_{SD,k,n} = \frac{2(n - 1/CRF_{k,n})}{n(n + 1)\, k} \quad (E.12)$$

$\overline{AC}$	=	Annualized system-resultant cost
X	=	Recurrent Costs
y_t	=	The year for a given investment outlay
$\overline{LPC}$	=	Levelized Produce Cost
CI	=	Capital Investment
OP	=	Operating Cost
MNT	=	Mainenance
FL	=	Fuel Cost
pv (subscript)	=	present value subscript
kg_A	=	Expected annual produce output

1. The Cost of Energy from Utility-Owned Solar Electric Systems- A Required Revenue Methodology for ERDA/EPRI Evaluations, ERDA.JPL-11012-76-3, June 1976.

Table 8. Constants for Cost Model

SYMBOL	DESCRIPTION	VALUE
N	System Operating Lifetime	20 years
k	Cost of Capital (and Rate of Return on Capital)	0.086
$CRF_{k,N}$	Captial Recovery Factor (8.6%, 20 yrs)	0.1064
g	Rate of General Inflation	0.060
g_c	Escalation Rate for Capital Costs	0.060
g_o	Escalation Rate for Operating Costs	0.070
g_m	Escalation Rate for Fuel Costs	15%
y_b	Base Year for Constant Dollars	1981
y_{co}	First Year of Commercial Operation	1986
y_p	Price Year for Cost Information	1981
	Raw Land Cost	$\$1.25/m^2$
	Cost for lined evaporation ponds	$\$25/m^2$
	Cost for fuel oil (31 GJ/m^3)	$\$157/m^3$
FCR	Fixed Charge Rate, Annualized	0.1437
n	Accounting Lifetime	16 years
$\beta_1 + \beta_2$	Insurance + "Other Tax" Fraction	0.020
α	Investment Tax Credit	0.100
τ	Tax Rate	0.5
$DPF_{SD,k,n}$	Present value of Sum-of-the-Years-digits depreciation	0.6376

SECTION 5
INTEGRATED SYSTEMS DESIGN CRITERIA

In this report the term integrated system design criteria is used to indicate those rules by which final selection of the system/subsystem will be made. The integrated system design criteria are described below.

5.1 TECHNOECONOMIC CRITERIA

The driving factor in the selection of the system is minimum cost per kilogram of produce. In this context cost is either net present value (NPV) or equivalently levelized life-cycle cost, and will include all significant capital and operating costs. The weight of produce will be determined either from past greenhouse experience relative to field production or from the crop production model of van Bavel's SG 79 Code.

5.2 RELIABILITY

An important factor in the overall selection process is that of reliability. The system must be designed to continue to operate even though unfavorable weather sequences may occur or specific component failures may occur due to part wear or operator neglect. The cooling/heating system must have a high probability of being able to protect crops from destruction by overheating or freezing.

5.3 O&M AND TRAINING

Owing to the overall complexity of the project, it is important that operations and maintance procedures be made as simple as possible. Requirements for highly trained operators could have a serious impact not only on operating costs and hence profitability of the facility, but also on the transfer of the technology to areas where highly trained technicians may not be available. In this context, a training manual shall be outlined which includes procedures for routine maintenance as well as trouble shooting of all the major subsystems.

5.4 SAFETY

It is imperative that the system be designed for safety to operating personnel as well as visitors.

5.5. CENTRAL CONTROL

Because of the overall complexity of the project, it is important that the systems/subsystems selected can be controlled from a central control station. Such a control concept will allow for a good knowledge of overall system status at any instant and for rapid handling and trouble shooting of problems as they arise.

5.6 TECHNOLOGY TRANSFER

The selection of systems/subsystems that can provide the necessary CEA functions in a broad range of operating environments is important for overall SOLERAS program success.

5.7 RELEVANCE FOR COMMERCIAL OPERATIONS

Because ultimate commercialization of the concept is fundamental to the program, systems/subsystems which are compatible with current or anticipated commercial practices will be favored.

5.8 INNOVATIVE SYSTEMS USAGE

The usage of innovative systems are encouraged. However, because a demonstration facility is to be constructed in the near term, innovative systems will be selected only if they have been proven feasible elsewhere or if all of the subsystems/components of the innovative systems have been proven feasible elsewhere.

SECTION 6
SUBSYSTEM DESIGN CRITERIA

This section describes the design criteria of the major subsystems. It supplements and expands upon the general system design criteria described earlier. The design criteria form the basis of the systems analysis process, and later on the design of a pilot facility. These are based on the original requirements of the project and the additional requirements given in the contract and dictated by the proposed system configuration. They must be established and documented at the outset of the project to ensure that the design process addresses the proper requirements. On a project such as the present one, the requirements and design criteria evolve from an iterative process of specification and system analysis. A continuous review of the criteria is therefore required to see whether they can be met.

The subsystem design criteria are defined for the following subsystems:

- Controlled Environment Subsystem
- Crop Production Facilities
- Crop Production Program
- Support Facilities
- Photovoltaic Power Subsystem
- Wind Energy Conversion Subsystem
- Back-up Diesel Generators
- Reverse Osmosis Subsystem
- Water Pre-treatment Subsystem
- Carbon Dioxide Injections Subsystem
- Crop Residue Combustion Subsystem
- Control Subsystem
- Data Acquisition Subsystem

For each of these major subsystems the criteria are described in a uniform format as follows:

SUBSYSTEM/EQUIPMENT IDENTIFICATION

Identify the item by name, nomenclature or function.

SUBSYSTEM/EQUIPMENT SCOPE

Identify the major items included within the subsystem or equipment.

BASIC APPROACH AND DESIGN PHILOSOPHY

Describe the approach envisioned for the subsystem or equipment. Use diagrams or tables if they enhance clarity or brevity.

SPECIFIC FEATURES

Identify and describe any important attributes which, at this level of maturity, appear to be necessary or desirable.

SPECIFIED CONSTRAINTS

Cite any constraints imposed by the SOW, regulations or codes which are of particular importance to the subsystem or equipment. (Note that the SOW requirements are summarized elsewhere).

ENVIRONMENTAL CONSTRAINTS

Describe any environmental constraints (climatological, geological, etc.) that are of particular importance to the subsystem equipment. An overall description of the environment should be elsewhere.

OPERATION AND MAINTENANCE REQUIREMENTS

Describe any requirements for operation and maintenance which should be considered in the preliminary design and analysis (e.g., periodic replacement of major elements such as R.O. membranes, storage batteries,etc.)

REFERENCES

Give pertinent references used in developing subsystem design criteria.

The design criteria for the subsystem listed above follow next.

6.1 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Controlled Environment Subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The controlled environment subsystem includes the envelope and the equipment required to regulate plant temperature, ambient humidity, and carbon dioxide level in the greenhouse chamber. It does not include irrigation and fertilization or any other aspects of crop production.

BASIC APPROACH AND DESIGN PHILOSOPHY

The controlled environment subsystem provides an optimum physical environment for plant production with regard to light, temperature, carbon dioxide level, humidity and protection from adverse weather conditions. The system is to be placed in an outside environment typical of hot desert areas.

In order to limit the energy requirements for operating the system within the biological and horticultural limits and, at the same time maximize the direct contribution of the available solar energy, the roof of the greenhouse shall be designed to control the effects of solar radiation. This is accomplished by the principle of selective wavelength filtration.

Since a greenhouse is basically a large scale collector in which the air temperature can rise in excess of 50°C, the key problem for such a system is cooling. In view of this we shall make use of the fluid roof/roof filter design. In this design, a double glazed roof system is used in which the inner glass is tinted to filter out the infrared radiation (beyond 700 nm) and transmit most of photosynthetically active light (between 400 and 700 nm). Water is passed through the two glazings to remove the heat generated by the absorbed infrared radiation. This heat is then either stored for later use during the night time (in winter) or rejected in a cooling system. Most of the conventional greenhouses achieve this cooling by continuous ventilation of the greenhouse air. In the absence of continuous ventilation, the ventilation requirements to keep relative humidity below 85% can be reduced by a factor of five or more as compared to a conventional system with evaporative coolers thereby resulting in significantly lower fan power requirements. This in turn reduces transpiration losses by at least a factor of two and CO_2 enrichment requirements by at least a factor of four. Because very high humidity levels for long periods increase the sensitivity of the plants to disease, the air humidity will be controlled not only by selected amounts of air exchange with dry outside air but also by a condensor using ground water from the aquifer. This also will result in water conservation.

An alternative scheme using a copper-chloride solution between a double layer of clear glass or plastic has also been described in the literature. In this case, since both the glass layers are transparent, the copper-chloride solution is supposed to intercept the infrared radiation and transport thermal energy. However, this scheme has a number of drawbacks including solution leakage and contamination.

SPECIFIC FEATURES

The roof design incorporating the fluid roof/roof filter configuration in which the inner glass is tinted to obstruct the infrared radiation shall be the preferred concept, since the copper-chloride solution method has inherent corrosion, leakage, and contamination problems. The greenhouse shall have a useful area in the range of 0.4-1.0 hectare and a system of internal corridors for production and maintenance operations. The exterior walls shall be constructed with a double walled plastic such as 10 mm clear polycarbonate. The selected material will be such that in addition to providing excellent insulation, it should be resistant to breakage, transparent to solar radiation and resistant to UV damage for long life.

The roof of the greenhouse will have appropriate geometry (ridge or furrow, N-shape, or a modified balloon shape) not only to withstand wind gusts but also to require minimum maintenance to remove any sand or loose soil which may accumulate due to wind and dust storms. The roof will have arrangements for water manifolds to circulate water through the double glazed roof. The size and thickness of the glass panels and the material and size of the supporting structure will depend upon the loads, availability of materials, and the overall economics of the subsystem. The water from the roof will be stored in a reservoir to be used for nighttime heating or cooling depending upon the season. Depending upon the actual requirements, this water may be heated or cooled (depending upon the season) by using the hot flue gases from the burning of the biomass residue, heat stored in the evaporation pond or by heat exchange with the underground aquifer water, as dictated by the economics of each alternative.

SPECIFIC CONSTRAINTS

The greenhouse shall be designed to provide complete protection against extreme temperatures inside the greenhouse. As a general rule, the indoor temperatures shall not remain at less than 10°C for more than one hour, or at less than 15°C for greater than 12 hours. The maximum temperatures cannot remain at more than 35°C for more than one hour, and cannot remain at more than 30°C for over 12 hours. The relative humidity shall be maintained within the range of 50 to 95% and shall not fall outside this band for more than one hour. The infiltration rate shall be less than one air change per hour. Appropriate work areas to wash and process the produce, to harvest yield, to carry out preplant operations including seed treatment and germination, etc. shall be provided.

ENVIRONMENTAL CONSTRAINTS

See Section 4.

OPERATION AND MAINTENANCE REQUIREMENTS

It will be necessary to periodically clean the roof of excessive dust and to maintain the double glazed roof transparent and clean. In each sub-unit of the entire greenhouse the equipment for circulating water and moving air shall be distributed over a suitable number of individual units so that overall capacity can be adapted to seasonal requirements, and that breakdown of a single unit will only marginally affect the environment in the unit as a whole. The roof circulation system shall likewise be broken down to allow for changing the liquid, cleaning of system, or replacing roof panels without having to interrupt the operation of the entire system. The emphasis during the design will be to maintain the modularity of this subsystem.

REFERENCES

See references 17-21.

6.2 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Crop Production Program

SUBSYSTEM/EQUIPMENT SCOPE

The crop production program includes all preplanting, planting, cultural, harvesting, and post-harvesting operations.

BASIC APPROACH AND DESIGN PHILOSOPHY

Crop production operations shall be excercisable from several locations within the CEA complex by personnel handling specific functions under the supervision of a crop production manager.

The organization of supervisory personnel is illustrated in Figure 7.

SPECIFIC FEATURES

a. Preplanting Operations

All preplanting operations, including automated washing of reusable flats, filling with media, dibbling, seedling, topping with vermiculite, irrigating, fertilizing, and monitoring of germination and seedling growth, shall be under the supervision of the "transplant supervisor". His essential function shall be the production of suitable transplants for subsequent planting in the CEA production sections (greenhouses).

The automated pre-germination process shall be conducted in the large N-S corridor situated in the middle of the CEA complex (see Support Facilities) while the growing area for seeded flats shall be located either within one of the greenhouse sections, or in a small corridor perpendicular to the large N-S corridor, on special benches designed for this purpose.

Storage space for peat moss, perlite, and vermiculite shall be provided in the large N-S corridor. This will be located near one end of the

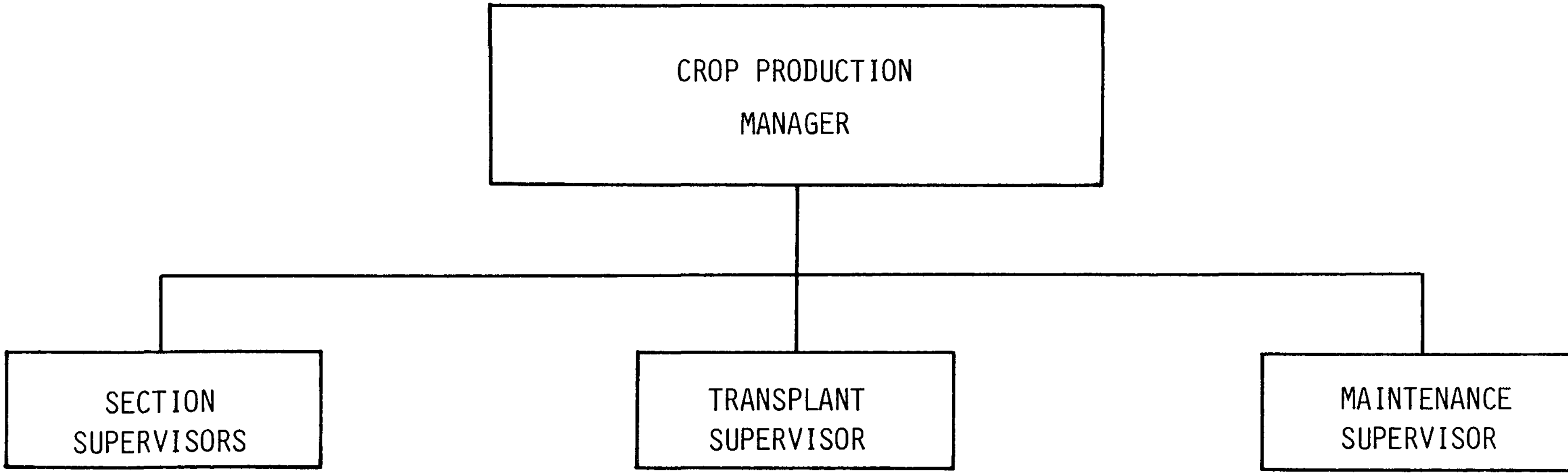


FIGURE 7 ORGANIZATION OF SUPERVISORY PERSONNEL FOR CROP PRODUCTION OPERATIONS

corridor for ease in replacement of depleted stocks, and adjacent to media-mixing equipment.

The seed-germination area shall have, in addition to benches, an automated spray-mist irrigation system with fertilizer-injection capability (see Support Facilities). This area shall include sufficient space for the efficient operation of small utility vehicles for transporting transplants to the crop-production greenhouse sections.

b. Planting Operations

Except for direct - seeded vegetables (i.e., radishes, etc.), crop production shall begin with the direct insertion of transplants into the sand growth medium within the four greenhouse sections. This process shall be automated using a tractor-mounted transplanter.

Fertigation (irrigation plus fertilizer injection) pipes shall be placed along the rows of transplants to provide sufficient moisture and nutrients for optimum plant growth and development (see Crop Production Facilities).

Fungicides shall be applied either through the fertigation system or by portable sprayers as necessary for disease control.

Insecticides shall be applied by a mist blower or by portable sprayers as necessary for insect control.

Growth and development of the crops shall be monitored continously, and adjustments in the cultural program (fertilization, irrigation, pesticide application) are made as needed to sustain optimum production. With respect to fruiting crops (tomatoes, peppers, etc.), first signs of fruiting shall be reported to the Crop Production Manager and estimates of first fruit set made to provide a basis for scheduling harvesting and post-harvesting operations.

c. Harvesting Operations

Harvesting of fruits and leafy vegetables shall be performed manually by personnel trained in selection and picking techniques. The produce shall be loaded onto carts pulled by small utility vehicles and transported to the large N-S corridor for post-harvest treatment. At the completion of the harvesting period, all crop residues shall be removed and transported to a common collection site for disposal or subsequent use.

d. Post-Harvesting Operations

The operations performed following harvesting shall be of two types: treatment of the planting bed in preparation for the next crop, and treatment of the produce in preparation for marketing.

The planting bed shall be fumigated or chlorinated to control soil organisms (fungi, nematodes) and to promote the oxidation of residual organic matter. Subsequently, the planting bed shall be thoroughly leached by applying pure water through the fertigation system to remove all soluble organic and inorganic residues from the sand growth medium. Finally, the planting bed shall be tilled with a tractor-drawn rake to prepare the surface for the next crop.

The harvested produce shall be thoroughly washed with dilute chlorine solution, waxed, and sized with an automated weight sizer. After packing the produce in appropriate cartons, it shall be transported either to a truck for subsequent shipment to the market, or temporarily stored in the cold room located in the support building.

REFERENCES

See References 14, 15, and 16.

6.3 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Crop Production Facilities

SUBSYSTEM/EQUIPMENT SCOPE

The crop production facilities subsystem encompasses the sand growth medium in which crops are produced, the drainage network for removing excess water dissolved substances from the growth medium, and the fertigation apparatus for supplying water, fertilizer nutrients, and some pesticides to the plants and growth media.

BASIC APPROACH AND DESIGN PHILOSOPHY

The growth medium for receiving transplants and direct-seeded crops, and for sustaining these plants to maturity, is a relatively coarse sand situated atop polyethylene sheets for isolation from the underlying indigenous soil.

Through the drainage network, excess water and soluble residues are removed from the growth medium, thus ensuring adequate aeration and freedom from toxic substances for the crops.

The carefully designed and operated fertigation apparatus provides all of the crops' moisture and nutritional requirements as well as a network for efficiently distributing certain pesticides.

These facilities provide nearly complete control of the crop production environment and thus enable the operator to sustain optimum conditions for highly efficient production of economic crops.

SPECIFIC FEATURES

a. Sand Growth Medium

The growth medium shall be composed of a uniformly coarse grade of silica sand with at least 70 percent of the sand in the 2.00- to 0.25-mm-diameter range. A minimum of fine and very fine sand particles (less than

0.25 mm) should be allowed as these substantially reduce infiltration and percolation of water through the medium.

The depth of the medium shall be approximately 30 cm. The surface shall have a slope of approximately 0.5 percent to facilitate drainage.

The sand medium shall be situated atop either two layers of 6-mil plastic or one layer of cross-laminated polyethylene to separate the sand from the underlying indigenous soil. Individual plastic sections shall be overlapped at least 60 cm to minimize leakage.

b. Drainage Network

A drainage network shall be constructed above the plastic sheets from 3.1-cm-diameter or larger polyvinylchloride (PVC) pipe. Each pipe shall be perforated at appropriate intervals. The pipes shall be spaced approximately every 45 cm, and connected to a main pipe located downslope. The flow of water from the main pipe shall be directed to a sump located outside of the greenhouse section; this water can be used to irrigate outside crops or trees, or directed to the RO subsystem for treatment and re-use.

c. Fertigation Apparatus

Fertigation lines shall be composed of twin-wall, drip-type pipe with 10-cm spacing between outlets. Each line can be up to 30 m long as long as the lines run down slope from the supply manifold; on level ground, maximum length should not exceed 15 m.

As fertilizer is almost always added to the irrigation water, injection shall be accomplished by either a twin-head proportioner, or from agitated tanks containing a 20:1 dilution of water and concentrated fertilizer solution.

The fertigation apparatus shall be operated two to eight times daily, depending upon crop maturity and temperature. (Larger plants and higher temperatures require more-frequent operation). Flow rate shall be constant, and fixed by the characteristics of the outlets; it shall be sufficient to promote a small, continuous trickle of water though the drainage pipe (i.e., 4 to 7 percent of water applied).

The drainage water shall be checked periodically for soluble salts. Excessive concentrations of soluble salts (i.e. 2500 ppm or more) necessitate leaching of the sand medium with pure water, or temporary irrigation with pure water to allow plants to take up, and thus reduce, the salt concentration in the sand medium.

ENVIRONMENTAL CONSTRAINTS

The fertigation lines shall be protected from vehicular traffic either by installation below the sand surface, or by the provision of protective covers within traffic lanes.

OPERATIONAL AND MAINTENANCE REQUIREMENTS

All components of the drainage network and the fertigation apparatus shall be selected for high reliability. Regular monitoring of performance is necessary to ensure proper operation, and periodic flushing may be required to remove accumulations that might eventually impede the flow of water and dissolved substances.

REFERENCES

See references 11, 12, and 13.

6.4 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Support Facilities

SUBSYSTEM/EQUIPMENT SCOPE

The facilities required to support the crop production include those that provide direct support, (i.e., transport of materials, preplanting operations, and post-harvest treatment of produce), and those that indirectly support the program (i.e., equipment maintenance and storage, and storage of production resources and produce.)

BASIC APPROACH AND DESIGN PHILOSOPHY

All direct-support facilities are situated within the corridors of the CEA complex, and thus are accessible for efficient use in routine operations. The indirect-support facilities are situated in an adjacent building; access to them is favorable while interference with routine operations in the CEA complex is avoided.

SPECIFIC FEATURES

a. Direct Support Facilities

The large N-S corridor in the CEA complex shall be situated at the center of this complex for optimum accessibility to operations within the four greenhouse sections. It shall be of sufficient size to incompass most preplanting and postharvesting operations (see Crop Production Program), and to provide for efficient movement of transport vehicles and equipment.

This corridor shall contain appropriately sized access doors to the outside of the CEA complex, and one or two access doors into each of the four greenhouse sections. If transplant production is centered in a small E-W corridor between two adjacent greenhouse sections (rather than in one of the greenhouse sections), access doors connecting the E-W and N-S corridors will be required as well.

The floor of the large N-S corridor shall be constructed with concrete, and shall be of sufficient strength to support all direct-support operations and vehicular traffic (i.e. small utiltiy vehicles plus pull carts, small tractors with mounted implements). Floor drains shall be installed to remove water from produce washing and general maintenance operations. The roof covering this corridor shall be of a highly reflective material to maintain a suitable environment for personnel involved in direct support operations.

The floor of the E-W (transplant production) corridors shall be the same as in the four greenhouse sections (i.e. sand growth medium and fluid roof - see Crop Production Facilities).

b. Indirect Support Facilities

The building adjacent to the CEA (greenhouse) complex shall contain specially designed rooms for: agrichemical storage (fertilizers, pesticides), bulk storage of transplant materials (flats, peat moss bales, vermiculite and perlite bags), equipment maintenance shop and parts storage, temporary cold storage of produce, and personnel offices. Additional space in this building will be necessary to house facilities such as controls, pumps, batteries, desalination equipment and others as may be required.

SPECIFIC CONSTRAINTS

The orientations of the CEA complex and the adjacent indirect-support building, with respect to each other, shall be established to provide for efficient movement of equipment, materials, and personnel between the two structures. Also, the indirect-support building must be located on the north side of the CEA complex, as any other location would shade (and thus reduce the amount of available photosynthetically active light for the greenhouse sections or transplant-production corridors.

ENVIRONMENTAL CONSTRAINTS

As the support facilities are locations of intensive activity by personnel involved in all facets of crop production, the environment (temperature, humidity) in these facilities shall be sustained in a fashion that is suitable for human activities.

Whenever pesticides or other toxic materials are used in the greenhouse sections, access doors between the sections and the direct-support (N-S) corridor shall be sufficiently sealed to prevent injury or discomfort to personnel present in the facility.

REFERENCES

None.

6.5 SUSBYSTEM/EQUIPMENT IDENTIFICATION: Photovoltaic Power Subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The Photovoltaic Power Subsystem, abbreviated as PV subsystem, includes the PV array complete with supporting structures, cabling and switchgear, and a power conditioning subsystem. Battery storage may or may not be integral to the PV subsystem. Foundations for the support structure and housing for the batteries are to be specified as part of the civil works.

BASIC APPROACH AND DESIGN PHILOSOPHY

A flat plate PV subsystem is preferred over a concentrating system because of its simplicity in operations and maintenance and because it does not require a heat rejection system. However, if analyses show a definite cost/performance advantage for a concentrating system, it may be specified.

The PV subsystem can be sized to carry all non-deferable daylight loads throughout the year, and in conjunction with the wind turbine subsystem generate and store sufficient energy to carry nighttime loads with minimal augmentation by the diesel generators. Since the majority of the large loads are approximately proportional to the level of insolation, this sizing should impose no major cost penalties.

Emphasis shall be placed on reliability. The array should be designed to be insensitive to small failures. The system should be sized to produce its required output at the end of 20 years without replacement of modules (except for those broken by accident or extreme environmental effects).

SPECIAL FEATURES

The output of the Power Conditioning Unit, PCU, shall be 480V, 60Hz, 3 ϕ. The inverter shall be configured for operation in a stand-alone mode or in parallel with the diesel generator and the wind turbine subsystem.

An electrical battery storage will be provided within the CEA system. It may be integral to the PV system or may be separate to facilitate battery charging by wind turbine. The optimum configuration will be determined during the systems analysis task.

The PV subsystem shall be configured for unattended operation. Integral controls to effect safe shutdown under fault conditions shall be included. PV modules to be employed shall be subjected to the JPL Block V tests.

SPECIFIC CONSTRAINTS

See Section 4.

ENVIRONMENTAL CONSTRAINTS

See Section 3.

OPERATION AND MAINTENANCE REQUIREMENTS

The system should be able to operate as fully automatic as possible. All components shall be selected for high reliability and known performance characteristics. Periodic maintenance shall be performed with minimum system downtime.

REFERENCES

See References 28 and 29.

6.6 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Wind Energy Conversion Subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The wind energy conversion subsystem, abbreviated as WECS, includes the rotor, hub, controls, transmission, generator, frame, tower, and cabling to the main distribution panels. Appropriate foundations are to be specified as part of the civil works and are assumed to exist.

BASIC APPROACH AND DESIGN PHILOSOPHY

The WECS shall provide power to the CEA load in conjunction with parallel inputs from electric storage batteries and a flat plate photovoltaic array. The relative contributions from each of these power systems is to be determined during the systems analysis task. The WECS must be able to operate continuously in a stand-alone mode and may consist of one or more separate units. The operation of the WECS, including start-up, operation, and shutdown, shall be controllable from a central control point and be completely automatic with manual control as backup. The inclusion of WECS in the power system increases the probability that power is available to the system at any given time and may reduce the overall cost of the system by displacing some of the photovoltaics and electric storage.

Wind turbines in their present state of development are poorly adapated to stand-alone operation or to parallel operation with small capacity generators. Integration of the wind machine into the CEA energy system will require an innovative approach to ensure compatibility with the other power sources. The technique required will depend upon the characteristics of available machines in the size range that is determined to be optimum.

SPECIFIC FEATURES

The WECS must be able to survive design windspeed at 10 m of 35 m/sec (80 mph). Appropriate safety features shall be incorporated to protect the subsystem from overspeed, overtemperature, and excessive vibration. The wind machine must have the capability to be self-starting or require a minimal amount of power to facilitate start-up. The machine must be self-regulating for wind gusts and changes in wind direction. The wind machine shall be capable of operating in a stand alone mode or in parallel with the PV system or the diesel generators. If feathering of the wind turbine blades is not possible, a load bank is to be incorporated to dissipate power in excess of load and battery charging demand.

SPECIFIC CONSTRAINTS

See Section 4.

ENVIRONMENTAL CONSTRAINTS

The WECS must be designed to operate in a temperature range of the climatalogical environment described in Section 3. The WECS is to be located in such a manner that in the unlikely event of tower or blade failure damage to other CEA subsystems is minimized. Television signal interference is to be minimized, if applicable, by appropriate placement of the machines.

OPERATION AND MAINTENANCE REQUIREMENTS

All components shall be selected for high reliability. Periodic maintenance shall be performed with minimum system downtime. System operation shall be completely automatic.

REFERENCES

None.

6.7 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Back-up Diesel Generators.

SUBSYSTEM/EQUIPMENT SCOPE

The back-up diesel generator subsystem, abbreviated as DGS, includes the diesel generator sets, their integral controls, starting batteries and fuel supply.

BASIC APPROACH AND DESIGN PHILOSOPHY

The back-up diesel generators are intended for use only when the power available from solar energy system is inadequate to carry essential operational and housekeeping loads. Since the consequences of a prolonged power outage are severe, and the probability that inadequate solar power is not available at some point in time is high, two diesel generator sets are required to provide the requisite degree of reliability. The smallest set shall have a capacity equal to or greater than the peak essential operational and housekeeping loads.

SPECIFIC FEATURES

The back-up diesel generators shall be equipped for starting and shutdown from a remote location and from a local control panel. They shall be equipped with automatic paralleling switchgear which connects their output to the main bus whenever they have been started and have reached operating speed. The diesel generator sets shall be equipped with alarm and automatic shutdown features for overtemperature, low lubricating oil pressure and other critical parameters. The alarms shall be displayed locally and transmitted to the central control station.

The diesel generator sets shall be configured for a 480V, 60Hz, 3ϕ output.

SPECIFIC CONSTRAINTS

The fuel storage capacity shall be adequate for seven days operation of one generator at full load.

ENVIRONMENTAL CONSTRAINTS

The capacity shall be derated, if required, to the environmental conditions specified in Section 3. In particular, the altitude and air temperature constraint shall be considered. Cold-starting aids shall be included if required.

OPERATION AND MAINTENANCE REQUIREMENTS

Routine preventive maintenance such as changing lube oil, filters, replenishing coolant, testing of starting batteries, etc. shall be within the capability of operators with no specialized mechanical training.

REFERENCES

None.

6.8 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Water Pretreatment Subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The water pretreatment subsystem, abbreviated as WPS, shall provide soft, iron and manganese free, water with an SDI of less than 5 and with a turbidity of less than 0.5 NTU. The subsystem includes mixed media filters, carbon filters, a sodium Zeolite water softener, a phosphate and acid feed system, cartridge filters, the heat exchanger to raise the RO feedwater to no more than 45^{o}C, and associated pumps, piping, valves, and controls.

BASIC APPROACH AND DESIGN PHILOSOPHY

The quality of the feedwater for an RO system is critical and requires very careful consideration of the pretreatment processes in order for the RO system to be able to operate efficiently, effectively, and with a minimum of maintenance and replacement of membrane elements. One of the most critical items that must be considered is the amount of particulate matter that is present. Turbidities and SDI's must be low to prevent fouling, clogging and excessive cleaning. Our goal here will be to produce an RO feedwater with as low a turbidity and SDI as is practical, in order to reduce cleaning requirements.

The concentration of salts within the membrane elements must be controlled to prevent crystallization or precipitation on the membrane surfaces. Some of the more critical salts are calcium sulfate, iron, manganese and barium. These can be controlled either by their removal, the adjustment of the pH of the feedwater, the addition of a phosphate or a combination of all three. The concentration of salts also determines the conversion rate (ratio of product water to feedwater) attainable. If low conversion rates are required or used, the power needs increase. The goal here will be to pretreat the RO feedwater to attain the highest practical conversion rate so as to conserve power. Water softeners will be used to increase the conversion rate of the RO as high as possible, therefore minimizing power requirements.

The reject brine from the RO will be used for backwash and partial regeneration of the sodium Zeolite water softeners, which will reduce the amount of salt required for regeneration.

SPECIFIC FEATURES

Since the raw water supply is to be a deep well it is not anticipated that chlorine will be required to sterilize the feedwater supply. This will permit the use of polyamide type membranes which can be operated over a wider pH range, but require zero chlorine in the feedwater. They can also be operated at higher temperatures, which results in a higher flux rate, decreasing power consumption.

The WPS shall be sized to be compatible with the capacity of the RO subsystem, and both shall provide sufficient water to supply product water for the greenhouse for regeneration and backwash of the equipment and the reject wastewater for the RO unit, and for other sanitary or cleaning operations.

The mixed media filter shall be used to remove particulate matter and oxidized iron and manganese from the raw well water supply. The filters shall be designed to produce an effluent water with a turbidity of less than 0.5 NTU and an SDI of less than 5.0.

A granular activated carbon filter shall be used to remove organic matter and traces of hydrogen sulfide.

Sodium Zeolite water softeners shall be used to reduce the calcium and manganese hardness to low levels to prevent deposition of calcium carbonate and/or calcium sulfate scale on the membrane surfaces. It shall also be used to remove the dissolved iron and manganese.

The heat exchanger shall be capable of raising the temperature of the feedwater to the RO system to $45^{O}C$ in order to increase the flux rate through the membrane.

SPECIFIC CONSTRAINTS

See Section 4.

ENVIRONMENTAL CONSTRAINTS

Disposal of sludges and other waste materials from the WPS shall be according to local codes and requirements.

OPERATION AND MAINTENANCE REQUIREMENTS

The system should be designed to operate as fully automatically as possible. All components shall be selected for high reliability. Periodic maintenance shall be performed with minimum system downtime.

REFERENCES

None.

6.9 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Reverse Osmosis Subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The reverse osmosis subsystem, abbreviated as RO system, includes the membranes, pressure housings, cleaning system, decarbonator, demineralizer, pumps, valves, piping, and controls. Foundations and/or housing are to be specified as part of the civil works and are assumed to exist.

BASIC APPROACH AND DESIGN PHILOSOPHY

The reverse osmosis, RO, process was selected because it has the lowest power requirement per unit of product water produced. Treated feedwater is pumped to the membranes at high pressure. The system must be designed to produce water containing less than 500 mg/l of dissolved solids with a sulfate and chloride content of not more than 250 mg/l each. The system must be able to operate automatically.

The function of the demineralizer is to provide high quality water for the recirculation loop through the glass panels to prevent buildup of minerals on the glass surfaces, the heat exchanger, the piping system, and to prevent the "weepage" or leakage of water from the glass seals where evaporation could cause buildup of crystalized salts. In an emergency this low TDS water could be blended with raw or pretreated water to supply the greenhouse agricultural water. The feedwater temperature shall be as high as possible, compatible with the selected menbrane characteristics and the cost of thermal energy, in order to increase the throughput of the membranes withouth increasing pumping power.

SPECIFIC FEATURES

The system shall be designed to operate not less than twenty-two hours a day with a maximum of two hours per day provided for the backwash and regeneration of the pretreatment equipment. To enhance reliability the system shall be designed with redundant pumps. The system shall be skid mounted and include all necessary pipes, valves, gauges, flow rate indicators and controls. The membrane elements shall be of the low pressure type capable of 90% or more of the dissolved salts in the softened feedwater when operated at design conditions. The system shall operate at a temperature of 45^{o}C.

The demineralizer shall be designed to operate on an intermittant basis, as treated RO product water and power are available. The treated water shall contain a total electrolytic content of less than 1.0 mg/l, as $CaCO_3$, and a pH in the range of 6.7 to 7.1

SPECIFIC CONSTRAINTS

See Section 4.

ENVIRONMENTAL CONSTRAINTS

The reject brine shall be disposed of in a manner acceptable to local codes and requirements.

OPERATION AND MAINTENANCE REQUIREMENTS

The system should be designed to operate as fully automatic as possible. All components shall be selected for high reliability. Periodic maintenance shall be performed with minimum system downtime.

REFERENCES

None.

6.10 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Carbon Dioxide Injection System

SUBSYSTEM/EQUIPMENT SCOPE

The carbon dioxide injection system includes all equipment for providing the carbon dioxide, appropriate storage facilities if necessary, and means for injecting the CO_2 into the greenhouse air.

BASIC APPROACH AND DESIGN PHILOSOPHY

Closed system greenhouses require the addition of supplemental CO_2 to maintain levels for optimum plant growth. Research has shown that most plants cease to grow at CO_2 concentrations below 125 ppm. Increased growth response has been observed on many crops grown in CO_2 enriched as high as 2,500 ppm. Recommended levels of CO_2 enrichment range from 600 to 1000 ppm during the daylight hours. Carbon dioxide at these levels is removed from the greenhouse not only by the plants, but is also via ventilation and infiltration of outside air which contains only 325 ppm. These losses must be made up by the carbon dioxide injection system. The system will have sufficient capacity to provide CO_2 to compensate for the maximum expected growth/rate of the crops and the estimated maximum number of air changes to be expected.

A number of different ways of providing the CO_2 will be evaluated. The system which is finally adopted will be chosen on the basis of cost, power consumption, and general applicability.

SPECIFIC FEATURES

The carbon dioxide injection system shall be designed to maintain the CO_2 level in the greenhouse air at 600-1000 ppm during the daylight hours.

The system will be controlled preferably by means of four CO_2 sensors, each one being located in one quadrant of the greenhouse. The four quadrants of the greenhouse will be separated from one another.

The system will be operated only during the daytime when the plants will be growing.

SPECIFIC CONSTRAINTS

The carbon dioxide injected into the greenhouse air must not contain pollutants which are harmful to the crops or the workers. Special attention will be paid to the possibility of the CO_2 containing harmful amounts of carbon monoxide or hydrocarbons such as ethylene.

ENVIRONMENTAL CONSTRAINTS

There are no environmental constraints associated with the carbon dioxide injection system.

OPERATION AND MAINTENANCE REQUIREMENTS

The specific operation and maintenance requirements will depend on the specific system selected.

REFERENCES

See References 24, 25, and 26.

6.11 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Crop Residue Combustion System

SUBSYSTEM/EQUIPMENT SCOPE

The crop residue combustion system includes the equipment needed to dry the residue, chop the residue to the required size, store the residue until needed, and burn the residue so as to recover the thermal energy and/or carbon dioxide in a useful form.

BASIC APPROACH AND DESIGN PHILOSOPHY

The basic philosophy involved in the design of the crop residue combustion system is that the residue production is periodic in nature, as is the need for the generated thermal energy. Thus, storage of the residue will be necessary, and the residue must be processed into a form suitable for storage. The system will also include the capability for storing the thermal energy for subsequent use.

The basic concept is illustratd in Figure 8.

SPECIFIC FEATURES

The number of days of storage to be provided will be determined during the systems analysis task. This will depend on the expected schedule of residue production from the selected cropping scheme.

The required particle size and residual moisture content of the dried material will depend upon the specific combustion equipment selected.

SPECIFIC CONSTRAINTS

There are no specific constraints except those dictated by economics.

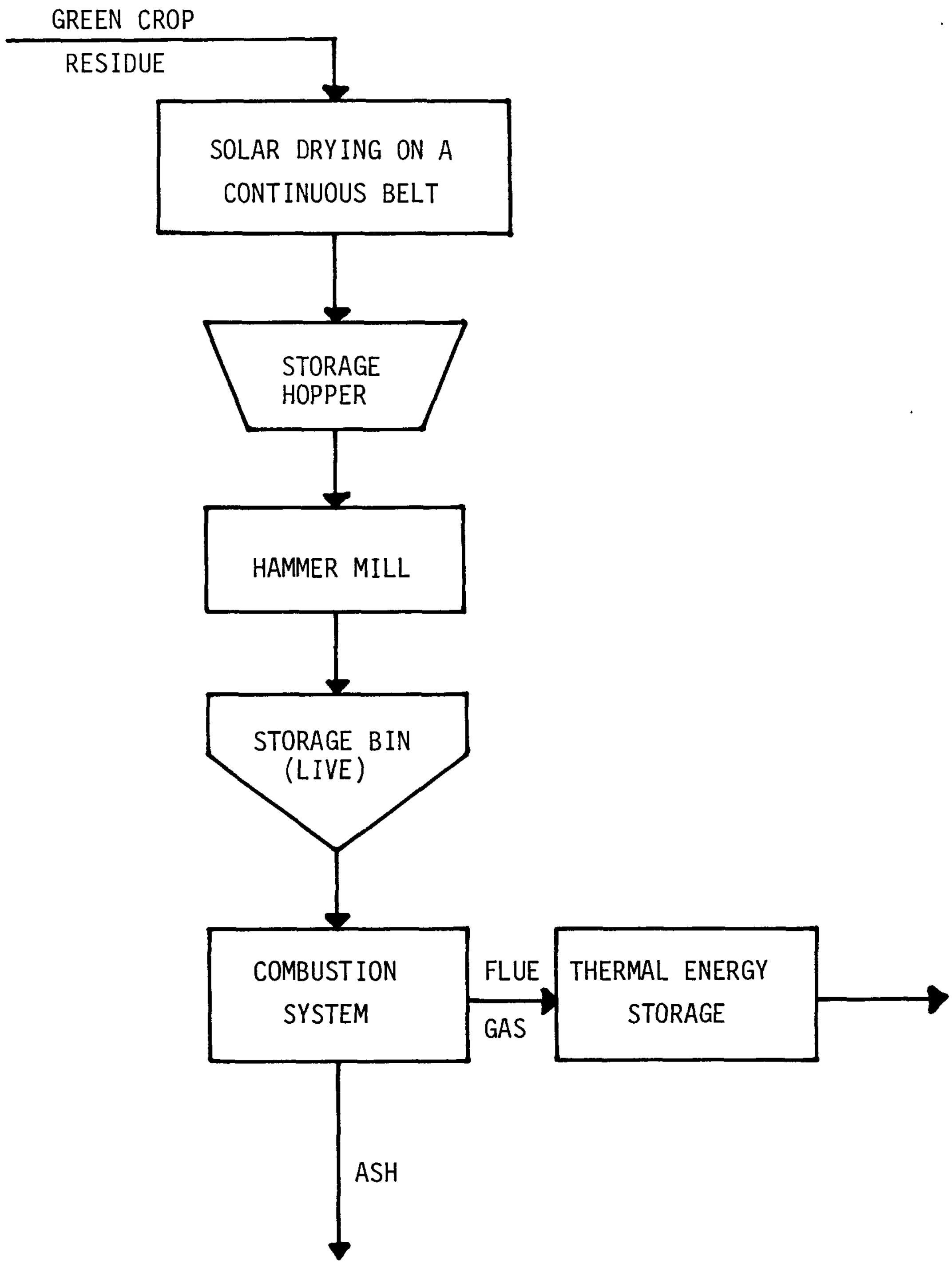


FIGURE 8 CROP RESIDUE COMBUSTION SYSTEM

ENVIRONMENTAL CONSTRAINTS

The emissions from this combustion system must meet the applicable regulations pertaining to allowable emissions. The ash will be disposed of in an environmentally acceptable manner.

OPERATION AND MAINTENANCE REQUIREMENTS

There should be no major maintenance requirements with this system. The knives/hammers in the grinding equipment will have to be replaced periodically.

The major operational requirements are for materials handling. The residues shall be removed from the greenhouse and put into a conveyor for drying and movement into the storage bin. Feeding of the residue into the combustion system shall be done by means of a conveyor. The ash shall be removed from the combustion system and be disposed of.

Operation of the combustion system including the feed and the combustion air shall be controlled automatically.

REFERENCES

See Reference 27.

6.12 SUBSYSTEM/EQUIPMENT IDENTIFICATION: CEA central control subsystem

SUBSYSTEM/EQUIPMENT SCOPE

The control subsystem includes all sensors, actuators and control modules required for operation of the solar energy subsystem and the electrical and mechanical subsystem required for the operation of the greenhouse and support faciliites.

BASIC APPROACH & DESIGN PHILOSOPHY

All control functions shall be exercisable from a single physical location with fully automatic or manual operation selectable by the operator.

Where practicable, discrete control modules for individual subsystems or equipments shall be used, with inhibit/enable control exercised from the central control station. Alarms and status indications from such distributed control modules shall be transmitted to the central control station for display.

Local indicators and manual controls will be provided for each controlled subsystem or equipment where required for alignment, test, trouble-shooting or operation during a central control system outage.

The basic concept is illustrated in Figure 9.

SPECIFIC FEATURES

a. Display and Control Panel

A display and manual control panel shall be provided at the central control station. It shall be designed to unambiguously indicate the status of all systems at a glance. Automatic-manual selector switches shall permit the

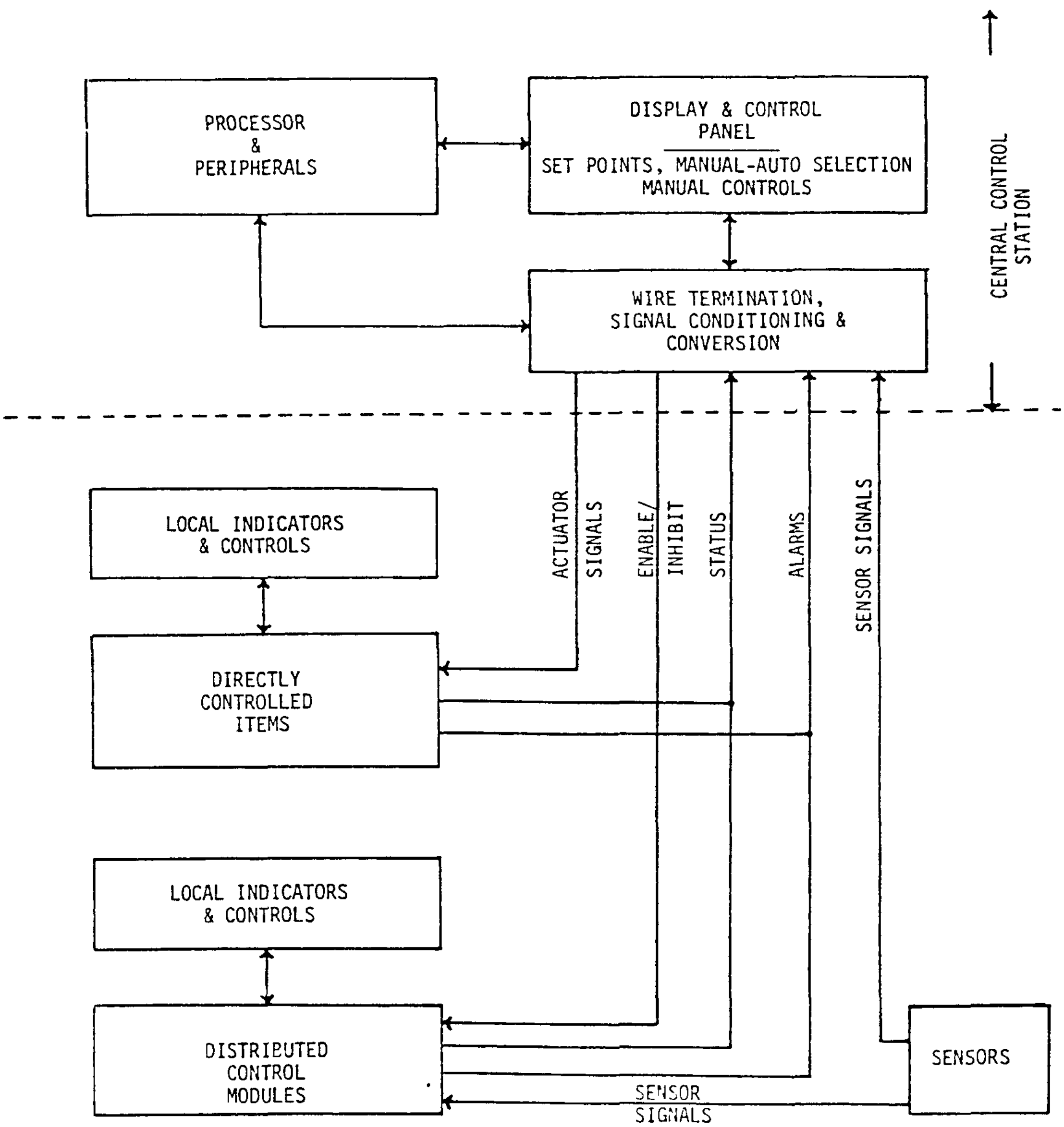


FIGURE 9   CONTROL SUBSYSTEM SIMPLIFIED CONCEPT

operator to choose between fully automatic and manual operation for common systems and for individual compartments. Manual controls on the panel shall be active only when the manual mode for the affected function has been selected.

b. Features to facilitate manual control

Status and alarm indications which are required for manual control, shall be converted and displayed on the display/control panel without intervention by the processor.

Sensor data required for manual control shall be converted and displayed on the display/control panel without intervention by the processor. Where displayed data is normally processed information generated by the processor, which would not be available in the event of processor failure, provision shall be made for direct display of sufficient raw data to permit manual operation when the manual mode is selected.

Operator selectable set-points shall be provided on the panel for all variable parameters.

SPECIFIC CONSTRAINTS

See Section 4.

ENVIRONMENTAL CONSTRAINTS

All control modules, sensors, actuators, and their associated cabling and signal conditioners, located within the greenhouse shall be designed for functioning in a temperature range of 0°C to 50°C and a relative humidity of 100%. The environmental conditions for the central control station are to be determined.

OPERATION AND MAINTENANCE REQUIREMENTS

All components shall be selected for high reliability. In general, high quality, industrial grade components will be adequate. The provision for manual override from the central station and at local points shall be considered in assessing reliability.

A FMEA analysis will be made to identify faults which have catastrophic effects and to quantify the probability of such faults. Where the consequences and probability are unacceptable, the design shall be modified accordingly.

The Central Control Station, distributed control modules, and the sensors and actuator for vital functions shall be supplied with electrical power through an UPS having at least a one-hour full load battery capacity.

REFERENCES

None.

6.13 SUBSYSTEM/EQUIPMENT IDENTIFICATION: Data Acquisition Subsystem (DASS)

SUBSYSTEM/EQUIPMENT SCOPE

The DASS includes the instrumentation, signal conditioning, recording and data processing equipment needed to verify the performance of the CEA and to provide an audit trace to permit evaluation of the effectiveness of the subsystems, techniques and procedures. It will share many of the sensors included in the control subsystem and may share portions of the control subsystem processor and peripherals.

BASIC APPROACH AND DESIGN PHILOSOPHY

The DASS shall record pertinent data at frequent intervals and produce periodic summaries which indicate the performance of the CEA and its several subsystems. The summaries shall be tailored to permit performance evaluation and produce management information.

Since it is unlikely that all correlations and data processing requirements will be anticipated in advance, the DASS shall include mass storage of raw data to permit post operations analysis.

Special recording instruments, such as multichannel chart recorders shall be provided for use as required by the facility manager to monitor parameters of special interest. The input to these special recorders will be wired to the central station wire termination closet where they can be connected to the desired signals by temporary wiring.

SPECIFIC FEATURES

There are extensive requirements for non-instrument data which should be machine readable to facilitate processing. These include planting (date, quantity, location, seed source, seed treatment, etc.), harvesting (date, quantity, quality, etc.), soil, chemical and water analyses, consumables used, etc. Special formats or an interactive query-response routine are needed to ensure correct and complete entry.

SPECIFIED CONSTRAINTS

See requirements summary, Section 4.

ENVIRONMENTAL CONSTRAINTS

None which limit design.

REFERENCES

None.

SECTION 7
LIST OF REFERENCES

CLIMATIC DATA

1. "Generation of a Typical Meteorological Year," Proceeding of the 1978 Annual Meeting of the AS of ISES, Denver, Colorado, Vol. 22.

2. "SOLMET, Volume 1 - User's Manual", U. S. Department of Commerce, 1977.

3. "SOLMET, Volume 2 - Final Report, TD-9724," U. S. Department of Commerce, 1979.

4. "Procedures for Determining Heating and Cooling Loads for Computerizing Energy Calculations; Algorithms for Building Heat Transfer Routines", Energy Calculations 1, ASHRAE, 1975.

5. "NBSLD, The Computer Program for Heating and Cooling Loads in Buildings", Kusuda, T., NBS Science Series 69, 1976.

6. "National Wind Data Index; Final Report", Changery, M. J., HCO/T1041-01, 1978.

7. "Typical Meteorological Year", User's Manual, TD-9344, National Climatic Center, U.S. Department of Commerce, 1981.

8. "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States, "Kusuda, J. and Ackenback, P.R., ASHRAE Transactions, Part 1, pp. 61-65, 1965.

9. "Periodic Variation in Ground Temperature with Depth," Kharty, A. K. and Sodha, M. S. and Maljk, M.A.S., Solar Energy, Volume 20, pp. 425-427, 1978.

10. "Climatic Atlas of the United States", U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, 1977.

CROP PRODUCTION PROGRAM

11. Bryan, H. H., 1977, "A Systems Approach to Growing Vegetable Transplants in Greenhouses", pp. 225-230, Proceedings International Symposium on Controlled Environment Agriculture, Tucson, Arizona.

12. Paterson, Don, 1981, "Personal Communication"

13. Larsen, John, 1981, "Personal Communication"

CROP PRODUCTION FACILITIES

14. Brooks, W. M., 1977, "Greenhouse Growing Techniques with Soil Culture", pp. 190-197, Proceedings International Symposium on Controlled Environment Agriculture, Tucson, Arizona.

15. Jensen, M. H., 1977, "The Sand Culture System in Controlled Environment Agriculture", pp. 198-207, Proceedings International Symposium on Controlled Environment Agriculture, Tucson, Arizona.

16. Paterson, Don, 1981, "Personal Communication".

GREENHOUSE DESIGN

17. Van Bavel, C.H.M., Damagnez, J., "A Simulation Model of Energy Storage and Savings of a Fluid-Roof Solar Greenhouse", Acta Horticulturae 76, 1978.

18. Van Bavel, C.H.M., Sadler, E. J., "Analysis of the Fluid-Roof Solar Greenhouse" Proc. 3rd Annual Conference Solar Energy for Heating Greenhouses and Greenhouse/Residence Combinations. April 2-5, Fort Collins, Colorado, 1978, pg. 60-67.

19. Van Bavel, C. H. M., Sadler, E. J. and Damagnez, J., "Cooling Greenhouse Crops in a Mediterranean Summer Climate", Acta Horticulturae 115, 1980.

20. Van Bavel, C. H. M., Sadler, E. J. and Heathman, G. C., "Infrared Filters as Greenhouse Covers: Preliminary Test of a Model for Evaluating Their Potential", ASAE National Energy Symposium, Kansas City, MO., Sept. 29 - Oct. 1, 1980.

21. Van Bavel, C. H. M., "Projecting Crop Growth in a Fluid-Roof Solar Greenhouse", ISHS Symposium on Potential Productivity in Protected Cultivation, Kyoto, Japan, August 30, 1978.

WATER RESOURCES

22. Texas Department of Water Resources, "Ground-Water Development in the El Paso Region, Texas with Emphasis on the Lower El Paso Valley", June 1980.

23. U.S. Geological Survey Open File Report 77-575, March 1978.

CO_2 IN GREENHOUSES

24. Ohio Agricultural Research and Development Center, "Conserving Energy in Ohio Greenhouses," OARDC Special Cir. 102, Extension Bul. 651, November 1979.

25. Ohio Agricultural Research and Development Center, "Management Practices to Consrve Energy in Ohio Greenhouses," OARDC Special Cir. 104, Extension Bul. 668, July 1980.

26. Holley, W. D., 1972, "The CO_2 Story", p. 157-160, In the Ball Red Book, (Vic Ball, Editor), 12th Edition, 502 pp.

EMMISSIONS FROM CROP RESIDUE COMBUSTION

27. Chi, C. T. and D. L. Zanders," Source Assessment: Agricultural Open Burning -State of the Art: EPA-600/2-77-107a (July 1977).

PV SYSTEMS

28. "Interim Performance Criteria for Photovoltaic Energy Systems", SERI/TR-742-654, December 1980.

29. Block V Solar Cell Module Design and Test Specification for Intermediate Load Applications - 1981, JPL 5101-161, February 1981.

SECTION 8

ENVIRONMENTAL ASSESSMENT OF FIELD TEST

8.1 INTRODUCTION

This section of the report addresses the environmental issues implied in the construction and operation of the solar controlled environment agricultural systems (SCEAS) on the site chosen in El Paso, Texas. The issues of particular interest are the potential impact of the SCEAS on various physical media (air, water and land) and compliance with existing and proposed State and Federal regulations. These issues are discussed in a conceptual sense. Compliance with State and Federal regulations are summarized briefly. A preliminary permit list is provided as a guideline for some areas of possible concern. Beyond the application of rules and regulations for the SCEAS are the subjective aspects of environmental and socio-economic impact. Since it is beyond the scope of this document to analyze specific impacts some of these issues are pointed out and discussed briefly.

Table 9 shows a summary of the effluents from the SCEAS facility in El Paso, Texas. These estimates are based on the conceptual design of a one-hectare field test greenhouse system and may somewhat vary from the final design which will follow later in this contract. However, it is believed that the estimates considered in this section are kind of upper bound values for the engineering field test. The major purpose of the study presented in this section is to identify specific areas which will need attention not only in the erection and operation but also in the final design of the proposed facility in El Paso, Texas.

8.2 SITE ASPECTS

The site chosen for the SCEAS is the experimental farm owned and operated by the Texas A&M Experiment Station in El Paso. The farm is located in the Rio Grande Valley about 24 kilometers (15 miles) from El Paso International Airport and 4.8 kilometers (3 miles) from Route 10, the main

Table 9. Effluents from a One-Hectare SCEAS

SOURCE	Magnitude	Comments*
Liquids		
1. Brine from desalination plant	7m^3/day at 45^{o}C TDS = 1.4% plus pretreatment chemicals	1, 3
2. Warm groundwater (after greenhouse cooling)	4,300 m^3/day at about 23^{o}C	1, 2
3. Fertigation medium overflow	1 m^3/day, TDS up-to 800 ppm of nutrients	1, 3 Spray on surrounding land
4. Soil leaching	40 m^3/day every 4 to 6 weeks TDS up to 1000 ppm of residual salts	1, 2, 3 Reuse for sanitary purposes, produce washing
5. Soil sterlization, seed and produce washing	Neglegible	1
6. Sanitary and wash water needs	1 m^3/day, will contain soap etc.	Septic tank or sewer line
Solids		
1. Garbage/trash disposal	Cardboard boxes, glass and plastic containers etc.	Incinerate, use in boiler, haul to a dump site
2. Ash from burning of crop residue	25 kg/day	Spread on surrounding land as fertilizer, land filling, haul to a dump site
Gases		
1. Combustion of crop open burning	Particulates: 1 kg/day SO_x: none NO_x: 4.0 kg/day CO : 0.6 kg/day Hydrocarbons: 0.6 kg/day	Burn in a controlled boiler these rates will go down. Use scrubber

*1. Discharge into irrigation drainage canal
2. Inject into the Aquifer
3. Evaporation pond

East-West interstate highway. The area for several miles around the site is devoted primarily to agriculture; so from that point of view the SCEAS is environmentally compatible. While there are some greenhouses in the general area, most agriculture, however, is on open land and totally irrigated.

There is in place a substantial agricultural infrastructure and a large population of farm workers to draw on for site personnel. Since the El Paso region is growing rapidly both industrially and in population there is a large construction industry which will be able to handle with ease the requirements for the SCEAS.

8.3 WATER USE

The primary source of raw water for the SCEAS facility will be the Rio Grande alluvium aquifer (1). The quality of this water is presented in Table 10. The use of this water for the proposed facility is not considered a problem because the state has built drainage canals which are fed by this aquifer specifically for irrigation purposes in the area. The temperature and the TDS (total dissolved solids content) content of this water source are about 18^{o}C and 3500 ppm respectively.

The SCEAS will use water from the underlying Rio Grande alluvium aquifer for two purposes: 1) to provide cooling and humidity control for the greenhouse, and 2) to provide brackish water feed for the reverse osmosis water purification system. The cooling water will be returned to the aquifer, essentially unchanged in chemical composition with the temperature raised by approximately 5^{o} centigrade (from 18^{o}C to 23^{o}C).

The effluent brine from the reverse osmosis system will contain approximately 1.4% total dissolved solids and be at a discharge temperature of approximately 45^{o}C.

As is evident from Table 9, the flow rate for the cooling water far exceeds that of the brine disposal. The maximum cooling water requirements

TABLE 10

ANALYSIS OF FEED WATER TO THE SCEAS TEST FACILITY

McCORMACK CORPORATION

ESTIMATED OPERATING RESULTS

Name University Farm Well   Address East of El Paso, Texas

1 Raw water sample collected after two hours pumping at 2,500 gpm, as

2 1 - converted to $CaCO_3$ 5 substance

3   7

4   8

Analysis of treated waters are typical of results anticipated. Any guarantees with reference to specific constituents are covered separately.

	Substance	Symbol	mg/L (PPM) As $CaCO_3$ 1	2
Cations	Calcium	Ca^{++}	108	270
	Magnesium	Mg^{++}	83.3	343
	Sodium	Na^{+}	781	1702
	Potassium	K^{+}	66.7	85
	Hydrogen Acidity	H^{+}	-	-
	Total Cations		-	2400
Anions (Alkalinity)	Bicarbonate	HCO_3^-	416	416
	Carbonate	CO_3^{--}	0	0
	Hydroxide	OH^-	0	0
	Phosphate	PO_4^{---}	1.5	2.4
Anions	Chloride	Cl^-	719	1014
	Sulfate	SO_4^{--}	920	957
	Nitrate	NO_3^-	1.5	1.2
	Total Anions		-	2391
	Total Hardness	$CaCO_3$	615	613
	Alkalinity A (Methyl Orange)	$CaCO_3$	416	416
	Alkalinity B (Phenophthalein)		0	0
			mg/L (PPM) As Substance Or In Units Indicated	
	Free Carbon Dioxide	CO_2	CALC.	26
	Silica—Total	SiO_2	16.4	16.4
2	Silica—Dissolved	SiO_2	15.6	15.6
1	Iron—Total	Fe	0.59	0.59
	Iron—Dissolved	Fe	0.40	0.40
	Manganese—Total	Mn	0.66	0.66
	Manganese—Dissolved	Mn	0.56	0.56
	Fluoride	F	1.15	1.15
	Oxygen Demand	$KMnO_4$	--	5.6
	Suspended Solids		24	24
1	Turbidity (NTU)		1.7	1.7
	Silt Density Index		-	-
	Color—Apparent		-	-
	Color—True (APHA)		50	50
	Total Organic Carbon	C	2.2	2.2
	Conductivity mmho/cm		5166	5166
	Total Ions		-	
	TDS—(By Evaporation)		3488	3488
	pH Field		-	-
	Laboratory		7.5	7.5
	Calculated		-	-

Barium <0.01

Strontium 9.0

1. Haze in sample cleared when acidified
2. Sample thru 0.45U filter.

are estimated at 4300 m^3/day (1.2 x 10^6gal/day) for the summer months of the year. In winter months, however, the cooling water flow rate may be a factor of 2 or 3 lower than this value. Two methods of disposal present themselves:

1. reinjection into the aquifer, and
2. discharge into an irrigation drainage canal.

In a sense the two methods are equivalent since the drainage canals are necessary to prevent the water table from rising due to the high level of irrigation and there is almost continuous discharge from the aquifer to the canals.

The second of these methods is preferred for disposal of cooling water. A permit to discharge will be obtained from the Texas Water Resource Board in Austin, Texas.

The brine reject from the desalination plant is estimated at 7 m^3/day, at 1.4% TDS and 45^{0}C. If this effluent were mixed with the cooling water discharge the resulting total discharge would be at 3516 ppm TDS compared to 3500 from the aquifer and the temperature would be 23.1^{0}C. Neither of these small changes is expected to cause any environmental problems for the system. If environmentally necessary and economically attractive, the rain water may be collected and mixed (after appropriate treatment) with the reject brine and the cooling water before discharging to the aquifer. Based on a precipitation rate of 20 cm/year, the rain water corresponds to an average flow rate of about 55 m^3/day. This water, together with reject brine from the desalination plant, would result in a TDS level significantly below 3500 ppm.

An alternate method of brine disposal would involve construction of an evaporation pond. However, this would probably, in the particular case under consideration, be environmentally more objectionable than discharge to the drainage canal nearby primarily because of the risk of brine leakage into the surrounding agriculture land.

Other minor water effluent streams requiring disposal will result from soil leaching* requiring approximately 170 m^3 of water once or twice a year, soil sterlization, possible crop washing, and fertigation medium overflow. The fertigation overflow will average approximately 1 m^3/day and will contain up to about 800 ppm of crop nutrients such as nitrogen, phosphorous, and potassium and some trace elements in concentrations less than 1 ppm. The soil-leaching for different sections of the greenhouse will be done at different times. Thus, the effluent from the soil leaching operation could be as much as 40 m^3/day, on an average once every four to six weeks. The TDS of this stream will be about 1000 ppm comprising mainly of residual salt (sodium chloride) in the soil.

It is expected that these water discharges can be handled in the same manner as the brine from the water purification system and diluted with cooling water before disposal. These streams will also lower the TDS content of the reject stream. However, these streams may have to be chemically treated before discharging into the drainage canal. On the other hand, some of these streams may be used for growing of trees and/or biomass in the surrounding land since it contains nutrients.

Lastly, the effluent stream of sanitary water which will approximate to about 1.0 m^3/day may be collected in a separate septic tank or discharged in the existing septic tank which is within 100 m of the proposed site.

8.4 AIR EMISSIONS

The primary evnrionmental issue with air emissions is the crop residue combustion subsystem. This subsystem provides (i) thermal energy for preheating the feed water to the desalination system and (ii) carbon dioxide for the greenhouse. The two products of combustion to receive the greatest attention will be particulates and SO_2. Since the sulfur content of the crop residue is inherently low, the need for an SO_2 scrubber would be eliminated.

---

* Based on a maximum of half gallon per ft^2 of leaf covered area.

Based on an EPA report on burning of agricultural residues (2), estimates of air emissions from the residue combustion subsystem are presented in Column 2 of Table 11. Based on an average crop residue rate of 132 kg(dry) per day (for a crop of tomatoes) for a one-hectare greenhouse, the daily emission rate for different compounds is shown in Column 3 of Table 11. The ash content of the residue varies with the crop but is probably between 10% (e.g., for ordinary grass) and 20% (for corn storer) on a dry basis.

The particulates from the combustion of the crop residue will be the emisssion of most concern to the state. The conceptual design anticipates using a mechanical collector to capture the large particulate particles. If required, additional equipment like an electrostatic precipitator to catch the finer material may be added to the final design. These systems have been found to work well for a number of operating wood-burning boilers and should allow compliance with the region's air quality standards.

Based upon our conversations with a boiler manufacturer (3) who has experience with burning agriculture residue, it is estimated that a crop residue combustion subsystem burning about 900 kg/day (1 ton/day) will produce about 3800 kg of steam per day (8400 lb/day). The total ash content of the crop residue will be about 110 kg/day (240 lb/day); based on 12% of the total dry mass. Generally about 30 to 50% of this incombustible material will end up in the flue gas. This corresponds to about 33 to 55 kg/day, or about 2.75 to 4.6 kg/hour for a system operating 12 hours per day.

According to the latest EPA requirements for the state of Texas (4), the combustion system would be allowed to release up to 0.8 kg of particulate per hour in the flue gas. In other words, the particulate collection system would have to be designed to capture at least 72 to 83% of the total particulates released from the boiler combustion chamber. According to boiler experts (3) this can be accomplished without much difficulty. However, the exact design and cost of the particulate collection system will depend upon the particulate size distribution, which in turn depends upon the size and the type of crop residue.

Table 11. Air Emissions from Combustion of Crop Residues

Effluent	Data on Emissions: kg/1000 kg of material burned*	Data on Emissions: kg/day for a one-hectare SCEAS**
Particulates	2.5-9	0.33-1.2
SO_x	-	-
NO_x	0.5-1	0.07-0.13
CO	10-35	1.3-4.6
HC	1-5	0.14-0.66
Ash+		13-26

* Based on open burning of agricultural residues, Reference 2.
** Based on an average production of 132 kg (day) per day for tomatoes.
\+ Assuming that the incombustible material constitutes 10 to 20% of dry crop residue.

It has also been pointed out (3) that the burning of crop residue in a well designed and controlled boiler will result in lower carbon monoxide (CO) and hydrocarbon production as compared to open burning. This is principally because the feed in the boiler can be fully exposed to the air resulting in more complete combustion. Again, there are a large number of operating boiler systems burning agricultural residue in which the emission levels of CO and hydrocarbons are well below the environmental requirements. Overall, the gaseous effluents from the SCEAS could be easily controlled below the environmental requirements without any problem.

8.5 SOLID DISPOSAL

Solid waste produced by the facility will be garbage/trash which must be disposed of properly. This will be no more than that associated with normal farming operations and will be handled according to local practices and methods on neighboring farms.

Approximately 25 kg of ash from burning of crop residues will be generated each burning day. Possible disposal of this residue as local land fill or as soil conditioner and low level fertilizer in land surrounding the SCEAS. As a last resort, if necessary, ash from the crop combustion and other solid waste will be periodically trucked to the University, or another appropriate dump site as commonly practiced by the other farms in the area.

The above analysis takes into account the environmental pollution impact of the SCEAS. As a general observation the resource uses and the discharges from the SCEAS will exert negligibly small impact on the local area.

8.6 WIND ENERGY SUBSYSTEM

The only structure which departs significantly from what would be considered normal and routine in the general area of the selected site will be the Wind Energy System. It is possible that a permit will be required from the Federal Aeronautical Administration. Compliance on the height of the wind system tower so as not to constitute a navigational hazard will be required and appropriate lighting and marking of the tower will be required. Additional information on the environmental requirements for the wind energy system will also be available from the manufacturer, once the design has been finalized.

Noise from the wind energy system is not considered to be an environmental hazard. However, performance data on wind machines similar to the one selected in the final design will provide the evidence of any noise problem.

8.7 SUBJECTIVE ISSUES

There are no known subjective issues such as historical significance of the site, archeological sites, or wild life refuges which will be raised by the construction of the SCEAS.

8.8 PERMITS

Four basic permits will be required for the construction of the SCEAS.

1. Permission for use of the local drainage canals for disposal of cooling water, brine from the water purification, and other miscellaneous aqueous effluents can be obtained from the Texas Water Resources Board in Austin, Texas. A permit application has been requested and will be reviewed for possible problems.

2. A permit from the Texas Air Control Board to burn crop residues may be required. In particular, approval of the crop incinerator may be required when the decision has been made on a specific design. On the other hand, the final design will take into account the environmental requirements of the State of Texas.

3. A construction permit will be required. At this time the source of that permit is not known. The site is owned by the State of Texas and as such is not directly subject to local zoning or building codes. The state agency involved will undoubtedly respect the local ordinances

but it seems now that agreement from Texas A&M to locate the SCEAS on its property will constitute the only construction permit required.

4. A permit from the Federal Aeronautical Administration to construct the tower for the Wind Energy System will be required.

8.9 LIST AND SUMMARY OF DISCUSSIONS WITH STATE AUTHORITIES

1. For Construction Permit -

Mr. Gomez (915) 546-2119
County Engineer
County of El Paso, Texas

Based upon our conversation with Mr. Gomez it appears that since the proposed site is outside the city limits, a construction permit may not be required.

2. Permit for Liquid Effluents -

Texas Water Resources Board
Permit Department of Austin
P.O. Box 13087, Capital Station
Austin, Texas
(512) 475-7896

We have received appropraite forms to file for the permit. It appears once the final design has been completed an application for the permit will have to be filed.

3. Permit for Air Emissions -

Mr. Manual Gary
Texas Air Control Board
El Paso, Texas
(915) 591-8128

Based on our conversation with Mr. Gary it appears that a permit for crop burning may not be required.

8.10 REFERENCES

1. Ground-water Development in the El Paso Region, Texas with Emphasis on the Lower El Paso Valley, Report 246, Texas Department of Water Resources, June 1980.

2. Chi, C.T. and D.L. Zanders, "Source Assessment: Agricultural Open Burning -- State of the Art," EPA-600/2-77-107a, July 1977.

3. Mr. Allen C. Manicke, Manager-Special Projects, International Boiler Works, P.O. Box 498, East Stroudsburg, PA 18301. Telephone: (717) 421-5100.

4. State Air Standards: Extracted from EPA Reports, Power Magazine, Page 5-9, June 1980.