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FINAL REPORT

Volume 4
Saudi Engineering Solar Energy Applications System Design Study

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SOLERAS

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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.

تقـديم

«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 سُمِّي «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 .

FOREWORD FOR VOLUME 4

In response to a Request For Proposal (RFP) from Solar Energy Research Institute (SERI) which is the operating agent for the SOLERAS agreement made between the Department Of Energy (DOE) of the United States of America and the Saudi Arabian National Center for Science and Technology (SANCST), this report has been prepared. The SOLERAS programme is a joint venture between the United States of America and the Kingdom of Saudi Arabia and is a major step in the development and application of solar energy.

The RFP, is for an Engineering Field Test (EFT) project of integrated solar Controlled Environment Agriculture (CEA) system to be installed in climatic zones similar to those of Saudi Arabia and south western parts of the United States of America. The term "solar energy", within the context of RFP, is defined to include all direct and indirect solar energy sources.

Saudi Engineering Solar Energy Applications (SESEA), a registered Saudi Arabian company with reg. no. 38917, incorporates a team of outstanding international firms who have contributed to the preparation of this study.

SESEA, has applied extensive methods of system engineering and economical analysis to select the best of the technologies involved. To arrive at the optimum system configuration, the full range of candidate Agriculture, Desalination and Electricity generation technologies were evaluated, both separately and in combination, within the limitations set in the RFP and the Sub-Contract. The selected system, uses the concept of the solar pond as the prime source of solar energy collection and storage.

Solar energy is one of the most abundant sources of energy available. Despite its abundance, the problems associated with its harnessing have restricted its wide-spread use. The principal difficulties with solar radiation involve its variability over time, direction and intensity, as well as providing an adequate method of storage. As a result, considerable effort has been divested to solar collectors and energy storage facilities, ususally as flat plate collectors and fluid or solid heat reservoirs. Even where radiation levels are sufficient for the successful application of such technology, costs have been high and the power delivered has been suitable only for domestic or minor industrial use. For the proposed CEA system, solar ponds have been selected as the ideal method for both the collection and storage of solar energy in the form of thermal energy. The thermal energy is converted into electrical energy, by means of a Rankine Cycle, to power fans, pumps, instrumentation, controls, lighting etc. Not only does the solar pond overcome the difficulties mentioned above, but it does so simply and economically. A viable solar pond can be established with minimum effort on any impermeable site (even without a liner) given sufficient salt, water and radiation.

Where electricity is the desired output, the Rankine Cycle coupled to a generator represents a minor capital investment to the user. This combination has been selected because it lends itself to this application very efficiently.

For the CEA, the hydroponic system based on Nutrient Film Technique (NFT) and sand culture has been selected.

For desalination of brackish water, the Reverse Osmosis (RO) system is found to be the best.

In the field of Saudi Arabian/U.S. cooperation and technology transfer, SESEA, in preparation of this study, has endeavoured to focus on the broad objectives of the Saudi Arabian/U.S. joint commission on economic cooperation and the SOLERAS project. To achieve these objectives, SESEA has:

- Conducted a training programme to promising Saudi Arabian Students;
- Selected design criteria which will be achieved by the use of materials and construction techniques new to Saudi Arabia;
- Selected System Performance Specification to achieve levels of Performance not yet reached in Saudi Arabia;
- Adopted a management approach which will fully integrate the technical and the management efforts of this project.

In RFP, SERI have specified the following sequence in the execution of work to be performed in Phase I of this project:

<u>Task I. "Programme Management and Control"</u>

In this Task, the contractor is requested to provide a team of management and technical personnel to begin the implementation of the project plans and to ensure timely completion of this Phase of the project. Attendance at project status review meetings and inerface meetings were also part of this task.

<u>Task II. "System Requirement Definition"</u>

The efforts to be made under this task were to culminate in a report which would provide the following information:
- Climatic data for the proposed site;
- System performance specifications;
- Integrated system design criteria.

<u>Task III. "System Analysis"</u>

The object of this report was to identify the major design trade-offs and to arrive at the most cost effective design consistant with performance and reliability requirements. The result of this study is a report which contains the following information:
- Detailed system definition for costing of a commercial-sized unit;
- Performance analysis of commercial-size unit;
- Recommendation on engineering field test size.

Task IV. "Preliminary Design of Pilot Plant of an Engineering Field Test"

Based upon the detailed system definition resulting from Task III, the contractor was expected to prepare a preliminary design for an EFT project of a solar CEA system, with a growing area in the range of 0.4 to 1.0 Hectare. The result of this study is a report containing the following information:

- Preparation of preliminary process engineering design of an integrated system;
- Preparation of process flow diagrams;
- Preparation of heat and material balance;
- Preparation of piping and instrumentation diagrams;
- Preparation of equipment specifications;
- Preparation of plot plans;
- Preparation of preliminary piping designs and studies;
- Preparation of preliminary civil engineering design and drawings;
- Preparation of preliminary electrical design and drawings;
- Preparation of preliminary instrumentation design and control diagram;
- EFT performance analysis;
- Test plans.

Task V. "Phase II - Definition Study"

Based on preliminary design made in Task IV, the contractor is expected to prepare detailed cost and schedule estimates for the detailed design, construction and operation of an EFT at the proposed site. Task V report contains the following information:

- Development of detailed plans for Phase II - the detailed design and construction of an EFT;
- Definition of all Sub-Tasks;
- Definition of project coordination requirements;
- Definition of project controls such as performance criteria, phasing, milestones and scheduling;
- Definition of operation and maintenance objectives;
- Definition of test plan objectives;
- Definition of cost estimates and schedule for complete system.

The above mentioned task reports have been condensed and modified for publication of the compiled volume. Proprietary information, as well as confidential cost reports, have been deleted. It should be noted however, that in preparation of these reports, the project team were able to discover, due to the passage of time, greater, more detailed and more accurate design information, which is reflected in the results shown. Hence, inconsistancies and discrepancies between the information given on each report should be seen in this light. Finally, the reader may discover a certain degree of repetition in the description of the system and sub-systems plus appearance of charts giving the same information. This is due to the fact that each task report was to be an independent source of information which resulted in material being used from the previous reports.

SUMMARY OF RESULTS

To summarize the results of this study it would be best to compare some key figures obtained from the work done in Task III and IV. Production and consumption figures are given for the 5 ha commercial unit (Task III) and the 0.4 ha EFT (Task IV).

The higher water consumption figures for the EFT are the result of the relatively larger solar pond area, selected on the basis of reasons given under Section 5 of Task IV.

		Commercial	EFT
Nominal Size	Hectar	5	0.4
Solar Pond Size	m^2	60000	8100
Crop Production	Ton/yr (note 1)	2750	250
Well Water Supply	m^3/day (Avg.)	990	143
" " "	m^3/day (July)	1720	254
" " "	m^3/day (Dec.)	418	61
Pond Water Make-up	m^3/day (Avg.)	542	107
" " "	m^3/day (July)	1063	201
" " "	m^3/day (Dec.)	211	44
Cooling Pad Evaporation	m^3/day (Avg.)	241	19
" " "	m^3/day (July)	450	36
" " "	m^3/day (Dec.)	0	0
Fresh Water Consumption	m^3/day	207	16.5
Electrical Energy Requirement	kWh (Avg.)	200	25
Desalination Energy Requirement	kWh/m^3 of sweet water	1.5	1.5
Thermal energy output	kW_{th} (Avg.)	2175	350
Electrical Energy ouput	kW_e	200	28.6

Note 1: Depending upon the type of crop, yields of 100 to 1000 Tons/ha-yr can be expected.

TASK II REPORT

SYSTEM REQUIREMENTS DEFINITION

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TASK II REPORT

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Fig. No.

1. SYSTEM DESCRIPTION SUMMARY

1.1 INTRODUCTION

After collecting environmental data and assessment of those data, SESEA confirms that its design contains the following Sub-Systems:

- a CEA-system based primarily on a NFT-culture with a supplemental sand culture.
- a brackish water treatment based on Reverse Osmosis Technology.
- an energy supply system based primarily on an Organic Rankine Cycle.
- an energy storage system based primarily on the thermal storage capacity of the solar pond, with a supplemental battery storage.
- an energy supply back-up system based on utilisation of a suitable Diesel Generator with auto-transfer.
- a waste disposal system based on evaporation of reject water and natural decay of crop waste.
- a centralized control and instrumentation facility.
- miscellaneous facilities and enclosures.
- data acquisition.

Reference is made to Appendix 'B', Fig. II-10, System Schematic.

1.2 CEA-SYSTEM

A 6750 m^2 of the growth area is based on an optimum produce production, utilising a hydroponic system, applying Nutrient Film Technique (NFT).

Another 2250 m^2 of the growth area is based on an optimum produce production, utilising sand culture with a drip irrigation system.

A separate section of the growth area is dedicated to seedling activities, as well as performance of tests for optimization such as:

- product varieties
- shading material
- nutrition

We have selected for this purpose an area in the center section of the CEA-system, which is due to the location most suitable to provide the type of services required to perform the proposed tests for optimization.

1.3 WATER TREATMENT

The selected water treatment system is based on Reverse Osmosis for which no alternative system will be installed, as this system is unique in its flexibility for treated water quality.

The system can cope with a wide range of quality and quantity requirements as set by climatic conditions as well as varying make-up water demands for nutrition. The Reverse Osmosis is incorporated in the design specifically for the treatment of irrigation water. Due to the fact that the available well-water at site is below 2000 ppm TDS, the salt removal for cooling water is far less stringent than for nutrition make-up water. Moreover, the system balances its reject against the energy requirements of the facilities.

1.4 ENERGY SUPPLY

The major energy supply source is the Organic Rankine Cycle, which uses the thermal energy of the solar pond as heat source, and the CEA-system exit cooling air as heat reject source. Both sources are designed to provide sufficient duty to operate the expander turbine driving the electric generator and the water heating requirements of the CEA-system.

The required power is primarily supplied in the form of electrical energy, which will be distributed to the equipment in the most efficient manner in accordance with the control requirements. Use will be made of a combination of AC and DC systems. All control functions will be supplied with a DC system.

1.5 ENERGY STORAGE

A major advantage of the above indicated prime sub-systems is the availability of an enormous energy storage capacity in the form of thermal energy in the solar pond.

The storage capacity of the solar pond not only covers the daily fluctuations, but also the seasonal variations even up to the point of being a direct storage of thermal energy for the heating requirements of the winter period.

An additional battery storage is envisaged for peak shaving and storage of surplus energy.

1.6 BACK-UP POWER

For emergency situations, Back-up Power will be provided via the utilisation of a stand-by Diesel Generator, with automatic transfer capability, which will work in coordination with the battery storage, to ensure continued operation in the case of unforeseen Solar Power interruption.

1.7 WASTE DISPOSAL OF AGRICULTURE WASTE

Agriculture waste (crop waste) is a highly valuable material for preparation of compost, which is essentially a natural process, supplying the necessary feeding stuff for produce.

The agricultural waste disposal system has the ability to either upgrade the available sand or to be mixed with artificial soil material, supplying in this way a product for soil stabilization around the project facilities.

1.8 SALT WATER REJECT

The reject water from reverse osmosis system is diverted to the solar pond to partially make-up the evaporation losses.

1.9 CONTROL AND INSTRUMENTATION

The proposed facilities comprise of the following major parts:

- Controls and Instrumentation necessary for the economic operation of the plant.
- Additional Instrumentation and monitoring equipment for research/testing programs with output formats enabling data processing at a later stage at another place. (See data acquisition).

The level of control and instrumentation for economic operation is based on the application of centralized automatic control (min. manpower) and recording with additional local hand control and indicators. All necessary alarms will be incorporated.

The level of instrumentation and monitoring equipment is directly dependent upon the test program to be performed in Phase II of this project and as such, it will be the result of Phase I specifications. Essentially all parameters influencing the operation of sub-systems under study will be directly or indirectly controlled as well as monitored.

1.10 MISCELLANEOUS FACILITIES AND ENCLOSURES

The facilities contain certain enclosures necessary for a complete integration of all prime sub-systems, such as:

- fencing
- control room
- produce storage
- maintenance facilities

1.11 DATA ACQUISITION

A continuous system of data acquisition will be incorporated to provide all relevant parameters for:

- Daily operation and daily reports
- Weekly program analyses
- Experimental performance evaluation of the system and sub-systems

The collected information will be reported on a magnetic tape for performance evaluation at a later stage.

2. ENVIRONMENTAL DATA COLLECTION

To collect the environmental data relevant for the design of the project in a reliable manner it was first decided to establish the required data (2.1) then the most available and suitable sources of data were to be identified (2.2) and then the actual data collection and the environmental assessment report (2.3).

2.1 DATA REQUIREMENT DEFINITION

The data requirements may be defined as; all environmental data that effectively will influence the performance and the design of the system. These requirements have been listed in Appendix A.

2.2 ENVIRONMENTAL DATA SOURCES

Based on the identification of the engineering field test site on the experimental farm of the College of Agriculture of the University of Riyadh, Saudi Arabia, it was decided to collect environmental data from:

2.2.1 College of Agriculture, University of Riyadh

The site location data, partially available for 1979, 1980 and up to June 1981, were recorded by The College of Agriculture.

2.2.2 Ministry of Agriculture and Water

Since the data does not cover a sufficient time period to provide a reliable design basis and certain specific data were unavailable (Solar Radiation and Cloud Cover) additional data, for the general geographic areas identified, have been obtained from The Ministry of Agriculture and Water, in Riyadh.

2.2.3 University of Petroleum and Minerals in Dharan

A preliminary review of the latter data indicated that a third source of data information was required to enable the verification of the site data and a reliable design basis.

The University of Petroleum and Minerals in Dhahran has collected climatic data for some years and this information was used as the third source of data.

2.3 EVALUATION OF ENVIRONMENTAL DATA

2.3.1 Introduction

In this report it is intended to assess the environmental conditions of the selected site for this project with the object of evaluating the suitability of the site within the set design parameters (hot, dry climate) and of determining the actual design parameters to be used, in order to optimize the design and at the same time, protect the natural environment.

2.3.2 The Natural Climate

Climate is a collective state of the atmosphere at a given place or over a given area within a specified period of time. The individual weather events and the meteorological elements characterizing them form at any place a group of properties peculiar to the particular locality. A group of observed values can be described by statistical measures such as the mean, the range, the frequency of intervals, the sequence of events, and their periodic repetition. In a narrower sense, many consider climate only as the mean local condition of the atmosphere. As such, it can be abstracted by the "mean values" of various meteorological elements, namely, pressure, humidity, wind direction and speed, cloud cover, solar radiation, etc. A characterization of collective "weather" in this fashion permits one to establish distinctions between atmospheric conditions at various localities.

The term used in the RFP for this project, identifying the climate as "hot, dry", is one of these characterizations. For evaluation purposes however, it needs further definition to allow comparison with the actual conditions in the selected locality and final verification that the chosen site meets the original specification.

2.3.3 Definition of "Hot, Dry" climate

Within the rather wide range of atmospheric conditions an infinite variety of combinations of climatic values, their frequencies, and their daily and annual variations appear. Therefore, to set up climatic categories is by no means easy. Two places may show the same temperature throughout the year but have different amounts of rainfall. Others may agree in these two elements but show discrepancies in fog occurence or in wind speeds. The best that can be achieved is a classification of climate for a specific purpose. This purpose has been kept in mind when for the solar CEA project, a "Hot-Dry" climate was specified.

Inherently this type of climate is not suitable for conventional types of agriculture but is excellent for solar energy collection.

It is essential however, that the climatic data from the selected location are evaluated against the general accepted climatic classifications. Two of the most widly used climatic classifications are those of Koeppen and Thornthwaite.

The methods of classification on which both described systems are based can be considered acceptable for the purpose of defining a "hot-dry" climate for the solar CEA project since they effectively identify areas in which conventional agricultural methods are not suitable and therefore become candidates for CEA units.

It should be noted however, that neither classification method takes into account solar radiation or cloud cover.

Therefore, localities identified through these methods should be separately assessed for the suitability of a solar operated CEA unit.

By reviewing the data available for the Riyadh area, Appendix 'A', Fig. II-1, this locality can be evaluated on the basis of Koeppen's or Thornthwaite's system for dry climates and may be definetely classified as a "Hot-Dry" desert climate.

2.3.4 Agricultural Sub-system

Since the agricultural sub-system is of the CEA type, and uses hydroponic growing techniques with desalted water, many environmental restrictions controlling conventional agricultural development are eliminated. However, the type of design selected for the CEA unit will impose certain conditions on the environment of the selected site.
Main concerns for the CEA system are:

- Availability of sufficient solar radiation in the photosynthetically active radiation (PAR) frequency range.

- Atmospheric temperature versus relative humidity conditions that may be modified to acceptable levels required for best crop conditions within the CEA shelter. This condition may require either additional cooling or heating of the atmospheric air entering the CEA shelter for ventilation purposes.

- Availability of sufficient water from the aquifir to provide the CEA irrigation and cooling system.

The environment has been assessed on the above criteria with the following results.

2.3.5 Availability of Solar Radiation for Photosynthesis

The PAR frequencies are those that are within the range of solar radiation required for the photosynthetic process in the plants grown within the CEA shelter. The frequency range is from 400 - 700 manometers.

For evaluation of this parameter a basis of average daily radiation can be used. This information is shown in Fig. II-3. The percentage of PAR of the total available radiation accounts for only about 42% of the total solar energy.

The limiting factor for design of a CEA unit is a minimum average PAR radiation of 19-25 W/m^2. This factor has been established as the optimum condition for plant development. More radiation will not result in extra crop production but only increase the heat load on the shelter and should be therefore prevented.

The tabulation in Fig. II-3 shows clearly that throughout the year sufficient PAR is available to satisfy the CEA crop requirement.

2.3.6 Suitability of Atmospheric Temperatures

The CEA shelter climate should be controlled within the following limits of temperature and humidity to achieve the optimum result in agricultural production.

TEMPERATURE:

	DRY BULB °C	
	RANGE	EXTREME
DAY	21 - 25	29
NIGHT	19 - 16	14

HUMIDITY:

		% RELATIVE	
	MIN.	RANGE	MAX.
24 hr cycle	60	70 - 80	90

Reviewing the absolute maximum and absolute minimum atmospheric temperatures recorded, it is clear that both heating and cooling of the CEA unit will be required to reach the set criteria for optimum CEA climate.

2.3.6.1 Heating

The heating of the CEA unit during the low temperature days and nights in the winter is not a problem. The solar pond, acting as a heat reservoir, can be adequately sized to provide the amount of heat required. Humidity can also be easily increased with the Misting system if the relative humidity of the heated air falls below 60%. It is clear from the data that at no time the relative humidity will be above the design range after heating the air in the CEA unit to the design level.

2.3.6.2 Cooling

The cooling of the atmospheric air used for ventilation of the CEA unit during the hot summer conditions is more critical. Since the cooling is based on an evaporative system and the maximum humidity in the CEA unit should be kept below 90% the combination of maximum atmospheric temperature and relative humidity should be evaluated.

As a design parameter, the limit of a wet bulb temperature of 24 °C is selected. If at any time the atmospheric wet bulb temperature exceeds this limit it will be impossible to cool this air by evaporative cooling to a temperature within the set range of operation.

From a review (Fig. II-1) of the site climatic data it is clear that the above case will not occur and the set design criterion will always be met.

2.3.7 Water Availability

Water is one of the basic needs for a CEA system. Although the selected hydroponic techniques ensure a minimum of water consumption and a recirculation of all unused water, the crops will need a considerable amount of water for production of the vegetables (most consist of 80% - 90% water by weight) and for leaf cooling through evapotranspiration.
In addition to the irrigation water, a certain amount of water will be needed for the evaporative cooling in the summer and to increase humidity in the winter heating cycle.

It is of little value to attempt to calculate the exact water consumption at the different growing stages of the crop under the different climatic conditions since the existance of the many variables would make such a calculation grossly inaccurate.

Therefore, certain maximum limits are set for design, against which, the water supply may be measured.

For the planned project site of 1 ha. the maximum design flow and estimated maximum consumption of water are set at the following values.

	CONSUMPTION AT MAX. SUMMER CONDITIONS m^3/day	
Irrigation	40	(75% recovery from R.O.)
Cooling pads	90	
Pond Make-up	214	
Total Raw Water Consumption	344	

The design criterion for water consumption at maximum summer conditions results in an hourly flow requirement of 14.3 m^3/hr from the well. However, it should be noted that this flow requirement will be some-what reduced due to the fact that the water quality of the aquifir on the selected site is good (max. 1900 ppm TDS) and mixing with the desalted water reduces the total amount of flow.

At the selected project site, there are presently several wells drawing water from the aquifir.
The total quantity of water drawn from the aquifir presently is not measured by its user, The College of Agriculture of Riyadh University. However, experience shows that adequate water flows can be maintained and that the new well, to be drilled for this project, will be able to supply the design flow, of good quality water.

2.3.8 Solar Sub-system

The solar pond planned for this project must provide high temperature brine for the Organic Rankin Cycle and the CEA shelter heating system. It must be sized to meet the total power requirement of the CEA project in a reliable and competitive manner. Compared to other solar collection and conversion technologies, solar ponds, which collect and store energy in heat form, are very attractice for a wide range of applications.

The suitability of a solar pond, for this project, has been investigated in the proposal and based upon the power requirements and operational cycle of the project, it has been found to be ideal.

For a cost-effective solar pond, certain criteria will have to be satisfied. The main site criteria for a solar pond are:

- Availability of sufficient solar radiation and a minimum of cloud cover.
- Sufficient area of a suitable geological character. This concerns mainly the ease of excavation to the desired depth, form of the pond, and absence of heat dissipating soil structures or ground water.
- Availability of water in sufficient quantities to meet the pond's requirements.
- Availability of salt to stock and maintain the pond.
- Minimum pollution hazard in the event of pond leakage.

Although none of these criteria, if not satisfied, prohibit the use of a solar pond, they will increase the design and construction cost. If this occurs it may make the use of a basic solar pond non-competitive and require the incorporation of alternate solar technologies. In special cases it may require additional hardware to improve performance or safeguard against leakage.

2.3.9 Climatic Environment

The climatic parameters of key importance to the thermal performance of the solar pond are radiation and temperature. In Fig. II-3 monthly radiation averages are shown calculated from the data collected for the selected locality. In addition, Fig. II-1 shows calculated average atmospheric temperatures. The average data for these climatic parameters are most suitable for the assessment, since the solar pond due to its large thermal inertia does not react to extreme conditions of short duration.

The percentage of cloud cover for the selected locality is a very important parameter. The pond design must allow for a set number of cloudy days during which power generation must continue. Fortunately, the power consumption of the CEA shelter also drops during cloudy days and the effect on the pond performance is generally compensated for on short duration of cloud cover.

The average and maximum number of successive cloudy days are tabulated in Fig. II-5.

Assessment of the collected data indicates that radiation levels are high and average temperatures are high, indicating a very suitable climatic location for a solar pond. In addition, the set design parameter of an average of 2.5 cloudy days is in accordance with the collected data for 50% - 100% sky cloud cover. Furthermore, the cloud cover effect has been considered in the radiation level calculation.

2.3.10 Suitable Geological Character over Sufficient Area

Based on the initial investigation of the site, it appears that sufficient area for the proposed solar pond is available at the selected locality.

In accordance with the University of Riyadh information, the geological character of the site appears to be a dry and sandy loam which extends 2.5m to 3m deep. There does not appear to exist a shallow water table or ground water at the levels reached for the solar pond.

In the light of this information, it can be stated that the geological conditions are quite suitable for solar pond construction and operation.

2.3.11 Availability of Water

The water availability on the site has been investigated for the CEA project and is discussed in paragraph 2.3.7.

The same concern as stated above applies to the solar pond water requirement. Inconsistent or insufficient water supply will upset the balanced operation of the solar energy system.

2.3.12 Salt Availability

To start a solar pond without the supply of brine or salt may take years and would place it out of the scope of this project. Therefore, the design is based on a starting procedure with concentrated brine.

An alternate supply of brine is the reject flow of desalination plants.

At the time of study it did not appear that a ready source of brine is available close to the selected locality. This will increase the start up cost of the pond and therefore make the site less suitable.

For maintenance of the pond, the reject flow of the reverse osmosis system will be used.

2.3.13 Polution Hazards

The brine used in solar pond has a high salt concentration. Mixing of this brine with the surrounding soil or nearby aquifirs would deteriorate the quality of the soil or water for agricultural purposes.

Since the selected project site is an existing farm development with a single aquifir the pond design and construction needs to pay special attention to leak detection and protection of the environment.

This will increase the cost of the solar pond compared to ponds using natural salt water storage areas such as Sabkha's saltlakes or sea.

2.3.14 Assessment Summary

Measured against an average "Hot - Dry" dessert location the following classification can be made of the environment for the selected locality.

- Above average points (positive):

- Existing wind breaks
- Good access roads
- Near a major city
- Good soil conditions
- Little sandstorm incidence
- Good climatic records
- No earth quake activity recorded
- No extreme wind conditions
- Good water quality (low salt)

- Average Points:

- Temperature levels
- Radiation levels
- Precipitation levels

- Below average points (negative):

- Higher humidity levels
- Limited water supply
- Remote from brine or salt source

2.3.15 Conclusion

The assessment of the environment of the selected locality for the solar pond operated CEA system project as discussed in this report has shown that in general the site is suitable for the planned project. The designers of the project need to pay special attention to some items such as water supply and polution hazards. However, an understanding of these problems will permit the designers to find suitable solutions and present a viable project.

3. ENGINEERING FIELD TEST SYSTEM PERFORMANCE SPECIFICATION

In considering the objective for the solar CEA program as stated in the request for proposal (RFP):

" To integrate controlled environment agriculture with solar energy and to demonstrate the technical and economical feasibility of commercially viable solar controlled environment agricultural facilities in hot arid zones ".

The engineering field test system performance specifications should be set in such a manner that they will provide realistic and measurable information to test the system against the objective.

Since the stated objective incorporates a large number of components, the requirements for this objective, as stated in the RFP (Section 4) are at first identified. The result of this analysis has been used in setting the overall system performance specification and the related sub-system performance specifications (Section 5).

4. INTEGRATION OF SYSTEM REQUIREMENTS

As stated above, the engineering field test has to meet certain specifications to enable evaluation against the stated objective.

A number of requirements directly or indirectly related to the objective have been set out in the RFP, the SESEA proposal and the contract.

A number of these requirements are generally applicable to the complete field test system, others are specific for each sub-system.

The requirements are identified and grouped under the headings, integrated system design requirements and sub-system design requirements. (Listed in Attachment - B -).
The sub-systems are numbered as follows:

1 Agricultural Sub-system
2 Desalination Sub-system
3 Solar Energy Sub-system
4 Water Storage and Delivery Sub-system
5 Waste Disposal and Recovery Sub-system
6 Back-up Power Generation Sub-system
7 Controls and Instrumentation Sub-system
8 Facilities and Enclosures Sub-system
9 Data Aquisition Sub-system

5. SYSTEM PERFORMANCE SPECIFICATIONS

The objective and design requirements as presented in Section 4 have been evaluated and formulated in the following manner.

5.1 General system specifications
5.2 Engineering field test system performance specifications
5.3 Sub-system performance specifications

5.1 GENERAL SYSTEM SPECIFICATIONS

To reach the stated objective and review performance of the system in accordance to the RFP requirements, the following general specifications have been set:

- The system should perform in hot-dry climates.
- Solar energy to be used as the only power source.
- The structures should have a 20 year functional life.
- All recognized international standards should apply.
- Local safety and construction codes should be respected.
- A fully optimized integrated system should be created.
- System and equipment should be selected to achieve maximum technology transfer.

5.2 ENGINEERING FIELD TEST SYSTEM PERFORMANCE SPECIFICATION

The system designed in Phase I of this project will be able to deliver the average yearly crop production stated below at a cost equal or less than specified.

The specified parameters will be achieved while operating the system in a "Hot/Dry" climate in Saudi Arabia (Derab Site) or an equivalent location in the U.S.A., with full solar power and with the minimum usage of water.

The individual sub-systems will be designed to meet their specific performance specifications and satisfy, as an optimized integrated system, the field test performance specification.

5.2.1 Crop Production

The following production targets are well within the range of CEA units with NFT and sand culture systems.

Crop Type	EFT production target kg/ha/day		Proven Performance of growing system kg/ha/day
Cucumber	1900	*	2800
Eggplant	1300		1300
Lettuce	1500		1500
Okra	300	*	400
Tomato	900	*	1200

* Yields for the variety suitable for Saudi Arabian markets are lower than yields with North American types.

5.2.2 Crop Cost

The crop cost for the engineering field test are established on the basis of regular CEA produced crop costs in similar geographic areas and calculated on the basis of the Annualized System Resultant Cost formula for 1983, expressed in 1980 Prices. This basis is selected in order to measure the realistic viability of the project compared to non solar operated CEA systems.

Crop Cost	U.S.$/Kg
Cucumber	0.78
Eggplant	1.23
Lettuce	1.05
Okra	4.91
Tomato	1.71

5.3 SUB-SYSTEM PERFORMANCE SPECIFICATION

The 4 major sub-systems that directly influence the performance of the overall system are:

5.3.1 Agricultural
5.3.2 Desalination
5.3.3 Solar Pond and Power Generation
5.3.4 Water Storage and Delivery

Individual performance specifications have been set to evaluate the field test results of each system and identify the influence of each of the systems on the overall results of the operations.

5.3.1 Agricultural Sub-system

The agricultural sub-system consists out of 2 major sections:

- The CEA Shelter
- The Crop Production System

Although the second section is fully dependent on the first, to satisfy its performance specifications, individual specifications have been set to enable the evaluation of each system as an independent entity.

The overall performance specification for this sub-system is basically the total amount of crop produced as stated in section 5.2, under the engineering field test performance specification.

- CEA Shelter

The performance of the CEA shelter is one of the most critical functions in the field test and needs to be carefully evaluated. The basic function of the CEA shelter is to provide an ideal growing environment for the produced crops at all times. It creates this environment by enclosing the growing area and controlling the major functions of the environment such as, light, temperature, humidity and wind. Therefore these functions are selected as the performance specifications and identified below:

		DAY	NIGHT
Dry Bulb Temperature °C	: - Maximum	29	25
	Mean	23	17
	Minimum	16	14
Relative Humidity %	: - Maximum	85	
	Mean	75	
	: - Minimum	60	
Air Velocity m/sec	: - Maximum	1.0	
	Mean	.3	
	: - Minimum	0 (Night)	
Radiation Level (PAR) W/m^2	: - Maximum	73	
	Mean	22	
	: - Minimum	0 (Night)	

- Crop Production System

The crops produced in the ideal CEA climate can only be optimized through a carefully matched production system. The systems performance will depend on its capability to provide the plants with a balanced flow of nutrients during its full growing periods. The hydroponic systems selected are most suitable to provide this requirement and at the same time avoid plant stress that could result in severe crop reductions.

The only relevant measurement of performance is, once again, the achievement of the set production specification. However, some individual functions may be measured to evaluate the system performance. See Section 5.2.1 for performance specification.

5.3.2 Desalination Sub-system

The desalination subsystem, a reverse osmosis unit will have to deliver the water requirements of the CEA Shelter and to partially feed the solar pond to replace evaporated water. The feed water will be from a well to be drilled on the selected site. Performance specifications derived from this and from the system design requirements are identified below:

Product water purity T.D.S.	: less than 500 ppmv -
Production of product water	: 40 m^3 per day
Production of reject flow	: 13.7 m^3 per day

5.3.3 Solar Pond and Power Generation Sub-system

The solar energy sub-system consists of two major sections:
- Energy Collection (Solar Pond)
- Energy Transformation (Organic Rankine Cycle)

Incorporated in this sub-system should also be the required energy storage to fully operate the field test system.

- Solar Pond

Solar ponds are bodies of salt-concentration, i.e. stratified brine. The density increases with depth rendering the fluid anti-convective against thermally induced convection. Although there is a net upward flux of salt induced by the salt concentration gradient, techniques have been established to concentrate the bottom by salt addition and dilute the top with "fresh" water to nullify the flux.

Having become anti-convective, the pond also becomes a heat trap. With this situation, the pond very quickly begins gaining temperature, which induces heat losses.

The incident radiation less surface reflected losses penetrates the pond and is absorbed at various depths. Heat losses to the surroundings begin when a temperature differential appears.

Losses through the gradient Non-Convective Zone (NCZ) coupled with surface effects, like wind, induce a surface Upper Convective Zone (UCZ) through which heat escapes to the atmosphere. Where increased thermal storage is desired, a homogenous Lower Convective Zone (LCZ) is induced below the NCZ.

As radiation attenuation causes a temperature increase, then heat is lost from the pond by conduction through the NCZ and to the side and bottom.

Solar ponds behave principally as first order systems. Their time constants are strongly dependant on depth due to the amount of radiation absorption vs. depth and decreased mass. The forcing radiation function resembles a sine wave.

The specifications governing the solar pond must ensure that the pond meets the anticipated power requirements. At this stage, these requirements are not yet optimized on a integrated system basis and include some assumptions regarding performance. The following data will be used as basis for specifications.

- Power Delivery: The solar pond should provide an estimated maximum continuous power in December and January of 1342 kW thermal and a minimum during the summer of 767 kW thermal.

  Pond Efficiency: The overall annual efficiency delivered energy/incident radiation energy should be equal to or greater than 10%.

- Energy Storage: The pond should provide the required power at all times considering 50 - 100% cloud cover during 2.5 days (typical Riyadh data).

- Operating Temperatures: The pond should deliver to the ORC sufficient flow of brine at the following temperatures:

  Summer - 85 °C
  Fall - 80 °C
  Winter - 65 °C
  Spring - 70 °C

- Organic Rankine Cycle

  The ORC and generator package converts heat energy to electrical energy through a closed loop. This package consists of:

  1. An evaporator, in which solar pond brine through a boiler evaporates and pressurizes a freon liquid.

  2. A motor (or turbine), driven by the pressurized freon, which drives an electrical generator.

  3. A condenser, through which low pressure freon from the motor (or turbine) is condensed against the cool exit air of the greenhouse.

  4. A receiver drum, in which condensed freon is accummulated.

  5. A pump, which pumps the freon from the receiver drum to the evaporator.

  The electrical energy generated by the ORC/Generator package is supplied to the central control panel from where it is distributed to ventilators, pumps, instruments, controls and to the battery storage.

The total electrical power requirement has been calculated and is used to set the ORC/Generator specifications, which are:

Electric Power Supply:	Summer	-	40.5	kW
	Fall	-	36	kW
	Winter	-	28	kW
	Spring	-	36	kW

5.3.4 Water Storage and Delivery Sub-system

The well water pumped to the surface, for use in the system, performs a number of critical functions in the following sequence:

- Provides cooling for CEA shelter;
- Supplies the reverse osmosis system, with resultant production of water for irrigation and humidification, plus partial solar pond make-up;
- Provides make up water for the solar pond.

The performance of the system should be carefully matched with the interdependent functions and the required storage capacity of the system. The following performance specifications are required:

- Raw Water Storage: 7 days' supply of raw water requirements.
- Raw Water Flow: Maximum 130 m^3/day + solar pond evaporation loss.
- Cooling Water Flow: 90 m^3/day maximum consumption.
- Irrigation Water Flow: 40 m^3/day maximum consumption.

6. <u>SYSTEM DESIGN CRITERIA</u>

Where the specifications have been set to evaluate the performance of the system against the objective, the system design criteria will be used as a guide to design a system that will meet the performance specifications.

The design criteria may be identified as the general criteria for the system design and the specific criteria for each sub-system.

6.1 GENERAL CRITERIA

Design criteria controlling all systems are:

- The environmental data for the site as identified in Section 2.
- 20 year service life.
- Maximum automation to reduce manpower (target: for operation of field test, 8 employees).
- Simplicity of design (target: maximum repair time for any failure, 3 days).
- Represent accurate system performance to allow evaluation on a full commercial scale of 4 to 5 ha.
- Material and equipment selection based on proven performance and availability within 6 months from the date of contract in order to meet contract schedule.

6.2 AGRICULTURAL SUB-SYSTEM

6.2.1 CEA Shelter

- Provide sufficient insulation, heating and cooling to maintain the specified environment.
- Provide shading for PAR-radiation to reach specified levels at all times.
- Keep leaf temperatures between 15°C + 35°C.
- Provide suitable support for crop system.
- Provide a total growing area of 9000 m^2.
- Provide a seedling area and test area of 1000 m^2.
- Provide clear overhead height of 2 meter.
- Have 20 day water storage incorporated in main foundation design.

6.2.2 Crop System

- Provide a fully automated, fail-safe system in order to prevent any crop loss due to insufficient irrigation, nutrients or disease.
- Maintain a root temperature of 30°C ± 5°C at all times.
- Provide the production targets specified.
- Maintain continous growing throughout the year.

6.3 DESALINATION SUB-SYSTEM

To fulfil the performance specification, the following design criteria have to be applied for the reverse osmosis unit.

6.3.1 Product water quality of less than 500 ppm can be achieved by using a two-stage B9 permeator module of Du Pont Permasep. Depending on feedwater analysis, the product can be blended with the feed to make economic use of expected low TDS (total dissolved solids) of product: a 1900 ppm feed will deliver a product of 120 ppm.

Blending with feed, in order to deliver higher production, but with higher impurity, is energy saving because the feed does not have to be pressurized (normal feed pressure, 2760 kPa).

The feed will be filtered up to 10 microns to remove particles that might foul the membrames.

To reduce the possibility of chemical reaction or to protect the membrane against micro-organisms, the feedwater will be pretreated with chemicals. Dosing rates and components are subject to feedwater analysis.

6.3.2 The RO unit will be designed with an excess capacity of 50%. This will allow the unit to be taken out of service during periods of high electrical demand.

6.3.3 The design life of membrames is about 10 years. All other components will be designed for a 20 year lifetime.

6.3.4 All controls will be of the automatic type.

6.3.5 Maintenance will be restricted to small cleaning periods. Cleaning and rinsing should be as simple as possible and will be arranged by the use of easy couplings and automatic controls.

6.4 SOLAR SUB-SYSTEMS

The solar pond design requirements are reflected in the following design criteria.

6.4.1 <u>Suitability as a field test facility</u>

The solar pond facility as well as the greenhouse facilities will be designed about certain axes of symmetry thereby allowing for actual comparison and duplication of experiments. Full instrumentation will be incorporated to record all heat and material flows. Full piping and pumping will be incorporated to allow maximum flexibility of brine transport, in order to study layer behavior when pumped from areas of various concentrations and temperatures to others.

In addition, a water analysis facility will be provided to chemically analyse samples as desired as well as regularly monitor source water.

6.4.2 Provide energy storage to support continuous operation under normal conditions

No particular problem can be envisaged by Solar Ponds, by virtue of their huge thermal inertia. A design criterion of withstanding 2.5 days of 100% cloud cover was set, this being typical, to determine "normal conditions" based on Riyadh.

6.4.3 Provision of maximum automation

Solar ponds have a tendancy to reach equilibrium with their environment. For this reason, constant monitoring and gradient maintenance is required to maintain maximum collection and storage efficiency. It is envisaged that with one technician and a qualified engineer it will be possible to maintain continuous operations successfully when maximum automation can be provided.

6.4.4 Simplicity of design

All facets of the solar pond will be designed to be as simple as possible. All instrumentation and controls will be visible and marked.

6.4.5 Pond depth

Partitioning the pond, or having several ponds, allows for experimentation with various depths. In addition, depth within any one pond may be varied with time. Hence, pond depths may vary up to 5.5 meters (Shah, et.al. 1980).

6.4.6 Pond sides

Vertical pond sides are required through the UCZ and NCZ. This requirement may be relaxed, depending on the range of operating depths not yet determined.

6.4.7 Pond Sub-Soil

Minimum conductivity is desired around and beneath the solar pond. If deep cores show an excess of conductive materials, these will be replaced with dry sand having high thermal insulating properties.

6.4.8 Pond Sub-Base

An impermeable layer will be installed beneath the pond to contain any leakage and to prevent any ground water from approaching the pond.

6.4.9 Leak Control

A subsurface drainage system will be specified above the impermeable layer to conduct any leakage to a sump. The brine will then be pumped to a non-leaking pond as designated by management.

6.4.11 Liner

A liner of proven performance will be installed to withstand the anticipated pressures and temperatures. Manufacturer's installation supervision will be solicited along with a maximum lifetime guarantee.

6.4.11 Innovations in design

Experimental requirements, flexibility, system optimization and provision of storage in case of serious leakage, necessitate having a partitioned pond, or a combination of ponds. The controls and operations of such a system will lend themselves to considerable original design work. The brine withdrawal manifolds, given the large flows involved, will exceed existing systems. The use of evaporation ponds and the injection of the Reverse/Osmosis system reject to maintain the overall salt balance is novel to solar ponds. Incorporating a reflector to possibly lessen the greenhouse heat load and improve the pond "average collection area" is under consideration. Other innovations are required for the successful operation of the pond and are discussed under other system requirements. The final envisaged design of the solar pond will include these innovations which will contribute to the improvement of the operation.

6.5 RANKINE CYCLE SUB-SYSTEM

6.5.1 The energy demand of the total system varies according to the season as well as day or night operation. The design will be such as to follow the load curve. This can be achieved by:

- Change of motor speed. This will make instrumentation on cycle more complicated because of freon speed control, brine flow control and air flow control and a more complicated generator control.

- Constant motor power, but with battery storage. This will deliver extra power to the network during peak hours and will be filled up during low load hours.

- Installation of several smaller units which can be started and stopped depending on power need (seasonal, or day/night) with small battery storage to handle small load curve changes.

6.5.2 High efficiency of the system can be achieved by the choice of equipment with high efficiency factors.

6.5.3 Reliability will be achieved by using equipment of proven technology. The proper choice of a turbine or a screw machine is very important for the reliable operation of the system.

6.5.4 All controls of the Rankine Cycle will be designed for automatic operation as far as possible. This will include all flow, temperature, pressure, speed and voltage controls.

6.5.5 The design life of all equipment will be 20 years. This will also apply to materials to be used for the brine circuit which will have to be very resistant to corrosion, such as titanium.

6.5.6 The system will be designed for minimum maintenance.

6.5.7 Investment cost will be mainly controlled by evaporator and condenser materials choice and arrangement. The turbine or engine itself will only be less than a quarter of the total sub-system costs.

6.6 WATER STORAGE AND DELIVERY SUB-SYSTEM

Water storage is divided in two areas. Raw water storage used for cooling and supply to the RO system and the irrigation water storage. All storage tanks will be designed to absorb a maximum amount of heat energy from the shelter during the warm days and reject this energy for greenhouse heating during the nights. Optimum water temperatures will be maintained at around 25°C $\pm$ 5°C.

Irrigation water will be mixed with the nutrients in an automated system controlling pH, salinity and nutrient composition. The nutrient flow will be maintained at the specified temperatures for the root systems of the plants. The RO reject flow will be sent to the solar pond. The system will be capable to provide the flows specified.

6.7 BACKUP POWER GENERATION SUB-SYSTEM

A diesel generator will be used for back up power generation which will be capable of starting and accepting the critical system component load in less than 5 minutes. Target is less than 50% of full system load.

The unit will be capable of operating continuously for 48 hours.

Battery power will instantaneously energize critical items such as, nutrient pumps, controls and data collection systems.

6.8 CONTROLS AND INSTRUMENTATION SUB-SYSTEM

The controls and instrumentation selected for the system will be in accordance with the general specifications and criteria set out before. The system will be designed with duplicate controls and manual override controls for all critical functions. Automation of control functions will be incorporated wherever possible without making the system less reliable.

6.9 DATA AQUISITION SUB-SYSTEM

Data Collecting Points (DCP's) will be established based on the final flow diagrams of all the systems involved. Essentially all points which either set or report the conditions of a process are DCP's.

6.10 CONCLUSION

The design criteria identified in this stage of the project will be used as a guide for the next step, system specifications and evaluation, Task 3. After completion of Task 3 and optimization of the systems the full set of design parameters will be available.

APPENDIX - A -

ENVIRONMENTAL ASSESSMENT DATA

UNITS OF METEOROLOGICAL DATA PRESENTED

VARIABLE	UNITS
Temperature	Degrees Celsius
Wind Speed	km/hr
Wind Direction	Degrees from north (x 10^{-1})
Relative Humidity	Percent
Cloud Cover	Oktas (0=clear, 8=total cover)
Solar Radiation	W/m^2
Evaporation	mm
Precipitation	mm

FIG. II-1

MONTHLY AVERAGE CLIMATIC DATA FOR RIYADH

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
ATMOSPHERIC TEMPERATURE °C												
Maximum daily average	19.9	24.1	28.2	33.3	38.5	41.6	42.4	42.4	39.9	34.4	27.7	21.3
Minimum daily average	7.8	10.2	14.3	19.2	23.9	25.7	26.7	26.4	23.7	18.6	13.5	9.1
Daily mean	13.5	16.9	21.1	26.3	31.5	34.1	35.0	34.8	32.1	26.5	20.4	14.9
RELATIVE HUMIDITY %												
Maximum daily average	72	61	56	48	36	22	22	22	25	35	52	70
Minimum daily average	29	22	20	16	12	8	8	8	9	12	20	30
Daily mean	49	39	36	30	22	14	14	14	16	22	35	49
WIND SPEED km/hr												
Maximum daily average	15	16	18	18	18	19	20	17	14	13	13	14
Daily mean	7	7	8	8	7	8	9	7	6	5	5	6

FIG. II-2

CLIMATIC CONDITIONS RELEVANT FOR DESIGN

1. ATMOSPHERIC AIR TEMPERATURES

   - Maximum and minimum daily mean temperatures
   - Maximum and minimum monthly mean temperatures
   - Absolute maximum and minimum temperatures

2. EVAPORATION

   - Monthly mean evaporation

3. HUMIDITY

   - Maximum and minimum daily mean relative humidity

4. WIND

   - Maximum mean daily wind speed
   - Maximum wind speed

5. PRECIPITATION

   - Daily maximum precipitation
   - Daily minimum precipitation
   - Monthly maximum precipitation

6. SOLAR RADIATION

   - Daily mean radiation

7. CLOUD COVER

   - Number of successive cloudy days
   - Percentage of sky cloud cover

8. BAROMETRIC PRESSURE

Fig. II-3

AVERAGE DAILY RADIATION IN

W/m²

YEAR	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	SOURCE
1978	174	208	271	260	346	334	323	328	307	261	249	191	MAW
1976	145	178	192	242	262	287	279	282	247	208	190	194	MAW
1975	146	175	216	186	223	238	251	234	206	223	171	105	MAW
1974	128	158	155	235	231	235	248	243	246	206	181	117	MAW
1973	181	197	226	223	233	263	247	222	215	213	194	N/A	MAW
MFAN	162	199	227	238	264	287	285	272	257	226	184	161	UPM
P.A.R.	68	83	95	100	111	121	120	114	108	95	77	67	

MAW: Ministry of Agriculture and Water – data measured at 24°34' N.LAT, 46°43' E.LONG

UPM: University of Petroleum and Minerals - average calculated from daily values recorded 1965 - 1978

FIG. II-4

CALCULATED WET BULB TEMPERATURES

DERAB FARM SITE

	1979			1980		
	D.B.T. °C	R.H. %	W.B.T. °C	D.B.T. °C	R.H. %	W.B.T. °C
JAN.	28	40	19	30.5	25	17.5
FEB.	37	12	18	32	22	18
MAR.	37	10	17	33	10	17.5
APR.	40	9	17.5	42	10	19.5
MAY	44	8	19	43	10	20
JUNE	45.5	8	20	44.5	10	20.5
JULY	45.5	8	20	46.5	10	21
AUG.	43.5	8	19	42	10	19.5
SEP.	43	8	19	39.5	11	18.5
OCT.	39.5	9	17.5	34	16	17
NOV.	34	15	17	34	16	17
DEC.	29.5	19	16	29	13	13.5

D.B.T. = Measured Absolute Maximum Atmospheric Temp.
R.H. = Average Minimum Relative Humidity
W.B.T. = Calculated Wet Bulb Temperature

Fig. II-5

AVERAGE AND MAXIMUM NUMBER OF SUCCESSIVE CLOUDY DAYS

	NUMBER OF SUCCESSIVE CLOUDY DAYS					
	THE PERCENTAGE SKY CLOUD COVER					
	75%-100%		50-100%		25%-100%	
Year	Average	Maximum	Average	Maximum	Average	Maximum
1970	2.33	3	2.77	4	4.33	14
1971	2.13	3	3.88	9	5.1	14
1972	2.38	3	4.0	12	6.29	16
1973	3.33	6	2.69	7	4.58	17
1974	2.38	3	3.44	8	5.34	29
1975	-	-	-	-	-	-
1976	-	-	-	-	-	-
1977	2.33	3	4.93	12	6.14	23
1978	3.0	5	3.13	9	5.85	38
1979	2.25	3	3.42	7	4.20	15
1980	2.0	2	3.24	8	5.78	15
Average Year	Zero	Zero	2.33	3	9.15	38

FIG. II-6

MEAN MAXIMUM AND MINIMUM TEMPERATURE
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN. 1, 1979 THROUGH MAY 31, 1981

MONTH	MEAN MAX. (°C)	MEAN MIN. (°C)
Jan.	22 (19.9)	8 (7.8)
Feb.	25 (24.1)	10 (10.2)
March	29 (28.2)	14 (14.3)
April	34 (33.3)	18 (19.2)
May	40 (38.5)	22 (23.9)
June	42 (41.6)	23 (25.7)
July	43 (42.4)	25 (26.7)
Aug.	42 (42.4)	22 (26.4)
Sept.	41 (39.9)	19 (23.7)
Oct.	35 (34.4)	14 (18.6)
Nov.	30 (27.7)	10 (13.5)
Dec.	22 (21.3)	6 (9.1)
Yearly	34 (32.8)	16 (18.3)

NOTES:

1. Between brackets are indicated the data from UPM. Report Table 2, PN-32-013-01-1, dated Sept. 1981.

2. The influence of the Derab micro climate versus the Riyadh climate may be noted in lower winter temperatures and higher summer temperatures.

FIG. II-7

ABSOLUTE MAXIMUM AND MINIMUM TEMPERATURE
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN. 1, 1981 THROUGH MAY 31. 1981

MONTH	ABS. MAX (°C)	ABS. MIN (°C)
JAN.	32	-1
FEB.	38	-1
MARCH	39	-1
APRIL	42	10
MAY	44	16
JUNE	46	18
JULY	47	20
AUG.	46	18
SEPT.	43	14
OCT.	40	10
NOV.	34	0
DEC.	30	-2
YEARLY	47	-2

FIG. II-8

MONTHLY EVAPORATION DATA (PAN)
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN. 1, 1979 THROUGH MAY 31, 1981

MONTH	MEAN (m.m.)
JANUARY	150
FEBRUARY	200
MARCH	300
APRIL	370
MAY	440
JUNE	530
JULY	640
AUGUST	510
SEPTEMBER	340
OCTOBER	290
NOVEMBER	190
DECEMBER	140
YEARLY	4100

FIG. II-9

PRECIPITATION

Precipitation recorded on the actual site during the period Jan. 1, 1979 through May 31, 1981

Daily Max.	10 mm
Daily Min.	Zero
Monthly Max.	50 mm
Monthly Min.	Zero
Yearly Max.	100 mm

BAROMETRIC PRESSURE

Based on the available data from the site, the following barometric pressure data can be used:

Max. Barometric Pressure: 956.5 Millibars
Min. Barometric Pressure: 920.5 Millibars

Yearly Avg. Barometric Pressure: 939.5 Millibars

WIND SPEED

Based on the available data of the site, the following wind speed data can be used:

Max. Wind Speed:	10 km/hr.
Min. Wind Speed:	4 km/hr.

APPENDIX - B -

ENGINEERING FIELD TEST SYSTEM

GENERAL INFORMATION

Fig. II-10

SYSTEM SCHEMATIC

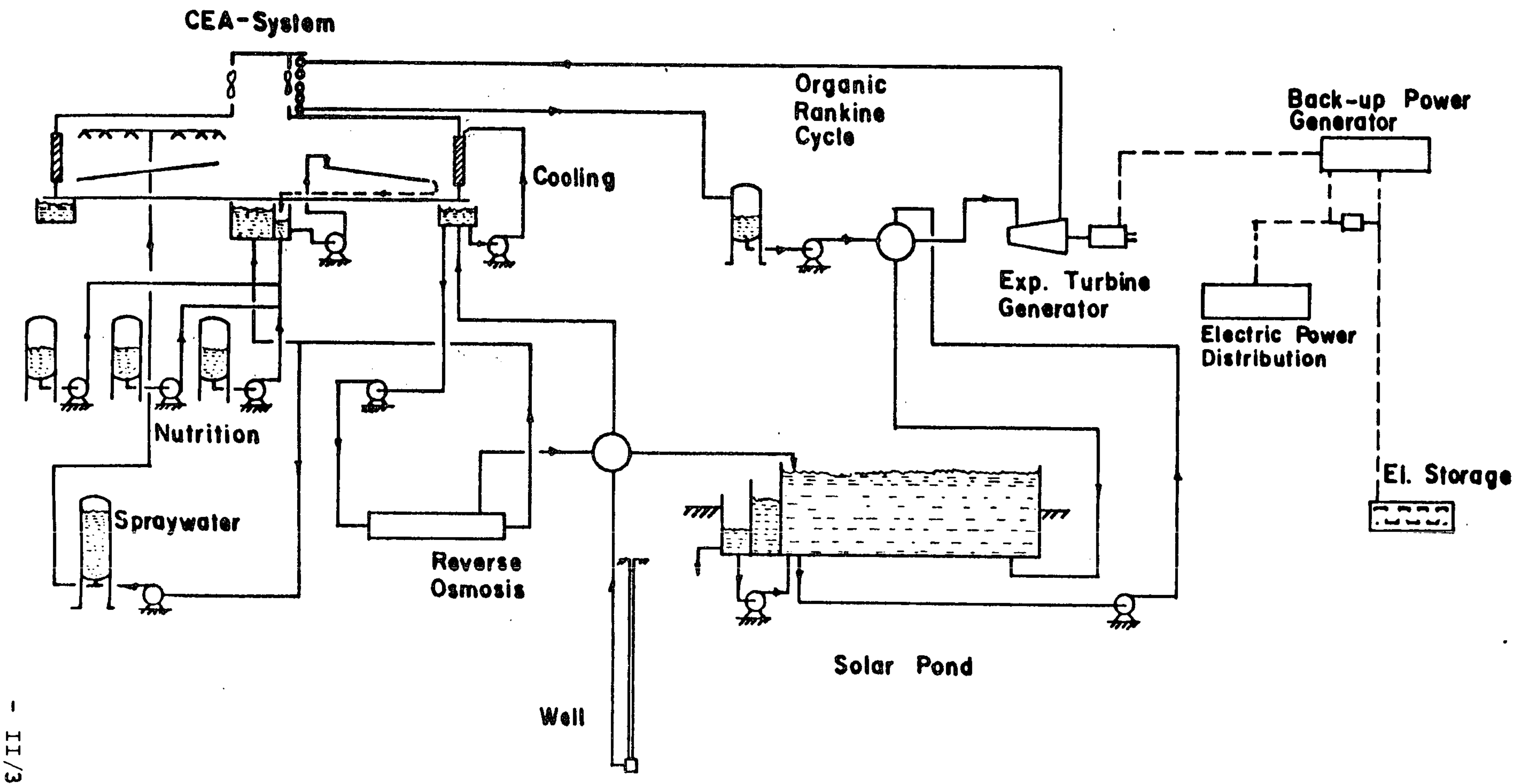
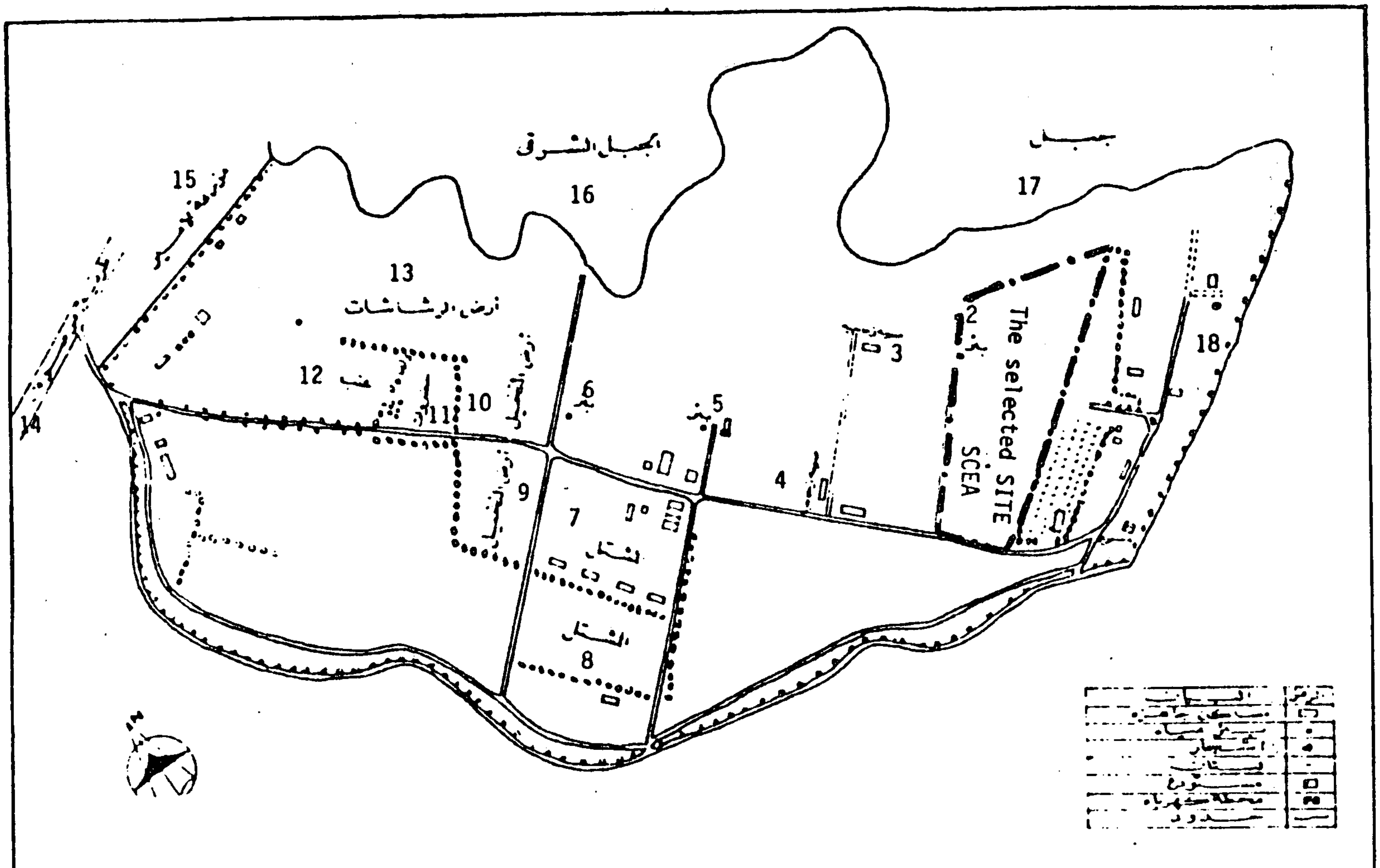


Fig. II-11



الموقع العام لمزرعة ديراب   كلية الزراعة

COLLEGE OF AGRICULTURE FARM IN DERAB (MAIN LOCATION)

INTEGRATED SYSTEM DESIGN REQUIREMENTS ESTABLISHED IN THE RFP

1. Produce economically competitive crops by regular CEA standards
2. Totally solar powered
3. Suitable as a field test facility
4. Optimized integrated system
5. Energy storage to support continuous operation under normal conditions
6. Suitable for hot-dry climate application
7. Comply with local safety & construction codes
8. Comply with recognized standards
9. Use S.I.-units
10. 20 year life for all structures
11. Suitable for U.S.A. and Saudi Arabia
12. Construction to meet project time schedule
13. Maximized system efficiency
14. Maximum automation (minimum manpower.
15. Design simplicity
16. Innovative design
17. High reliability
18. Minimum maintenance
19. Use readily available technology, proven equipment
20. Installation by local labour
21. Management by local management
22. Construction material available locally

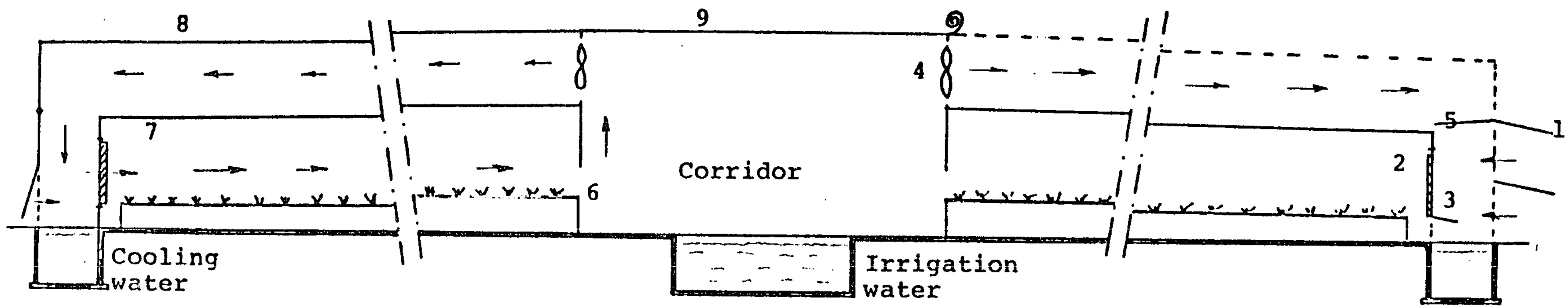
SUB-SYSTEM DESIGN REQUIREMENTS ESTABLISHED IN THE RFP

	SUB-SYSTEM DESIGN	APPLICABLE TO SUB-SYSTEM NO.
1.	Minimized water consumption	1, 2, 3
2.	Non-polluting waste disposal	5
3.	Minimum aquifir pollution risk	3, 5
4.	Optimum growing conditions within CEA unit	1
5.	Maximum use of by-products	5
6.	Different crops	1, 5
7.	Growing area 0.4 -/1 ha	1
8.	Raw Water Storage for 7 days' min.	4
9.	Irrigation water 500 ppm	1, 2, 4, 5
10.	Possible use of brackish raw water	1, 2, 3, 4, 5
11.	Instrumentation for system and crop protection	7
12.	Instrumentation for data logging (operation & research)	9
13.	Appropriate support facilities	8
14.	Air conditioning, hearing, ventilation for support facilities and control rooms	8
15.	Provide data for CEA system scaling	9
16.	Fuel storage (back-up) $\pm$ 7 days	6
17.	Back-up power	6
18.	Fencing for security	8

Fig. II-12

CROSS-SECTION CEA-SYSTEM

1 = Fresh air vents
2 = Evaporative cooling pads
3 = Heating - air vents
4 = Ventilating fans
5 = Recirculation valve
6 = Crop supports
7 = Crop shelter
8 = Shading shelter
9 = Corridor shelter



- Shading situation
- Air recycle

- Non-shading situation
- Air once-through
- Bottom (heating) flap opened

APPENDIX - C -

ANALYSIS AND CALCULATIONS

CONTENTS

1. INTRODUCTION

Due to the non-linear relationships between the various sub-systems, an iterative procedure has been adopted by which an overall balance is approached. This iterative procedure, involved supplier data, calculated figures based on best estimates and some arbitrarily assigned numbers. With the continuous receipt of new data, the solution is approaching an optimum. The solution starting points have varied from very conservative to realistic. The calculations shown herein are valuable to determine orders of magnitude for this project.

2. SYSTEM POWER REQUIREMENTS

The system power requirements are the summation of the sub-systems power requirements. These were reported as estimated maximum continuous power in December and January of 1342 kW thermal and a minimum during the summer of 767 kW thermal. (See Section 5.3.3). The calculations and assumptions used to arrive at these two values, at the time of writing, are presented.

2.1 SCEA SHELTER HEATING REQUIREMENTS

For the proposed one hectare CEA shelter, the following parameters were employed;

Surface Area	: 10800 m^2
Average Thermal Resistivity	: 4.95 m^2.hr.°C.$Kcal^{-1}$
Minimum Average Temperature Difference	: 17°C
Heat Transfer Efficiency	: 80%

The load was computed according to the formula

$$Q = 100. \quad T.A/R.n$$

where Q : heat transfer rate/hour
A : Area
n : heat exchange efficiency
R : thermal resistance
T : difference in temperature for December and January

yielding a peak hourly thermal requirement of 53.9 kW. To reach a daily requirement, this thermal loading is integrated on time scale, based on the values shown in Fig. II-13.

Fig. II-13 : WINTER HEATING REQUIREMENT DISTRIBUTION

No. Hours	% Load	Total %
6	100	600
4	75	300
3	50	150
2	25	50
Daily equivalent hourly full load : 1100 %		

Hence, the peak daily heating requirement is 53.9 kW x 1100% or 592.9 kW_{th}.

As December and January include the greatest temperature extremes, values for the remaining cold months were established as fractions of the extremes. Fig. II-14 shows daily heating requirements per month.

FIG. II-14 : DAILY HEATING REQUIREMENTS

Month	% Requirement	kW_{th}
September	0	0.0
October	25	148.2
November	75	444.7
December	100	592.9
January	100	592.9
February	75	444.7
March	25	148.2
April	0	0.0

2.2 SOLAR CEA SYSTEM SEASONAL ELECTRICAL REQUIREMENTS

Most of the electrical requirements of the overall project have been preliminary accounted for in the following section. No option of load scheduling was applied at this time, i.e. users like the Reverse Osmosis Unit were assumed to be in continuous operation. Fig. II-15 shows the seasonal daily load per hour.

FIG. II-15 : DAILY SEASONAL ELECTRICAL DEMAND IN KW

Hour	Six Month 'Summer'	Three Month 'Fall/Spring'	Three Month 'Winter'
1	18	18	24
2	18	18	24
3	18	18	24
4	18	18	24
5	23	18	24
6	31	18	24
7	38	25	24
8	45	31	18
9	45	38	18
10	45	45	25
11	45	45	31
12	45	45	31
13	45	45	31
14	45	45	31
15	45	45	25
16	45	45	18
17	45	45	18
18	45	45	18
19	45	38	18
20	45	31	18
21	38	25	18
22	31	18	24
23	25	18	24
24	18	18	24
Average	36	31.5	23.5
Brine Pump	3	3	3
ORC	1.5	1.5	1.5
Hourly Total	40.5	36	28

2.3 THERMAL DEMAND FOR ELECTRICAL GENERATION

In order to calculate the ORC thermal demands, the following computations, based on Sofretes (French Manufacturer) are presented.

2.3.1 Brine supply temperatures

Brine temperatures used in the following calculations are assumed figures based on existing solar ponds. The maximum value used is lower than that observed in New Mexico.

2.3.2 ORC

Nett power at alternator : 50 kW
Motor shaft power : 75 kW
Boiler: 150 cu.m./hr brine (15%) with T of 5°C from 85°C to 90°C
Condenser: 350,000 cu.m./hr. humid air at 26°C

Carnot efficiency for this cycle: $\dfrac{82 - 36}{273 + 82} = 0.1296$

2.3.3 Summer

Brine temperature 85°C — max. cycle temp.: 77°C.
Air temperature 25°C — max. cycle temp.: 35°C

Carnot efficiency $= \dfrac{77 - 25}{273 + 77} = 0.120$

Brine flow (T = 5°C): $\dfrac{0.1296}{0.1200} \times \dfrac{40.5}{50} \times 150 = 131.22\ m^3/h.$

Heat from ORC: $\dfrac{132\ m3/h \times 3.8\ MJ/m3°C \times 5°C}{3.6\ MJ/kWh} = 697\ kW + 10\%$ heat loss

$= 767$ kW

2.3.4 Fall

Brine temperature 80°C — max. cycle temp.: 72°C
Air temp. (average) 22.5°C — min. cycle temp.: 33°C

Carnot efficiency: $\dfrac{72 - 33}{273 + 72} = 0.113$

Heat from ORC: $\dfrac{36}{40.5} \times \dfrac{0.12}{0.113} \times 767 = 724$

2.3.5 Winter

Brine temperature 65°C — max. cycle temp.: 57°C
Air temperature 18°C — min. cycle temp.: 29°C

Carnot efficiency: $\dfrac{57 - 29}{273 + 57} = 0.085$

Heat from ORC: $\dfrac{28}{40.5} \times \dfrac{0.12}{0.085} \times 767 = 749$ kW

2.3.6 Spring

Brine temperature 70°C
Air temperature 22.5°C

max. cycle temp.: 62°C
min. cycle temp.: 33°C

Carnot efficiency: $\frac{62 - 33}{273 + 62} = 0.087$

Heat from ORC: $\frac{36}{40.5} \times \frac{0.12}{0.087} \times 767 = 940$ kW

2.3.7 Total Power Demand

The overall system power demand is the sum of the shelter winter heating load and the thermal demand for electrical generation. An inherent assumption in the addition is no ORC waste heat is recovered in shelter heating.

The maximum demand occurs in winter: 592.9 kW + 749 = 1342 kW_{th}
The minimum demand occurs in summer: 767 kW_{th}

3. SOLAR POND EFFICIENCY

The percent efficiency of a solar pond is generally defined as

$$n_{sp} = \frac{\text{useful heat x 100}}{\text{incident radiation}}$$

Because this number may be very positive at times and negative at others (e.g. under high drawdown winter conditions), an annual average is generally regarded as more meaningful than a daily or short duration value. Furthermore, the "incident radiation" term is directly related to the "effective collection area", which has no rigorous definition. This area may be considered as an average of the top and bottom pond areas where sloping sides are involved or as the area occurring at the top of the LCZ below which useful heat is being transferred. The variation between these numbers is usually small. However, the definition of the area does not affect the value of the n_{sp} directly.

SESEA previously cited an efficiency of 10%. This figure was set as a considered estimate based on a review of the existing literature on solar ponds.

In Columbus, Ohio, at the "Farm Science Review" grounds, 40°00'N. Lat., an uninsulated 200 sq.m. effective-collection-area bowl-shaped solar pond 2.5 m deep reached 62°C (Nielsen, 1976). A second more recent pond near the West Campus of the Ohio State University in Columbus of 400 sq.m. area with an insulating moat reported a 3% "total heat gained/incident energy" value (Nielsen, 1981). In Wooster, Ohio, at the Ohio Agriculture Research and Development Center (OARDC) at 40°45'N. Lat., an 8.5 x 18.3 m. rectangular pond 3.6 m deep with side insulation developped 55°C with a reported 4.5% efficiency (Fynn et al, 1980). In Albuquerque, New Mexico, 35°03'N.Lat., a round, 2.5 m. deep pond with 105 sq.m. "average collection area" reached 93°C on August 6, 1977 and reported an average collection efficiency of 9% (Zangrando, 1979).

A short-term maximum efficiency of 21.20% was reported by Jain in 1973 in India. Theoretical efficiencies exceeding 20% were anticipated by Weinberger in 1963. An unofficial report from the University of New Mexico states bubbles from boiling were observed in the above mentioned Albuquerque pond while "thermo-couple readings as high as 107.2°C (225°F) have been recorded in the deeper regions".

In addition to incident radiation and heat removal, several other factors affect the temperatures attained and the efficiency of a solar pond. These include:

3.1 Ratio of perimeter area to surface area. As the pond increases in size, the percentage of side heat losses decreases, thereby improving performance.

3.2 Side walls. In order to decrease heat losses through the NCZ and the UCZ, to decrease "localized heating" on the side walls and to minimize the vertical salts flux, vertical walls are recommended above the LCZ. Sloped walls represented a "heat leak" in the Albuquerque solar pond (Bryant, 1979).

3.3 Surrounding soil thermal conductivity. A very significant heat loss occurs to the surrounding soil, which is very strongly influenced by the soil 'K' value, or thermal conductivity. The lower the soil conductivity, the better the pond performance.

The Ohio figures were observed in low radiation, low temperature areas with heavy, wet soils and are therefore not applicable to the Derab site. The Derab site is a high radiation, high ambient temperature site not unlike New Mexico. It will have a high area/perimeter ratio, with minimum sloped side walls and dry, low conductivity, surrounding soil. For these reasons, SESEA hopes to exceed the 9% efficiency reported in New Mexico.

For the proposed solar pond, the efficiency will be calculated for steady-state or quasi-steady-state conditions from the results of the simulation model.

4. SOLAR POND DIMENSIONS

Simulation studies made by Shah et al, 1980, and further simulation studies conducted by the RI/UPM for this project confirm that added depth increases the pond heat storage capacity.

SESEA, in keeping with standard scientific practices, did not wish to exclude the possibility of a deep pond. More recent studies however, suggest that 5.5 m depth is not warranted. (See section 6.4.5).

Estimates on the required pond surface area have varied from less than 18,000 to over 24,000 sq.m.

5. EVAPORATION FROM THE SOLAR POND

The various energy and mass fluxes occurring in large bodies of water are treated qualitatively in various meteorologic and climatologic references. These treatments, however, do not provide a ready method by which large body evaporation fluxes can be calculated. The variables governing evaporation from large bodies depend very strongly on local conditions over large areas. Their measurement is seldom attempted due to the difficulties and costs involved; the results obtained at a particular location cannot be directly applied to an alternate location. In nearly all instances, the verification of such measurements with an acceptable degree of certainty is very difficult.

The factors affecting evaporation in general and the solar pond in particular are mentioned below:

5.1 The turbulence existing at the earth/atmosphere boundary plays a strong role in the rate of evaporation. Turbulence is not only affected by wind velocities but also by surface friction. With greater turbulence, greater evaporation exists. For a solar pond, wind induces waves which increases evaporation and enlarges the UCZ. Small, floating mechanical partitions have been successfully used to dampen wave activity to safeguard the UCZ. In this application, these partitions will also help decrease evaporation.

5.2 The rate of evaporation is influenced by the vapor pressure differential above the fluid body under consideration. Where low humidity ambient conditions exist, a strong vapor flux exists. In stagnant conditions, however, a degree of saturation above the fluid body may be reached inhibiting evaporation. This favorable condition would exist until a dry wind replaced the humid, existing air mass. Berming up the pond sides and maintaining an adequate freeboard assist the partial entrapment of air above the solar pond. Windbreaks to decrease the fetch would also decrease evaporation.

5.3 The presence of salt in the UCZ will decrease the rate of evaporation.

Although none of the above considerations bring the numerical estimation of evaporation any closer, it is important to incorporate them in the design stages. See appendix -A-, fig. II-8 for monthly evaporation data.

6. ORGANIC RANKINE CYCLE

The selection of the Organic Rankine Cycle fluid is dictated by the temperatures anticipated at the boiler and condenser. The heat source and sink have been designated as the solar pond LCZ and the greenhouse air stream respectively. The ORC will incorporate a turbine and use R-114 as the working fluid.

7. SITE DUST ACCUMULATION

Although no measured data are available on dust accumulation, it is known to exist in significant amounts, with seasonal variations. Dust arises with turbulence in the atmosphere. It is most pronounced during the late spring and summer when radiation levels are very high; very strong winds commence in the early morning and persist throughout most of the day, transportating with them large amounts of particulate matter. Locally, these northerly winds are known as "shamal" which, in translation, means "north". Aside from the shamals, other winds exist throughout the year which also carry dust.

The deposition of dust most strongly affects the CEA shelter and the solar pond. Although the dust removal is a necessary maintenance task, it does not represent a major obstacle to the overall CEA project.

7.1 CEA SHELTER

By using a sloped and smooth surface as the roof of the CEA shelter, no major dust accumulation will occur. The air inlet vents are protected by gravity-type sand louvres to filter dust from the air before allowing it to enter the cooling system.

7.2 SOLAR POND

Dust and other particulate matter, including leaves and insects, are detrimental to the performance of the solar pond. Their presence on the pond surface or at any depth in the pond where they are in density equilibrium with the brine decreases the amount of radiation available. Other researchers have very effectively eliminated this problem by filtering the brine layer containing the unwanted dust or other pollutants. With layer withdrawal at the proper flow rates, no adverse effects to the gradient or other zones occur. Brine pumping through the filter may be scheduled as part of the flow cycle to the ORC, as part of a layer mixing/relocating operation or strictly for filtering.

With regard to debris at the pond bottom or salt that precipitates out of solution, a suction manifold resembling a vacuum cleaner has been used successfully. Alternatively, turbulence may be generated by high flow rates at the bottom to "kick-up" the debris, and then remove by filtration as described above.

8. DERAB WATER ANALYSIS

A chemical analysis of Derab aquifir water from an existing well showed the following composition:

Total Dissolved Solids (tds)	1881 ppm
Conductivity	2500 ohm/meter
pH	7.75
Ions	
K	14.5 mg/l
Na	277 mg/l
Ca	186 mg/l
Mg	88 mg/l
HCO_3	177 mg/l
SO_4	586 mg/l
Cl	415 mg/l
NO_3	138 mg/l
Fe	less than 0.1 mg/l

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Solar energy is one of the most abundant sources of energy available. Despite its abundance, the problems associated with its harnessing have restricted its wide-spread use.
The principal difficulties with solar radiation involve its variability over time, direction and intensity as well as providing an adequate method of storage. As a result, considerable effort has been divested to solar collectors and energy storage facilities, usually as flat plate collectors and fluid or solid heat reservoirs. Even where radiation levels are sufficient for the successful operation of such technology, costs have been high and the power delivered has been suitable only for domestic or minor industrial applications.
For the proposed one hectare CEA system, solar ponds have been selected as the ideal method for both, collection and storage of solar energy in the form of thermal energy. The thermal energy is converted into electrical energy to power fans, pumps, instrumentation, controls, lighting etc. by means of an Organic Rankine Cycle (ORC). Not only does the solar pond overcome the difficulties mentioned above, but it can do so simply and economically.
A viable solar pond may be established with minimum effort on any impermeable site (even without a liner) given sufficient salt, water and radiation. The ORC coupled to a generator represents a minor capital investment to the user, where electricity is the desired output. This combination has been selected because it lends itself to this application very efficiently.

TASK III REPORT

SYSTEM ANALYSIS

CONTENTS

1. SUMMARY

1.1 INTRODUCTION

Task III involves the use of detailed performance and cost analyses to identify the optimum controlled environment agriculture project design. The Task started with a 5.0 hectare concept design and, as requested by SERI, resulted in the recommendations for a 0.4 hectare experimental size unit.

The first step was to define the system evaluation criteria. The prime evaluation criteria will involve system cost - both initial and recurring life-cycle cost. The factors of reliability and maintainability, which, in turn, affect the system availability, were incorporated into the life-cycle cost analysis in the form of recurring costs and in determining the quantity of product over which the plant capital is amortized.

Most of the effort in Task III has been devoted to the systems analysis which involved the detailed configuration of several different solar, desalting and growing culture concepts. Included was the application of performance and economic models to evaluate both the technical and economic merit of each configuration. Key analyses included sizing the collection area in the solar technology as well as establishing the operating temperatures of the Organic Rankine Cycle and the greenhouse and the specific control modes to be utilized in the various anticipated operating scenarios. The growing area of greenhouse was analyzed as a function of heating, cooling and ventilation load to determine the optimum size of the CEA farm.

In optimizing the desalination plant, for a given water quality, the recovery rate is one of the key parameters to be examined. Recovery rate will influence the power requirements of the solar power sub-system since the power requirement of the R.O.- unit directly affects this rate. Configurations involving a range of recovery rates were therefore simulated and evaluated to identify the optimum unit.

Once the preliminary design of the engineering test unit (Task IV) is completed, the system concept will be revised as appropriate.

The final design identified as optimum will be documented in the form of specification reports, engineering drawings, process flow diagrams and a description of the procedures and results of the systems analysis will be provided. A preliminary top level drawing package has been included in this report. Finally, a recommendation to construct a 0.4 hectare field test experiment to prove the technology is recommended and the justification provided.

1.2 APPROACH

The SESEA approach to systems analysis is to use the performance requirements generated in Task II as guidelines.

A parametric analysis of each sub-system is then performed which leads to cost and performance estimates and to component configuration selection. This output yields a commercial assessment which is then fed back to both the parametric analysis and cost and performance estimates to yield an optimum system selection.

Both the experimental and commercial system designs flow from this data as is shown in figure III-1.

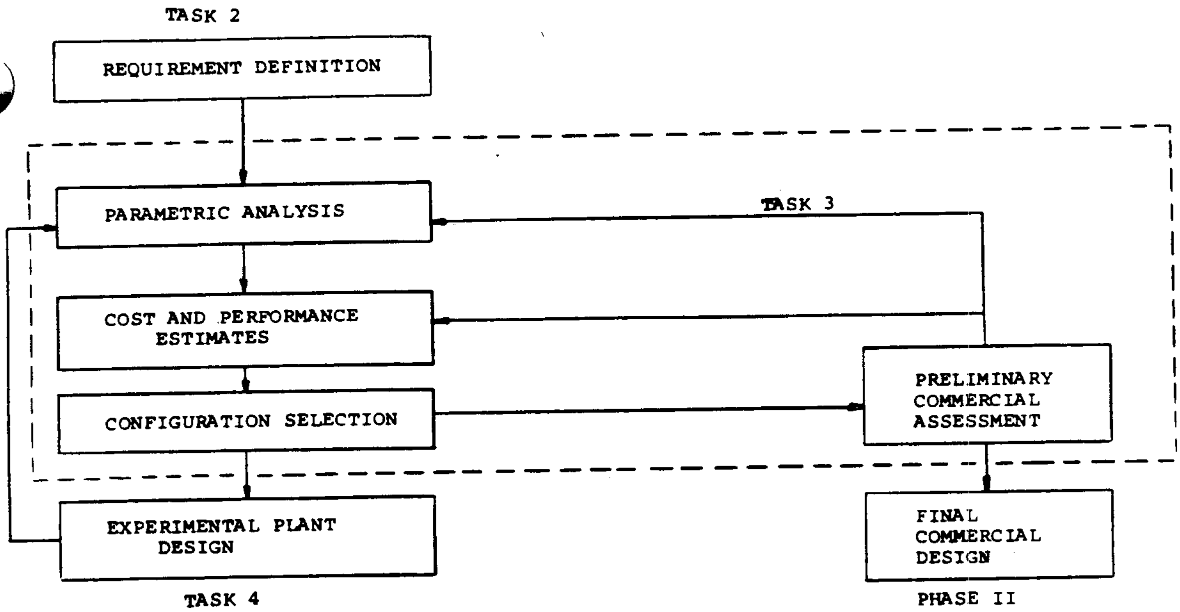


Fig. III-1
C.E.A. SYSTEMS ANALYSIS METHODOLOGY

1.3 SYSTEM ANALYSIS

As a result of the systems evaluation, selection of components, trade-offs and optimization, the following sub-systems were selected:

A CEA sub-system applying Nutrient Film Technique along with sand culture was selected, as it satisfies all conditions for a reliable commercial enterprise. Greenhouse cover will use acrylic covering with additional macrolon dropped ceiling to provide proper radiation characteristics, while optimizing on heating and cooling requirements.

Reverse osmosis was chosen to be the desalination technique over all competitors. The selection of hollow fine fiber over the spiral wound technique receives thorough attention.

The Organic Rankine Cycle Turbine Generator section contains substantial detail on the choice of working fluids and cycle options. For heat reject source, exhaust air from the CEA sub-system will be utilized.

The solar pond size for the CEA system has been defined and data are provided on the composition and gradient control as well as construction details.

As a result of the systems evaluation, selection of components, trade-offs and optimization a multisegment solar pond has been selected using dual Organic Rankine Cycle Turbine for power generation.

The Electrical Sub-system has been minimized and simplified with the utilization of battery storage for short term load fluctuations and back-up by diesel generator.

The Control and Instrumentation Sub-system are analyzed to yield a recommendation of a HP-85 desktop computer. With the required data base and number of sensors, this unit is adequate for both data acquisition and control and is both reliable and inexpensive.

1.4 COST AND PERFORMANCE

SESEA developed a computer model based on EPRI/DOE technique to define a parameter labeled Levelized Farm Crop Cost (LFCC). The cost estimates for the 5 Hectare system exclude transportation and distribution .

For these figures the LFCC technique yielded costs per kilogram produced based on the predicted annual crops. These economic projections are extremely encouraging and confirm the assumption that the optimization of all operating parameters during the experimental test, will yield a solid economic enterprise. This justifies the SESEA position that this technical approach is ready for immediate commercialization.

2. SYSTEM ANALYSIS

This section contains a description of the SESEA approach to system analysis in Task III of Phase I of this project. The topics discussed within this section are:

- Configurations
- System Level Trade-Offs
- Component Design Optimization
- Agricultural System Optimization
- Solar Power System Optimization
- Desalination System Optimization
- Performance and Cost Models
- Reliability, Availability, Maintainability

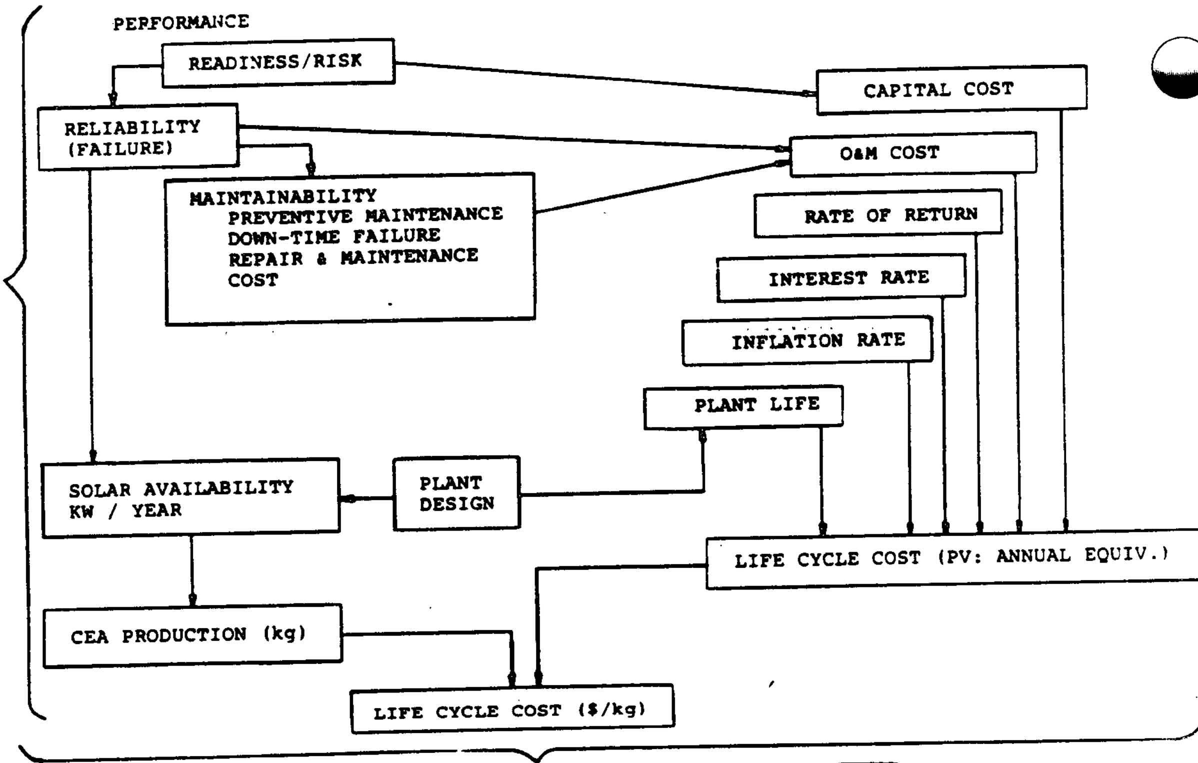
The system evaluation criteria are discussed followed by the approach to the optimization of the CEA system. The system analysis begins with a discussion of the configurations to be considered and the system level trade-off to be performed. The procedures for component design analysis, agricultural system optimization, solar system optimization, analysis and optimization of the electricity generation, and the desalination plant, are described as the models used to perform the analysis. The factors included in the determination of the plant availability, reliability and maintainability are delineated, and the format for the engineering documentation and pilot plant scaling considerations are discussed.

2.1 SYSTEM EVALUATION

Life-cycle costing was the technique used as the principal system evaluation and selection criterion because it incorporates the effects of all other major systems criteria such as capital cost, Operating and Maintenance (O&M) cost, system availability, reliability, maintainability, technology readiness and risk. However, the optimization process in the systems analysis may produce a number of design alternatives which display life-cycle costs that do not differ significantly. In this case, a multivariant criterion function was established to make the final selection. An overview of the process is shown in figure III-2.

During the systems analysis, performance and cost analysis was utilized to define the overall system life-cycle cost in terms of dollars per kilogram of mixed crop produced over the life of the system. This life-cycle costing technique considered all appropriate cost parameters of the CEA plant. The key design evaluation and selection criteria discussed above, affect both the cost and technical performance of the system.

LIFE CYCLE COST IS THE KEY CRITERION BECAUSE IT INCLUDES ALL OTHER EVAL./SELECT CRITERIA



VAR. NO.	EVALUATION/SELECTION CRITERIA	IMPORTANCE WEIGHING FACTOR
x_1	LIFE CYCLE COST ($/Kg)	a_1
x_2	CAPITAL COST ($)	a_2
x_3	O&M COSTS ($)	a_3
x_4	AVAILABILITY (%)	a_4
x_5	RELIABILITY (%)	a_5
x_6	MAINTAINABILITY ($ TIME)	a_6
x_7	READINESS/RISK (PROB.)	a_7

WHERE LIFE CYCLE COSTS OF DESIGN ALTERNATIVES ARE NOT SIGNIFICANTLY DIFFERENT A CRITERION FUNCTION WILL BE USED

CRITERION FUNCTION

$$CF = MIN \left(\frac{x_1(i)a_1}{\bar{x}_1} + \frac{x_2(i)a_2}{\bar{x}_2} + \frac{x_3(i)a_3}{\bar{x}_3} + \frac{a_4}{\left(\frac{x_4(i)}{\bar{x}_4}\right)} + \frac{a_5}{\left(\frac{x_5(i)}{\bar{x}_5}\right)} + \frac{x_6(i)a_6}{\bar{x}_6} + \frac{x_7(i)a}{\bar{x}_7} \right)$$

.... WHERE ....

$$\sum_{1}^{N} a = 1,0 \text{ .....AND}$$

CRITERION	RANGE VALUE
x_1	/kg - LCC
x_2	INVESTED
x_3	TIME
x_4	0.82-1.0 KW YEAR
x_5	UP TO 100% = 100% - $P_{FAILURE}$)
x_6	0-1.0 UTILITY FUNCTION WHERE 1.0 LOW MAINT COSTS & DOWN TIME
x_7	0-1.0 UTILITY FUNCTION WHERE 1.0 IS NO RISK TECH. READY, PROVEN AND AVAILABLE

Fig. III-2 System Evaluation and Selection Criteria and Criterion Function

The technology readiness risk will have an effect on the capital cost of the technology being used and will also influence the reliability or probability of failure of the system. Reliability will affect the maintenance and repair requirements of the system and will, therefore, be a key factor in the determination of the operation and maintenance cost utilized in the analysis. The probability of failure defined by the reliability and the down time per failure will directly affect the plant availability, and the availability will define the total production.

With the definition of the capital cost of the plant and the recurring O&M costs, additional life-cycle costing parameters (e.g., rate of return as specified by SERI, etc.) will be incorporated into the definition of the total system life-cycle cost. This life-cycle cost will be shown both as the present-day value and equivalent uniform annual cost.

This cost factor will be used in conjunction with the total plant production to produce life-cycle parameters in terms of dollars per kilogram of mixed crop.

2.2 SYSTEM TRADE-OFFS AND OPTIMIZATION

2.2.1 Systems Analysis and Optimization

An iterative approach was used in conjunction with detailed performance and cost models to analyze and optimize the CEA system. This approach involved identifying system level trade-offs for a finite number of alternative system-configurations which were optimized over a range of operating conditions. The product of this optimization was a thorough analysis of the capital and life-cycle costs of each configuration which allowed the selection of the most cost-effective solar, desalination and agricultural units. An overview of the steps involved in the systems analysis process are shown in figure III-3.

The first step involved the identification of the systems and sub-system trade-offs to be analyzed and the specific configurations to be optimized. These system level trade-offs involved selecting the field size, recovery rate of the desalination system, the operating temperature of the solar power system, and such trade-offs as collector versus thermal energy storage sizing. Configurations examined include combinations of the reverse osmosis and brine concentrating desalination units and the form in which the power is to be provided, electrical or thermal.

The second step involved component design and design trade-offs based on constraints and design criteria. Those design criteria, such as sizing or capacity selection, that should be included in the system level analyses were characterized over a range of capacities (e.g., capital costs as function of component capacity) and were carried forward into the system level analyses as is shown in Figure III-3. Figure III-4 illustrates the system level comparison of the solar power systems.

The third step, one of the most demanding tasks within the system analysis, was to optimize the solar energy power system over a range of capacities. This involved the configuration of solar power systems in various operating conditions and modes which can satisfy the range of power requirements dictated by the CEA system configuration. For the range of capacities (which may vary a factor of 2 from winter to summer) the minimum capital cost, and likewise, bus-bar energy cost of the electrical power produced was defined. The characterization was then carried into the systems analysis of the CEA system.

In the optimization of the total system, the solar power, feedwater pretreatment, desalination, waste evaporation ponding and greenhouse were characterized in terms of capital cost over a range of capacities. This can be translated into capital costs as a function of the crop yield. These various components were then integrated in an optimization algorithm to identify the total system configuration. This provided minimum life-cycle costs for the produce.

After one specific configuration had been optimized, the process was repeated for alternative configurations until all configurations were optimized. The product of this task was the identification of the CEA system which provided the lowest life-cycle cost per unit of produce delivered.

2.2.2 System Configurations Analysed

A hydroponic greenhouse using a nutrient film technique (NFT) and a separate sand culture was chosen as the baseline configuration. However, seven other configurations were analysed as depicted in figure III-5. Using the criteria of technology readines, risk, capital cost, water consumption, power requirements, nutrient requirements, and maintenance, the initial decision was confirmed.

Due to the need for 24 hour operations, the solar pond with dual Organic Rankine Cycle Turbines was chosen over competing technologies. Trade-offs with various low/high temperature thermal and photovoltaic configurations were performed as is indicated in figures III-6 through III-9. The unique system requirements of the CEA system from thermal, electrical and storage aspects drive the selection to the pond configuration as is easily seen from the cost estimates. One item left for consideration is the selection of the ORC turbine. As is described in unit 300, the Rotaflow device satisfies all our operational criteria.

The requirements for water quality yield analyses of several desalination systems, as shown in figure III-10, A thru E. Trade-offs were made with multi effect evaporators (MEE) and vapor compression evaporator (VCE). The life cycle cost of the RO system is substantially less than other configurations. The combinations of the various solar, desalination and hydroponic options were examined in the optimization procedure yielding the ultimate plant configuration.

2.2.3 System Level Trade-offs to be Performed

There were system level trade-offs performed within each of the candidate configurations. Since the life-cycle cost of the solar pond system, for the CEA application, is an absolute winner no further consideration was given to the other options.

The key trade-off issues for the pond include area, depth, operating temperature and maximum temperature. The sizing of the pond will allow for storage capacity to handle cloudy days.

A principle trade-off parameter in the overall desalination system is the recovery rate or the percentage of product water recovered from the source (well) feedwater.

With regard to the solar pond and recovery rate of desalination system, the relationships traded off during the analysis are illustrated in figure III-11. Desalination systems configured at higher recovery rates (evaporators) would require additional energy from the solar sub-system thus increasing the capital cost. However, high recovery rates will substantially reduce the amount of waste water produced from the plant and therefore proportionally reduce the evaporation pond area required. Since our reject water is used primarily for SOLAR pond make-up, the overriding consideration is the power required for a given yield of the required water quality for the hydroponic process.

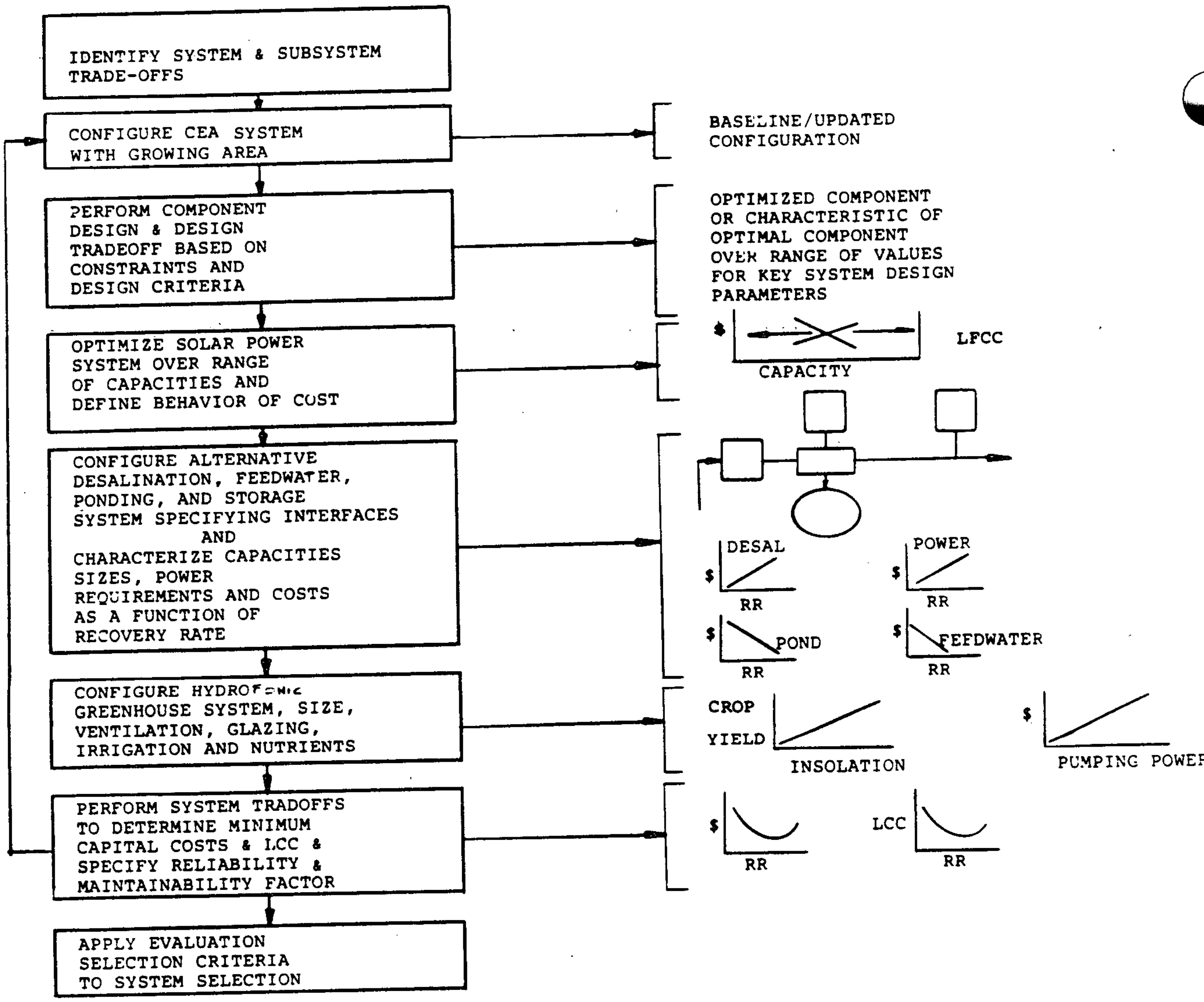


Fig. III-3. Systems Analysis and Optimization Process

Fig. III-4

SYSTEM LEVEL COMPARISON OF MAJOR SOLAR POWER COMPONENT COSTS

	SOLAR — THERMAL — ELECTRIC				PV		
	SOLAR POND	LPT	DISH	CENTRAL RECEIVER	FLAT PLATE	FRESNEL CONCENTRATOR	STIRLING CYCLE
COLLECTOR COST (INSTALLED)	$2,402,000	2,363,391	4,073,200	3,781,500 ①	11,557,320	10,501,150	5,311,674
TURBINE/PCS COST	600,000 ②	600,000	600,000	600,000	300,000 ③	300,000	—
ENERGY STORAGE COST	0	780,000 ④	780,000	271,870 ⑤	189,500 ⑥	189,500	189,500
TOTAL	3,002,000	3,743,391	5,453,200	4,653,370	12,046,820	10,990,650	5,501,174
RELATIVE COST	1.00	1.25	1.82	1.55	4.01	3.66	1.83

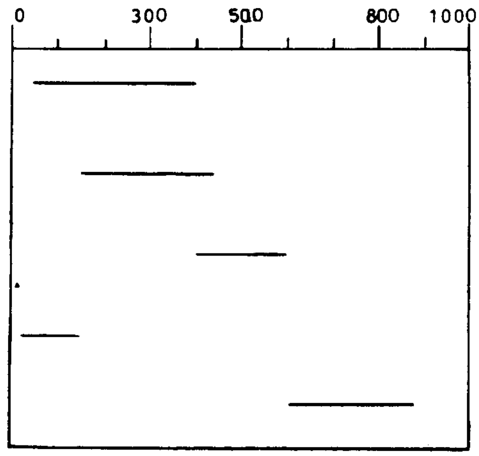
① DOES NOT INCLUDE TOWER.
② $2000/kW
③ $1000/kW STATIC INVERTER
④ 15,000 kW-hr (THERMAL) $52/kW-hr (72°C ΔT/T-66)
⑤ 15,500 kW-hr (THERMAL) $17.54/kW-hr (BARSTOW HT43 @ 274°C)
⑥ LEAD-ACID TRACTION BATTERY, 3790 kW-hr, $50/kW-hr

	TECHNOLOGY READINESS	RISKS	CAPITAL EXPENDITURE	WATER CONSUMPTION	POWER REQUIREMENT	NUTRIENT REQUIREMENT	MAINTENANCE	TOTAL DEGREE OF DIFFICULTY
NATURAL SOIL SPRAY	5	1	4	5	5	4	5	24
DRIP	5	3	3	4	4	3	4	21
SOAKER HOSE	4	4	3	4	4	3	4	22
FLOOD	5	5	1	5	1	5	1	18
HYDROPONIC DRIP	5	3	3	3	3	2	3	17
SOAKER HOSE	5	4	3	3	3	2	3	18
N.F.T.	4	1	2	2	2	1	2	10
AEROPONIC	1	1	4	1	3	1	3	13

Fig. III-5 AGRICULTURE SUBSYSTEM EVALUATION

Fig. III-6

CHARACTERISTICS OF COLLECTOR TECHNOLOGIES



SOLAR-THERMAL/ELECTRIC COLLECTOR SYSTEMS	TEMPERATURE RANGE °F	COMMENTS
DISTRIBUTED LINE FOCUS (LINEAR THROUGH)		- DEMONSTRATED PERFORMANCE COMMERCIALLY AVAILABLE - CONTINUING DEVELOPMENT
DISTRIBUTED POINT FOCUS (PARABOLIC DISH)		- LIMITED PROTOTYPE TESTING WITH ONE COMMERCIAL - DEVELOPMENT IN PROCESS
CENTRAL RECEIVER POINT FOCUS (POWER TOWER)		- PROTOTYPE OPERATION - EXTENSIVE DEVELOPMENT IN PROCESS
SOLAR POND		- GOOD THERMAL/ORC TURBINE CHARACTERISTICS EXCELLENT STORAGE STABLE 24 HOUR OPERATION
STERLING CYCLE POINT FOCUS DISH		- ONE COMMERCIAL UNIT WITH LIMITED APPLICATION EXPERIENCE - HIGH TEMPERATURE CAUSES MATERIAL RELIABILITY PROBLEM

PHOTOVOLTAIC SOLAR COLLECTOR SYSTEMS	ELECTRICAL DESIGN RANGE	
FLAT PLATE	5V, 1A D.C. PER SILICON CELL - INTERCONNECTED IN COMBINATION TO PROVIDE DESIGN VOLTAGE & CURRENT - POWER SCALES LINEARLY TO AREA	- COMMERCIALLY AVAILABLE BUT HIGH COSTS - INITIAL INTERMEDIATE APPLICATIONS EXPER. CELL FAILURE PROBLEMS
CONCENTRATORS	5V, VARIABLE CURRENT (A) DEPENDENT ON CONCENTRATION COMBINED FOR DESIGN VOLTAGE & CURRENT - LINEAR POWER SCALING	- FIRST FIELD EXPERIMENTS IN PROCESS, IMPROVED COST BUT MORE STRINGENT DESIGN TOLERANCE REQUIRED

	LINE FOCUS COLLECTOR OPTIONS		DISHES		CENTRAL RECEIVER POINT FOCUS	SOLAR POND
	SKI	ACCUREX	GE	OMNIUM-G		
ANNUAL ARRAY EFFICIENCY (%) 1	44.2	34.8	64.6	64.6	51.9	20
ANNUAL OUTPUT ($GJ/M^2 YR$)	4.03	3.18	5.91	5.91	4.74	.9
OPERATING TEMPERATURE 1 (recommended °C/Max. °C)	302/343	302/343	399/427	399/427	454/593	80/100
\$ M^2 (APERTURE) FOB/INSTALLED	\$ 215/323 2	\$ 237/377 2	\$ 592/942 3	\$ 807/1284 4	\$ 398/633 5	\$31.5/31.5
CORRESPONDING STEAM 6 TURBINE (if applied) — HEAT RATE (GJ/MW HR)	20.05	20.05	16.4	16.4	13.72	NA
CORRESPONDING STEAM 6 TURBINE (if applied) — CYCLE EFFICIENCY	18%	18%	21.9%	21.9%	26.3%	-
CORRESPONDING ORGANIC 6 TURBINE (if applied) — HEAT RATE (GJ/MW HR)	15.79	15.79	13.72	13.72	7 12.66/16.35	40.5
CORRESPONDING ORGANIC 6 TURBINE (if applied) — CYCLE EFFICIENCY	22.8 %	22.8 %	26.3 %	26.3 %	28.4/22.0 %	8.9 %
TECHNOLOGY READINESS (PHASE 1 TIME FLOW) 5 PROVEN COMMERCIAL PRODUCT 4 TESTED PROTOTYPE OF MODIFIED EXTENDED COMMERCIAL PRODUCT 3 TESTED PROTOTYPE OF NEW TECHNOLOGY 2 MODIFIED DESIGN OF TESTED PROTOTYPE 1 NEW UNTESTED TECHNOLOGY DESIGNED	5	5	3	5	3	3

1. ESTIMATED WITH THE USE OF SANDIA LABORATORIES DATA ASSUMING ALBUQUERQUE LOCATION
2. MANUFACTURER DATA
3. SLA THERMAL MID TEMPERATURE TEST FACILITY DATA 1979 DATA
4. MANUFACTURERS PRICES
5. DATA PROVIDED BY SANDIA 5MWth CENTRAL RECEIVER TEST FACILITY PERSONNEL FOR MARTIN MARIETTA HELIOSTATS BEING USED IN BARSTOW LOMW FACILITY
6. DATA CALCULATED WITH THE FOLLOWING THROTTLE TEMPERATURES: LINE FOCUS : 288 °C
   DISH : 371 °C
   CENTRAL RECEIVER: 454 °C
7. OPERATION FROM CAL HT43 SENSIBLE STORAGE ASSUMED AT 274 °C (i.e. BARSTOW DESIGN)

Fig. III-7

Fig. III-8
Comparison of Solar Collector Cost and Performance

EFFICIENCY FACTORS \ ELECTRICAL CONVERSION COLLECTORS	FLAT PLATE PHOTOVOLTAIC (34^{o} TILT)	FRESNEL CONCENTRATING PHOTOVOLTAIC	STERLING CYCLE PARABOLIC DISH	SOLAR POND	LINEAR PARABOLIC THROUGH
	ANNUAL	ANNUAL	ANNUAL		ANNUAL
COSINE FACTOR	.72	1.0	1.0	.98	.77
MIRROR REFLECTIVITY (p)	-	-	.83	-	.92
INTERCEPT (g)	-	1.0	.98	-	.85
TRANSMISSIVITY (τ)	.9	.85	1.0	.33	.91
ABSORBIVITY (α)	.9	.9	.9	.33	.91
PACKING FACTOR	.85	1.0	1.0	-	-
CONVERSION EFFICIENCY ( )	.16	.16	0.35	.089	.85
TOTAL COLLECTOR EFFCIENCY	.08	.12	0.26	.13	.60
INSOLATION AVAILABLE TO NORMAL SURFACE (KW-HR/M^2-YR)	4,022	3,430	3,430	-	-
TOTAL ACTUAL AVAIL. (74)	2,977	2,530	2,530	2,015	2.530
ELECTRICAL ENERGY COLLECTED (KW-HR/M^2-YR)	- 238	- 309	- 648	- 24	- 310
COST$_2$ (M^2 APERTURE) FOB/ INSTALLED	\$ 760/ 1140	\$ 976/ 1342	\$ 807/ 1614	\$ 31.5/ 31.5	\$ 829 1658
TECHNOLOGY READINESS	COMMERCIAL, APPLIED PRODUCT	TESTED PROTOTYPE FIRST FIELD EXPERIMENT IN PROCESS	COMMERCIAL APPLIED PRODUCT	TESTED PROTOTYPE SEVERAL FIELD EXPERIMENTS IN PROGRESS	COMMERCIAL APPLIED PRODUCT

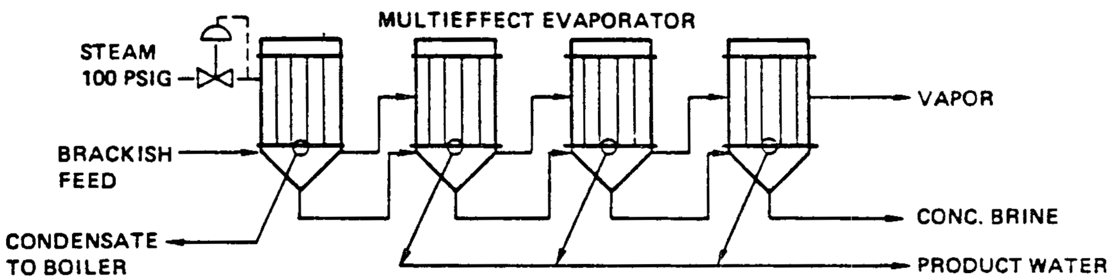
1 BEST QUOTED PRICES, 1979
2. SANDIA PUBLISHED DATA "PHOTOVOLTAIC SYSTEM COST EXPERIENCE FOR INTERMEDIATE SIZED APPLICATIONS", E.L. BURGESS, 1979
3. MANUFACTURER DATA

FIG. III-9

COMPARISON OF SOLAR TECHNOLOGIES

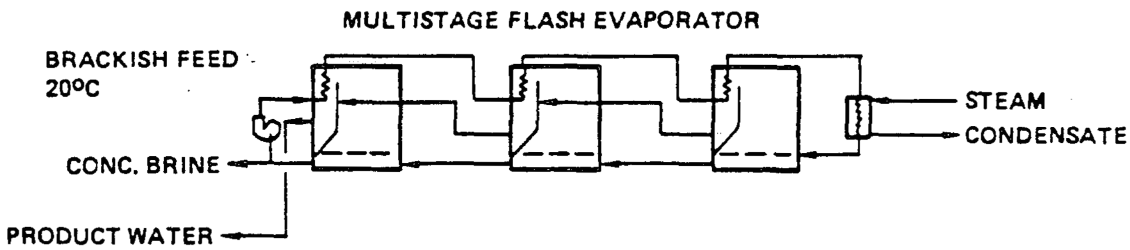
Method	Annual efficiency	Annual energy output MJ/m^2-yr	Annual electrical energy kWh/m^2-yr	Installed cost $/m^2
Flat plate PV	8%		233	1140
Fresnel PV	12%		309	1342
Sterling cycle	26%		648	1614
Linear Parab through PV	8%		202	1658
Linear Parab	44%	4.03		323
Parabolic dish	65%	5.91		952
Central receiver	52%	4.74		633
Solar pond	13%	1.0		31.5

DESALINATION TECHNOLOGY



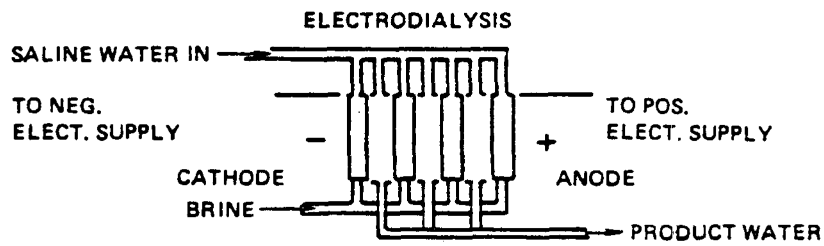
- CAPITAL COST: $2,344/m³ D INSTALLED CAP. /W/AUX)
- RELATIVE OPERATING COST: LOW
- ENERGY REQUIREMENTS: 350 mj/m³ (THERMAL) + ELEC.
- FEEDWATER CAPABILITY: VERY HIGH 100,000 mg/l
- PRODUCT WATER CAPABILITY: VERY LOW 2 mg/l
- WASTE % OF FEED: SUBJECT TO SPECIAL APPLICATION
- RISK: LOW
- AUXILIARY TREATMENT REQUIREMENTS: ACIDIFICATION/FILTRATION
- RECOVERY RATE — 96%

Fig. III-10A Desalination Technology Trade-Offs



- CAPITAL COST: $2,344/m³ D INSTALLED CAP.
- RELATIVE OPERATING COST: LOW
- ENERGY REQUIREMENTS: 4 kWhr/m³ EL + 220 MJ/m³ THERM
- FEEDWATER CAPABILITY: VERY HIGH
- PRODUCT WATER CAPABILITY: VERY LOW
- WASTE % OF FEED: ABT. 10%
- RISK: LOW, BUT HIGH ENERGY REQUIREMENTS
- AUXILIARY TREATMENT REQUIREMENTS: ACIDIFICATION
- RECOVERY RATE — 90%

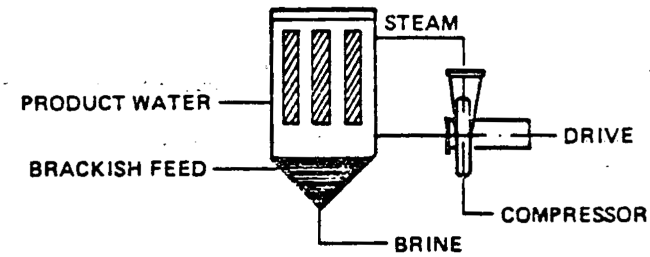
Fig. III-10B Desalination Technology Trade-Offs (Continued)



- CAPITAL COST: $3,350/m³ D. (INST. W/AUX)
- RELATIVE OPERATING COST: LOW
- ENERGY REQUIREMENTS: 1.12 kWhr/m^3 (1900 mg/l DEPENDENT ON TDS
- FEEDWATER CAPABILITY: 3000-5000 mg/l MAX
- PRODUCT WATER CAPABILITY: 2 mg/l
- WASTE % OF FEED: 34%
- RISK: NOT RECOMMENDED FOR APPLICATION > 2000 mg/l
- AUXILIARY TREATMENT REQUIREMENTS: PREFERABLY ARE NONREMOVAL
- RECOVERY RATE — 66%

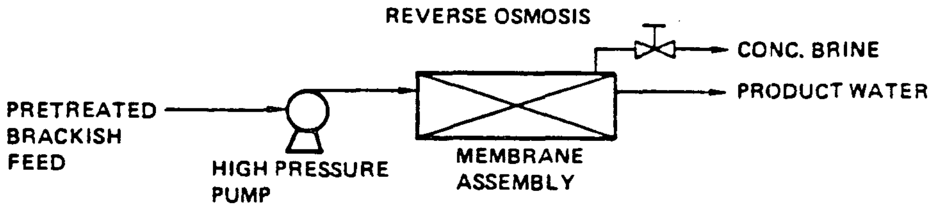
Fig. III-10C Desalination Technology Trade-Offs (Continued)

VAPOR COMPRESSION EVAPORATOR (BRINE CONCENTRATOR)



- CAPITAL COST: $2,332/m³ D. CAP. (INST. W/AUX)
- RELATIVE OPERATING COST: LOW
- ENERGY REQUIREMENTS: 13 kWhr/m^3
- FEEDWATER CAPABILITY: 60,000 mg/l
- PRODUCT WATER CAPABILITY: 2 mg/l
- WASTE % OF FEED: APPLICATION SPECIFIC
- RISK: LOW
- AUXILIARY TREATMENT REQUIREMENTS: ACIDIFICATION/FILTRATION
- RECOVERY RATE — 98%

Fig. III-10D Desalination Technology Trade-Offs (Continued)

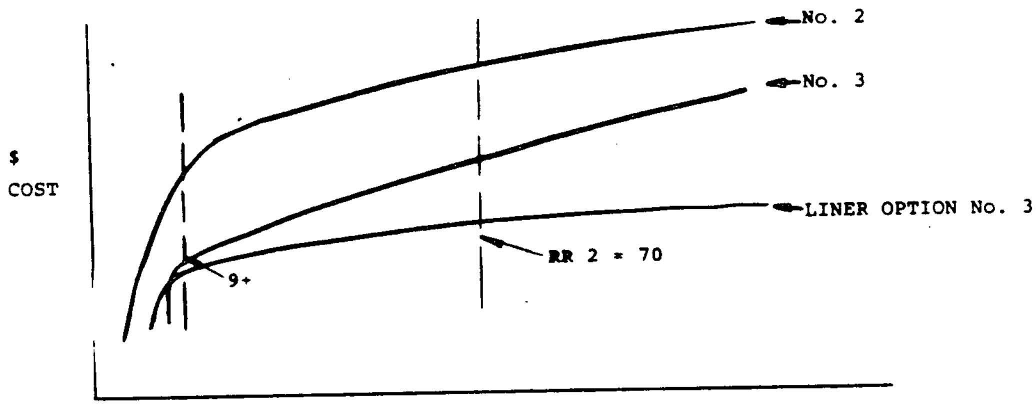


- CAPITAL COST: $2,000/m³ D. (INST. W/AUX)
- RELATIVE OPERATING COST: MOD. REQ. CHEM. PRETREAT
- ENERGY REQUIREMENTS: 1.45 kWhr/m³ FOR 1900 PPM TDS
- FEEDWATER CAPABILITY: UP TO 35.000 mg/l
- PRODUCT WATER CAPABILITY: 50 mg/l
- WASTE % OF FEED: 10-50%
- RISK: LOW-MOD.
- AUXILIARY TREATMENT REQUIREMENTS: FILTERING AS MINIMUM MAY REQUIRE CHEM. WATER TREATMENT
- RECOVERY RATE — 60-75% AT THIS DESIGN POINT

Fig. III-10E Desalination Technology Trade-Offs (Concluded)

DECISION 3 : USE THICK PLASTIC AS LINER

RATIONALE : (SEE GRAPHIC)



INITIAL COST OF OPTION 5 LOWER OVER RANGE OF RECOVERY RATES ... RELIABILITY OF THICK PLASTIC (OPTION 5) ≥ OPTIONS 3 AND 2 ... THEREFORE RECURRING COSTS OF 5 ≤ 3 AND 2

Fig. III-11 Example Component Design Analysis and Selection Process for Waste Evaporation Ponds

2.3 COST AND PERFORMANCE ANALYSIS

2.3.1 Cost Considerations

A full range of different agriculture, desalination and solar energy performance and cost parameters were evaluated to select the most reliable and cost-effective approach. The commercial system finally selected is comprised of six units as follows:

Unit	100	Controlled Environment Agriculture Sub-system
Unit	200	Overall Water Flow Sub-system
Unit	300	Organic Rankine Cycle Sub-system
Unit	400	Solar Pond
Unit	500	Electrical Sub-system
Unit	600	Instrumentation Sub-system

Cost estimates for a Saudi Arabian site were prepared for each unit.

The installed capital costs were obtained from actual supplier quotations where possible. Where cost estimation was required, standard construction cost estimation manuals and techniques were utilized as in the case of the site preparation for the solar pond.

Nutriculture provided an estimate for the growing system cost based on their experience. Actual supplier equipment costs were obtained for the R.O. system, ORC turbine generator, heat exchangers, pumps, instrumentation, and solar pond liner.

Operations and maintenance costs were individually arrived at for each unit based on discussions with manufacturers and experience with fielded equipment. These costs were aggregated to produce an overall estimate for the complete system. The total operations and maintenance costs represent approximately 6% of the installed capital costs. Operation costs were developed to include labor costs and equipment for facility operation adjusted for Saudi Arabia. These labor costs include provisions for 23 personnel for the commercial system operation.

Design, engineering and construction management expenses were based on SESEA experience and represent approximately 26% of installed capital costs.

The ERDA/EPRI cost technique and parameters specified in the RFP were input into the model to produce the levelized farm crop costs (LFCC) of $ 1.27/Kg of crop output.

Annual mixed crop production of 2750 metric tons per year was used for the life-cycle analysis based on Nutriculture production estimates for the commercial facility.

2.3.2 Cost Model

A cost model was developed using the SERI required technology. Input parameters used in the cost model are shown in Figure III-12. Calculations were performed to determine the present value of capital investment, the present value of recurring costs, annualized system - resultant costs and levelized farm crop costs.

The present value of capital investment takes into account a given escalation rate for capital costs as well as the cost of capital and rate of return on capital as follows:

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

where:

CI_{pv} = Present Value of Capital Investment

g_c = Escalation Rate for Capital Costs

p = First Year of Commercial Operation less Price Year for Cost Information

CI_t = Year for a Capital Investment Outlay

k = Cost of Capital (and rate of return on capital)

j = Year for Investment Outlay less First Year of Commercial Operation

Figure III-12

INPUT PARAMETERS FOR COST MODEL

Symbol EPRI		
Y_b	Base Year	1981
Y_{co}	First year of Commercial Operation	1986
Y_p	Price year for Cost Information	1981
N	System Lifetime	20 yrs
B_1	Insurance + "Other Tax" Fraction	.020
B_2	Investment Tax Credit	.100
	Tax Rate	0.5
g	Rate of General Inflation	.06
g_c	Escalation rate for Capital Costs	.06
g_o	Escalation rate for Operating Costs	.07
g_m	Escalation Rate for Maintenance	.07
g_f	Escalation Rate for Fuel Costs	.15
	Recurring Costs-Operating	--
	Recurring Costs-Maintenance	--
	Recurring Costs-Fuel	--
K	Cost of Capital (and Rate of Return on Capital)	.086
$CRF_{k,n}$	Capital Recovery Factor	.1064
FCR	Fixed Charge Rate, Annualized	.1434
n	Accounting Lifetime	16 yrs
	Raw Land Cost	$\$1.25/m^2$
	Cost for lined evaporation ponds	$\$25/m^2$
	Cost for fuel Oil (31 GJ/m^3)	$\$157/m^3$
$DPF_{SD,k,n}$	Present value of Sum-of the Years-digits depreciation	.6376

The present value of recurring costs was calculated using:

$$X_{pv} = \begin{cases} (1 + g_x)^P \; Xo \; \dfrac{1 + g_x}{k - g_x} \left[1 - \dfrac{1 + g_x}{1 + k} \right]^N & \text{if } k = g_x \\ (1 + g_x)^P \; X_O \; N & \text{if } k = g_x \end{cases} \qquad (2)$$

X_{pv} = preseny value of recurrent costs

g_x = the escalation rate for operation, maintenance and fuel costs

K = cost of capital (and rate of return on capital)

N = system operating lifetime

p = equation 1

j = equation 1

Annualized System - resultant cost was determined by:

$$\overline{AC} = (1+g)^{-d} \left[FCR \; CI_{pv} + CRF_{k,n} \; (OP_{pv} + MNT_{pv} + FL_{pv} \right] \qquad (3)$$

where:

$\overline{AC}$	= annualized system-resultant cost
g	= rate of general inflation
d	= first year of commercial operation less base year for constant dollars
FCR	= fixed charges rate, annualized
CI_{pv}	= present value of capital investment
$CRF_{k,n}$	= capital recovery factor (8.6%, 20 years)
OP_{pv}	= present value of operating cost
MNT_{pv}	= present value of maintenance
FL_{pv}	= present value of fuel costs

Levelized farm crop costs were calculated using:

$$LFCC = \overline{AC}/MWH_A \qquad (4)$$

where:

LFCC = levelized farm crop costs

$\overline{AC}$ = annualized system - resultant cost

MWH_A = expected annual crop output

The levelized farm crop cost is calculated reflecting revenues required to cover the costs of the system over its lifetime, including the rate of return on capital.

The calculation considers a number of economic factors including operation and maintenance costs, fuel costs and differing escalation rates of annualized present values of capital investment and recurring costs. When annualized present values are divided by the net crop output, the levelized farm crop costs result.

2.3.3 Performance

SESEA developed a computer code, SOLAR, to utilize the SERI costing algorithms discussed above. The progam calculates the cost incurred for a given agricultural production plant (excluding transportation and distribution costs). The program takes into account the expected annual crop output to determine the levelized farm crop cost (LFCC). In order to calculate the LFCC, a crop production table was generated to determine tons of produce per year per 5 hectares as follows:

Annual Crop Production Table

Crop yield/yr		Tons/Year/5.0 HA
5	Cucumber Crops	1736
3	Tomatos Crops	1014 +
	Total Mixed Crop Yield	2750

By assuming an average cost of $1.15/kg, total mixed crop production for 5 HA amounts to 3.2 million dollars per year. From this, LFCC was calculated on the basis of:

Expected annual mixed crop output: 2,750,000 KG
1986 Commercial Availability
1 year construction period
Capital cost : $ 2,777,950/HA
O & M cost : $ 156,200/HA

Using the SEPI required technology for cost evaluation, a levelized farm crop cost was generated by the SOLAR program as:

LFCC = 1.27 $ /KG

It should be noted that a one year construction period was considered feasible to achieve full commercial crop production. Assuming that construction of the solar pond and greenhouses began in January, 1985, both would be commercially operable by the end of 1985 assuming the ponds were capable of collecting energy by June 1985. In order to verify the impact of the construction period on LFCC, the program was run using 2, 3 and 4 year construction periods.
The following results were obtained:

LFCC = 1.34 $/KG assuming 4 year construction period
LFCC = 1.32 $/KG " 3 " " "
LFCC = 1.29 $/KG " 2 " " "

This cost projection does not consider escalation of crop prices over the 20 year period, thus the rate of return can be anticipated to be much greater than our conservative projection.

In parallel with the above analysis a similar study was made of a site located in the United States. Base of the study was the assumption that local climatic conditions are similar (insolation, temperature, humidity wind, etc.). Input parameters of fig. III-12 were used where applicable. With the same economic and crop production assumptions as before, a LFCC of $ 1.31/kg of crop output was obtained.

In general, cost differences are due to transport and labor.

3. COMMERCIAL PROJECT (5ha) DEFINITION

3.1 DESCRIPTION

The sub-systems in which the total project can be divided and are used for optimization and integration are:

UNIT 100 : Controlled Environment Agriculture Sub-System
UNIT 200 : Overall water flow Sub-System
UNIT 300 : Organic rankine cycle Sub-System
UNIT 400 : Solar pond Sub-System
UNIT 500 : Electrical Sub-System
UNIT 600 : Instrumentation Sub-System

3.1.1 The CEA subsystem (UNIT 100) has the task to transform the energy and water produced by other subsystems in the final product, vegetables.
The CEA system may be divided in two sections:
- The CEA shelter
- The Crop Production System.

The CEA shelter has been designed for reliability, low maintenance and long life.

The microclimate that will be controlled consists of:

- Dry bulb temperature	(14-29°C)
- Relative humidity	(60-85%)
- Air velocity	(0-1.0 m/s)
- Radiation level	(0-150 langley)

To cope with local conditions such as high radiation levels, high temperatures, sand storms etc. SESEA has selected a flat, slightly sloped roof construction. The roof consists of two layers, the outer layer will be made of a double acrylic sheet with an avispace of 13mm, the inner layer consists of a flat fibre glass.

The results of this combination are:
- The crops will receive at all times a diffuse radiation with optimum frequency levels
- A reduced heat load
- Maximum insolation
- Maximum reliability

The greenhouse cooling will be done by circulating the air through evaporation pads and heating is achieved by using waste heat of the condenser of the Organic Rankine Cycle which also is mounted in the circulating air stream.

The crop production system will be based on sections. Each section will have its own nutrient control system because the feed requirements of each crop are different. The growing techniques that will be used are the hydroponic system or NFT (Nutrient Film Technique) and Sand culture. The NFT-system consists of a continuously moving thin film of nutrient solution circulating along plastic channels.

The roots of the crops grow in the channels through which the solution flows, the quality of which is continuously monitored and replenished by automatic equipment. A quarter of the greenhouse will be used for a sand culture system. For this, plastic-lined beds will be used with drain-pipes in it.

3.1.2 <u>The water sub-system</u> (UNIT 200) consists of the water flows from the well to the greenhouse cooling pads and the reverse osmosis system and the water flow to the solar pond for evaporation make-up. For the desalination unit a reverse osmosis system will be used.

The feedwater (approx. $300m^3$/day) to the reverse osmosis system is pumped into the modules at a pressure of 28 bar on the outside of hollow fibers made of semipermeable material. Only water with a small amount of salts is permitted through. The product stream (200 m^3/day) that comes from the inside of the fibers can be used as product feed water for the CEA system. The concentrated waste flow (approx. 100 m^3/day) from the modules will be used for evaporation make-up of the solar pond.

Well water will also be used for the evaporative cooling function of the CEA-system. Because part of the water will evaporate, the salinity must be controlled by removal of part of the circulation flow which will be used to make-up the evaporation losses of the solar pond.

3.1.3 <u>Organic Rankine Cycle</u> (Unit 200) produces the electrical power required (average 234 kW) for running of all pumps, ventilators, instruments and controls of the system. The essential function of the Organic Rankine Cycle is to convert the thermal energy, accumulated in the solar pond into electrical energy. The main equipment is the expansion machine that drives an electric generator. The expanded fluid (freon R-113 or R-114) is condensed in a combination of condensers:

- A finned tube type condenser located in the exhaust airstream of the ventilators supplying either inside air from the CEA-system or outside air or a mixture of both.
- A shell and tube condenser, condensing cycle fluid against raw water used on evaporation make-up flow for the solar pond.

The shell and tube condenser returns heat to the solar pond which otherwise would have been rejected to air and heats up the make-up flow to the pond, thus avoiding thermal instability, due to a cold make-up stream.

The cycle fluid is evaporated in a kettle type shell and tube exchanger against the flow of hot brine from the solar pond, acting as high temperature heat source. Taking into account that a minimum level of battery storage is required to safeguard instrumentation, control and datalogging, the additional installation of batteries to balance electrical requirements reduces the maximum sub-system capacity.

3.1.4 The solar pond Sub-System (UNIT 400), for the commercial system, consists of two adjacent identical square ponds of 30 000m^2 each. Two evaporation ponds of 3000m^2 each are required to maintain the salinity control outflow, and processing solar pond flushing reject and miscellaneous reject flows from CEA. Two solar ponds are specified to ensure reliability of operation (one pond can power the system for a short period). A utility corridor exists between the ponds for piping and controls.

3.1.5 The electrical Sub-System (UNIT 500) is based upon the requirements of small electrical systems with high efficiency and complete control. The basis of design, equipment and installation practices is according to US electrical standards, and engineering standards and SESEA electrical requirements. The electrical distribution system will be designed to smooth the load curve as much as possible with division of all consumers over the time (timesharing) as much as possible.

3.1.6 The instrumentation Sub-System (UNIT 600) is based on the following key objectives and criteria:

- Maximum usage of optimized control system for minimum and economic use of energy.

- A system requiring minimum operator intervention.

- Very simple, highly reliable performance oriented control system.

3.1.7 Interfaces

The main features showing the high level of integration of all sub-systems are:

- Reject water from desalination system and greenhouse cooling system is used for solar pond make-up.
- Greenhouse ventilation air is used for condensor duty of Organic Rankine Cycle.
- Solar pond feed flow is used for condensor duty of Organic Rankine Cycle.
- Water storage in the greenhouse works as a heat and cooling buffer.
- Rankine Cycle condenser is used as greenhouse heating source.
- Rankine Cycle fluid brings waste-heat partly back to pond.

3.2 SYSTEM DESIGN CRITERIA

SESEA has developed a set of system design criteria to serve as an overall guide for the project. The approach to the development of the system design criteria is shown in figure III-13. The approach begins with the system requirements as called out in the RFP and subsequently expanded by SESEA. In some cases, the design requirements can be translated directly into a criteria - for example, the CEA should be configured to minimize water consumption. Other criteria require additional analysis. In these cases the approach is to identify a system measure that is responsive to the requirement and then establish the level(criteria) that ensures satisfaction of the requirement. An example of this type of criteria is, that the CEA must be economically competitive. Life cycle cost can serve as the measure and the criteria is that the LCC of operating the CEA is less than the farm price of a similiar crop mix.

As shown in figure III-13 there are several types of system design criteria applicable to this project. The criteria range from economic through system performance and operation, to site suitability. Each of the criteria are discussed in turn. The interaction of the design criteria and their realtionship to the system requirements are also discussed.
In case the climate and insolation are fixed by site selection, there is no criteria regarding these elements other than the system to be as flexible as possible with regard to climate and insolation characteristics.

3.2.1 Food Production Criteria

- Life Cycle Costs (LCC) of produce should be less than the farm price of the same produce. This limited criteria is sufficient for economic feasibility assuming the LCC economic parameters are realistic. Some portions of the CEA crop-mix may be imported rather than grown locally and an estimate will have to be made of the market price which a CEA farm could expect for a given crop

- Growing system should maximize production of crop per unit of CEA system. The overall and operational costs of the CEA system are assumed to dominate, therefore a high production density growing system is desired.

3.2.2 Green House

- The greenhouse should pass maximum amount of the sunlight in the photosynthesis band into the growing area. This criteria directly reflects the anticipated cost of providing growing area and indirectly the fact that electrical energy consumption should be minimized since the CEA is to be energy selfsufficient.

- A sub-system criteria is of course to minimize the contribution of the greenhouse to the LCC of the CEA system.

3.2.3 Water Supply

- The consumptive use of water by the CEA system should be minimized. This is a direct implementation of an RFP requirement. This requirement also reflects the realities of the situation in which water is expensive.

3.2.4 Energy Supply

- The CEA system should be selfsufficient in energy with its primary source being the sun. This criteria must be balanced against the economic feasibility criteria.

  The reliability of supply and percentage of total energy requirement, including electrical and thermal energy, met by the sun should be maximized to be consistent with the goals of SOLERAS.

  Related subcriteria are that the energy demand profiles should be as flat as possible. The required supply temperature for a given component should be minimized.

3.2.5 Plant Operation

- The reliability and availability of the system concept should be maximized. This criteria directly relates to the need for a low LCC, assuming a prohibitively expensive approach is not used. Design simplicity both from an initial design viewpoint as well from an operation and maintenance viewpoint is desirable. A measure might be the total number of parts required to construct the system. This criteria also reflects the desire for operational simplicity.The ratio of CEA area to total system area should be maximized.At present non-productive land is plentiful. which is an economic benefit of the SESEA system.

3.2.6 Environmental

The CEA system should have minimum or beneficial impacts on the environment both during construction and subsequent operation.

3.3 SUB-SYSTEM DESIGN CRITERIA

SESEA has also formulated a general set of design criteria as input to the system analysis of Task III. These criteria comprise of a list of parameters that form the basis of evaluating the sub-system's ability to function with others such that the overall system performance specifications will be met. The Task III analysis uses these criteria as the basis for the sub-system trade-offs and optimized component selection.

The general criteria are:

3.3.1 Cost - capital cost and operation and maintenance costs.
3.3.2 Availability - including reliability and maintainability.
3.3.3 Efficiency - in terms of both throughput and energy utilization.
3.3.4 Readiness - technical risk associated with state of technology.
3.3.5 Safety - personnel and equipment.
3.3.6 Environment - impact of construction and/or effluents.

PLANT DESIGN REQUIREMENTS (FROM RFP)

- Economically competitive produce
- 20 year design life
- Minimize water use
- Maintain optimum growing conditions
- Energy self sufficient using solar energy
- Environmentally safe disposal of desalination byproducts and agricultural wastes
- Back up power
- Design simplicity
- Plant operational characteristics.
  20 days irrigation water storage. 7 days fuel for back up minimum O&M manpower required

SYSTEM CONCEPT

- Hydroponics NFT
- Greenhouse dual glazing shading, evap. cooling
- Desalination 2 stage RO
- Saltpond electrical power and waste disposal

SUBSYSTEM CHARACTERISTICS

- Size
- Efficiency
- Reliability
- Materials

SYSTEM DESIGN CRITERIA

- climatic data
  - wind, rain, temp.
- Insolation
- Food production
  - cost of produce
  - growing system
- Greenhouse
  - life
  - thermal integrity vs photosynthesis light flux
- Water supply
  - consumptive use
  - quality
- Energy supply
  - electrical power capacity, demand profiles, back up system
  - thermal, temperature, demand profiles
- Plant operation
  - life time
  - land area
  - availability
  - operating manpower
  - environmental discharge

Fig. III-13 Development of System Design Criteria

4. COMMERICAL PROJECT SUB-SYSTEM DESCRIPTION AND DESIGN

4.1 UNIT 100, CEA SUB-SYSTEM

The CEA sub-system is the productive component of the project. This unit has the task to transfer the energy and water produced by the other subsystems to the final product, vegetables, in the most reliable and efficient manner.

Due to this unique position in the project and due to the fact that no back-up or extra storage to cover down time can be provided, the design and selection of equipment, materials and components must receive special attention for reliability, proven performance, minimum maintenance and maximum efficiency.

For design purposes, the CEA sub-system may be divided in two sections with specific requirements:

- The CEA Shelter
- The Crop Production Sub-system

In the following parts the design, material selection and operation of these two sections are discussed.

4.1.1 CEA Shelter, Basis of Design

The design criteria as stated in the RFP and contract are used as the principle guidelines for the design of the shelter. The major criteria, among others, are:

- 20 year service life
- Reliability (minimum risk to structure or crop)
- Minimum maintenance
- Automatic control for the following micro climate:

		DAY	NIGHT
Dry Bulb Temperature,°C	: Maximum	29	25
	Mean	23	17
	Minimum	16	14
Relative Humidity, % R.H.	: Maximum	85	
	Mean	75	
	Minimum	60	
Air Velocity, m / Sec.	: Maximum	1.0	
	Mean	0.3	
	Minimum	0 (Night)	
Radiation Level (PAR), W/m2	: Maximum	73	
	Mean	22	
	Minimum	0 (Night)	

4.1.2 Shelter Format

The usual shapes for "Greenhouses" are quonset-style, single or gutter connected gable-style and gutter connected curved roof style. These common types have been developed over the years by greenhouse builders mainly in countries on latitudes above 35°N. The house form was guided by local conditions such as solar angle of incidence, snow load, rainfall and local acceptance by the grower.

To assume that such a proven CEA shelter format may be transferred to lower latitudes with "hot-dry" climate would be erroneous, although in the past, this mistake has been made by many growers.

The local conditions of the "hot-dry" climate such as the Riyadh area require special attention to the format and roof shape of the CEA shelter to cope with local conditions such as:-

- High solar radiation levels
- High atmospheric temperatures
- High solar angle of incidence
- Sand/dust storms
- Little or no rainfall

A study of roof shapes has been made by Manbeck & Aldrich, see Fig. III-14 which indicates that hemispherical dome or hyperbolic paraboloid roof shapes are marginally more efficient at latitudes of 35°N than flat roofs. In the Riyadh area (24°N) it may be stated that a flat roof will be as efficient as a cylindrical shaped roof.

In addition to the transmission efficiency a flat roof construction for areas of low roof loads (no snow or water accumulation) requires less material and induces less stress than any other shape. The accumulation of sand or dust due to storms can also be avoided by using a smooth, flat roof design. A flat roof also avoids dead air spaces that require additional cooling capacity.

Taking into consideration all advantages of the flat roof construction, SESEA has selected for the CEA shelter a flat, slightly sloped roof construction. (10 degree angle with horizontal level)

The only disadvantage of the flat roof construction is that a large percentage of the solar radiation will be direct. To overcome this, a second roof layer will be installed to diffuse the solar radiation.

The size of the CEA shelter should be based on the optimum enclosed growing area with the minimum of outside wall area while taking into consideration the maximum practical ventilation distance, structural support distances, shutter design and transport distance in the shelter.

SESEA experience in Saudi Arabia has shown that a distance of 30 meter between ventilating fans and cooling pad/fresh air inlets provides the best results. Based on this, for the commercial size shelter, 1.3 hectare units (25% of total) are selected. See Fig. III-15.

The overall size of each unit will be 205M x 65M providing such features as:-

- Smooth, flat exterior roof with 10° slope
- A shaded air intake with sand louvres
- Cooling/humidifictation pads
- Controlled ventilation
- Closed loop or open loop air circulation
- Adjustable shading for high radiation periods

FIG. III-14

RELATIVE DAILY SOLAR ENERGY TRANSMITTED BY VARIOUS SURFACES*1

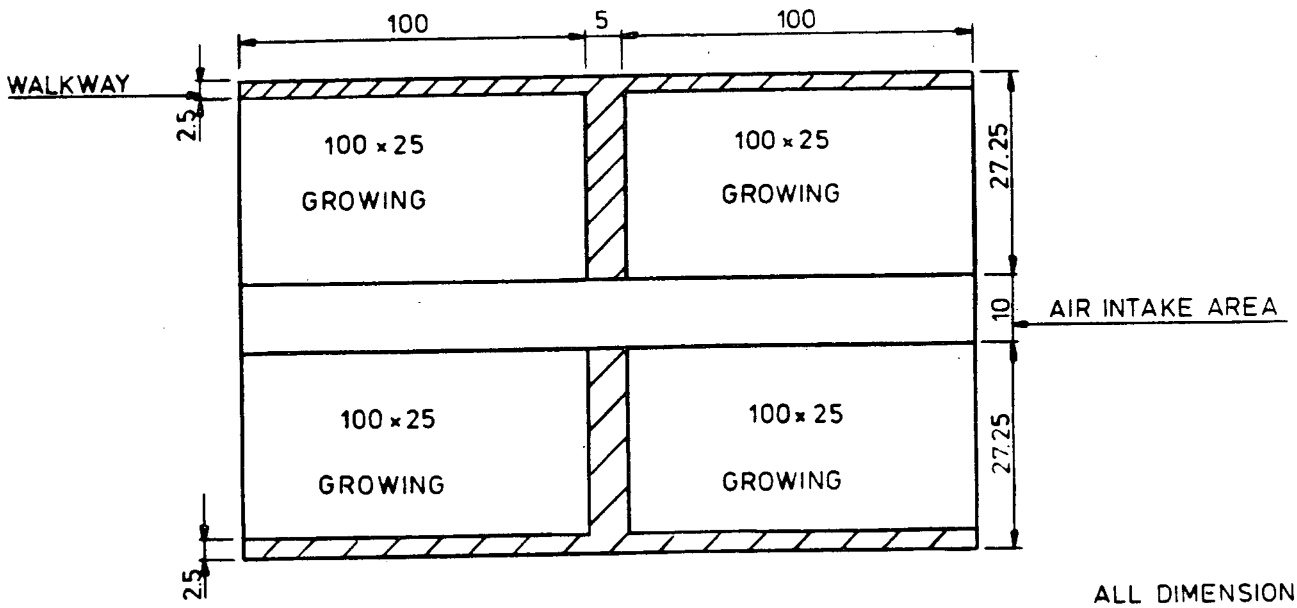
	Latitude Deg. North		
	35	40.8	45
1 Hyperbolic Paraboloid A:B:H=5:5:2	81	83	69
2 Single cylindrical vault (N-S)	69	84	73.5
3 Gable-Slope = 26 deg (N-S)	90.5	84	76
4 Gable-Slope = 0 deg	80	68	59
5 Gable-Slope = 10 deg*2	84	74	65.5

*1 Based on optimum relative rating of 100 for spherical dome and tests by Manbeck & Aldrich (1966)

*2 Interpolated value

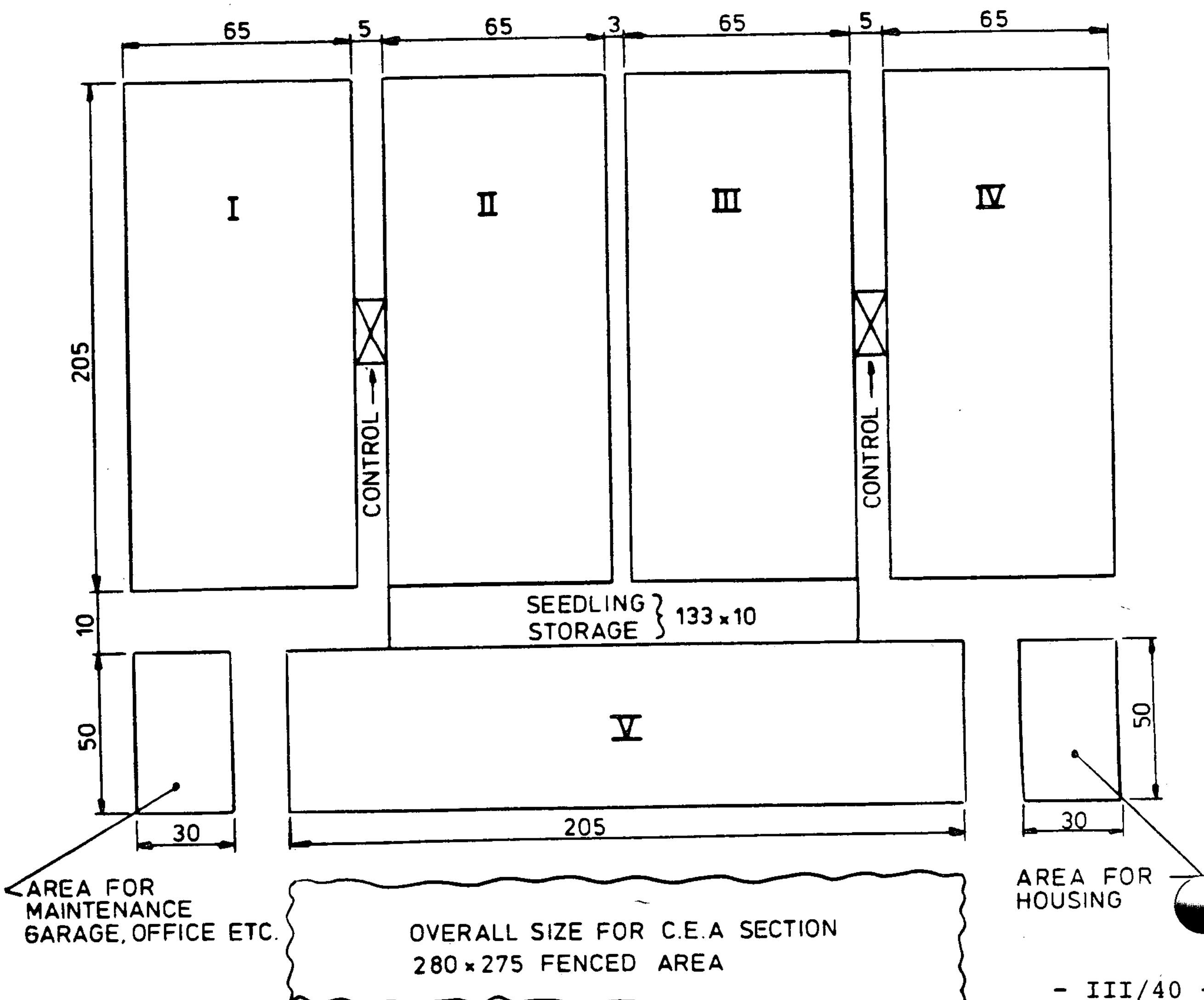
Fig. III-15

SECTIONAL LAYOUT



ALL DIMENSIONS
IN METERS

PROPOSED LAYOUT FOR 5 HA FARM



4.1.3 Shelter Material Selection

Many materials are available today that are proposed for the cover of the CEA shelter. SESEA has reviewed the technial data on all potential materials and selected to use a roof construction that combines a maximum service life (20 year) with selective transmission of solar radiation.

The main (outer) cover of the shelter will be made from a double acrylic sheet with an airspace of 13 mm. The supporting webs are at 32mm distance. This material has been selected based on its excellent properties plus the fact that it has proven performance in similar applications*. It is guaranteed for 10 years but designed to last the 20 years set as the design criterion. This material has been tested by Sankia Laboratories and is predicted to be stable for the 20 year system life. The material also has a smooth outer skin on which neither sand nor dust will accumulate.

* Experimental CEA structures have been under test with this material in Kuwait for 3 years and by the King Faisal University in Alhassa for 2 years. No deterioration has been indicated under the high summer temperatures even when cooling in the house failed due to power loss.

The transmission of radiation of the material is optimum for the PAR group.
Manufacturers data show:

RADIATION WAVE LENGTH RANGE (NANO METER)	SOLAR RADIATION (PERCENT) (1)	TRANSMISSION OF DOUBLE ACRYLIC (PERCENT) (2)	
280-400	6	1.6	(2.2)
400-800 (PAR)	52	43	(58.6)
800-1400	29	23.75	(32.4)
1400-3000	13	5	(6.8)
Total radiation	100	73.35	

1) Distribution of solar radiation over frequency.
2) Percentage of solar radiation measured after passing through double acrylic sheet and converted to 100% basis.

Furthermore, it may be noted that for wave lengths above 2800 Nano meter, the material is completely opaque. This quality combined with low heat transfer coefficient of 2.7 W/M2-^{o}C makes it ideal for effective insulation of the CEA interior against hot and cold climate temperatures outside.

The second roof or crop shelter ceiling is selected mainly for its high rate of diffusion. However, this material should also have a 20 year life, a flat surface to avoid air turbulence in the recirculation duct, and be selective in its radiation.

According to Bond, Godbey & Zorning a single layer of flat fibre glass, premium, 40-mil has the best qualities for this application with a 200% increase in diffuse radiation, only 11% direct radiation and a 6% longwave transmission, (2800 Nano meter). The combined action of the two selected materials reduces the PAR radiation to 44% and the other shortwave radiation to 19% of the total amount of solar energy transmitted in the shelter.

The selection of these materials have resulted in the following advantages:

- The crop will receive at all times a diffused radiation with the main energy levels in the PAR band.
- A reduced heat load on the house.
- Maximum insulation, reducing the heating requirements in the winter.
- Maximum reliability and service life. Since no material replacement is anticipated in 20 years.

4.1.4 Shelter Operation

The cooling of the CEA shelter is most important in order to ensure correct temperature and climate in the green-house. A heat balance has been made based on extreme and mean temperatures, (daily cycle).

Calculations show that the temperature criteria of the CEA Shelter will hold with a maximum ventilation rate of less than one house volume per minute (General Industry Standard). This is mainly achieved through the use of the selective cover materials.

The heating of the CEA shelter, essential during cold nights, is achieved by using the waste heat of the organic rankine cycle. The condenser is mounted in the air flow, downstream of the ventilation fans. During recirculation (closed loop) the heat rejected from the condenser will keep the roof duct warm and allow warm air to enter the house in sufficient quantities to maintain the temperature levels at design values.

The temperature balance of the house will be improved due to the fact that the water storage is incorporated in the foundations and the interior of the house.

4.1.5 Adjustable Shading

Although all calculations show that the fixed double roof design provides the most reliable optimum performance for the commercial scale project at the present state of the art, SESEA suggest to incorporate a variable shading system that makes use of a shading cover over the double acrylic outer roof of the CEA shelter.

The shading cover will be used during periods of high solar radiation (above 45 Langley) to reduce the amount of radiation that will enter the house.
The shading cover will be adjustable through a tensioning system to allow a variation in radiation levels to be covered without continuous movement of the shade.

The cover will be mounted outside the house with the minimum space between the double acrylic roof and the shade.

Alternative methods of shading have been studied but found either impractical or non-reliable such as a liquid over the outside of the roof or within the interior of the roof panels.

4.1.6 Crop Production, Sand Culture

Approx. 1 Ha of the CEA unit can be dedicated to a sand culture system for the production of okra and eggplant.

Two methods of utilizing sand as a growing medium have proven to be satisfactory. One is the use of plastic-lined beds and the other involves spreading sand over the entire greenhouse floor. For ease of maintenance, SESEA recommends the first method.

Growing beds with plate liner can be built as above-ground troughs with wooden sides. 20-Mil vinyl may be used for the liner. The bottom of the trough should have a slight slope of 10 cm per 25 meter, so that it can be drained or leached when necessary. The drain pipe can be placed in the entire length of the bed. Since in sand culture, only excess solution (less than 10 percent of that added) is drained, a 5 cm drain pipe may be used. The drain pipes from all beds should be connected to a header at one end which collects the waste water from all beds and conducts it away from the greenhouse.

The system design will be for a drain flow less than 5%. This flow can be returned through the RO system after pretreatment. The sterilization can be achieved with chemicals of the methyl-bromide type. A portable steam generator may be used once a year for further sterilization of the beds. Steam can be injected in the drain system and the beds.

The advantages of a sand culture system are as follows:

- It is an open system, that is, the nutrient solution is not recycled, so the chances of diseases such as Fusarium or Verticillium spreading in the medium are greatly reduced.
- There is less problem with drain pipes getting plugged with roots since the more dense medium of sand favors lateral root growth.
- The finer sand particles allow lateral movement of water through capillary action so that solution applied at each plant becomes evenly distributed throughout the root zone.
- With the right choice of sand combined with a drip irrigation system, adequate root aeration is achieved.
- Each plant is fed individually with a new complete nutrient solution during each irrigation cycle; no nutrient imbalance occurs.
- Construction costs are lower than for a subirrigation gravel system.
- The system is simpler, easier to maintain and service.
- Due to the smaller particle size of sand, water retention is high and only several irrigations are required each day. If a failure occurs, there is more time available to repair the system before the plants will use up the existing water in the medium and begin to experience water shortage.
- Smaller, centrally located nutrient reservoirs or injectors can be constructed away from the actual growing area of the greenhouse.
- Sand is readily available in most locations. When using calcaneous sand, the formulation can be adjusted to compensate for daily pH changes and shortages of iron and/or other elements.

4.1.7 Crop Production with Nutrient Film Technique

The Nutrient Film Technique is a method of growing crops without soil. It is, in effect, a true hydroponic system where the plant roots grow only in liquid.

It can be used in any part of the world, provided suitable growing structures are available. The system was developed for the production of salad crops such as tomato, lettuce and cucumbers but has proved successful for raising many other crops such as mint, strawberries, squash, and carnations.

Plants are propagated by conventional methods in compost filled pots, Jiffy-7 pellets or blocks. When the roots system is sufficiently well established the pots are placed at appropriate intervals in gullies formed from polythene sheeting. They grow to maturity in these gullies with their roots in constant contact with a continuously moving thin film of nutrient solution composed of water and selected nutrients.

In a typical installation, the polythene gullies are laid out in rows on the soil surface which has previously been sloped to at least 1%. Alternatively, the gullies can be laid on shallow metal trays which are given a slope of 1% or more by means of adjustable legs beneath the trays.

The nutrient solution enters the gullies at the top end via feeder pipes and flows down the gullies past the roots and into a catchment system at the lower end of the gullies. This returns the nutrient solution to the circulation tank from where it is pumped by electrically driven pumps via the flow pipes and header system to the top end of the gullies to begin another cycle, see Fig. III-16 and III-17.

The re-circulating nutrient solution can be continuously monitored by electronic control equipment and replenished automatically whenever necessary from stock nutrient tanks by dosing pumps. Systems can be checked manually with a simple hand-meter.

The gullies are formed by turning up the edges of a long strip of polythene film and clipping them together at intervals round the stems of plants placed in the gullies.

By providing ideal rooting conditions, the system enables high quality crops to be grown in areas where poor soil conditions would otherwise make this impossible.

The advantages of the NFT system are as follows:

- Low capital cost
- Eliminaton of soil sterilization and preparation
- Rapid turnaround between crops
- Precise control of nutrition
- Maintenance of optimum root temperatures by heating of the nutrient solution (25°C for tomatoes, 29°C for cucumbers)
- Simplicity of installation and operation
- Reduction of transplanting shock by use of growing pots or cubes via preheating of nutrient solution to optimum root temperatures.
- Easy adjustment of nutrient solution formulation to control plant growth under changing light conditions.
- Use of insecticides and fungicides in the nutrient solution to control insects and diseases of ornamental crops.
- Possible energy savings by keeping the greenhouse air temperature at lower than normal levels due to maintenance of optimum root temperatures.
- Elimination of plant water shortage between irrigation cycles by continuous watering.
- Conservation of water by use of a cyclic system rather than an open system.

The future of succesfull crop production lies in an universal cropping system in which water and fertilizers can be used efficiently. This is particularly true in arid regions of the world, such as the Middle East, where land is non-fertile and water is scarce. In such areas desalinated sea water can be used but it is very costly. Sand culture is used in many of these areas, but often it is of calcareous nature which causes rapid changes in pH and drying-up of essential elements such as iron and phosphorus. In areas of high solar energy, efficient use of costly desalinated water is essential. The nutrient-film technique is the system which makes this possible.

4.1.8 Crop Production System

The growing area is approximately 50,000 sq. metres consisting of twenty 2500 sq. metre sections separated by a central service corridor which will supply all water, heating, cooling etc. to each section of the house.

The success of a commercial growing system will be greatly influenced by the prices that may be commanded on the market and the quality of the produce.

Experience has shown that in commerical operations where the same type of crop is grown throughout the year, on average, higher profits are made than growers trying to catch the off-season market.

It is therefore recommended that the commercial operation of the CEA system should specialize on a maximum of 3 crops with the following production targets:

		Avg. Production kg/ha/day	Recommended Area ha
Tomatoes	-	900	2
Cucumber	-	1900	2
Lettuce	-	1500	1*
Strawberry	-	250	

1* For both lettuce and strawberry

The location of a commercial solar CEA system will be primarily influenced by the availability of land and brine (salt). It is unlikely that this location is near one of the larger urban centres. Therefore, shipping from the farm needs to be done by refrigerated trucks.

SESEA has developed a storage system using containers holding from 2000 kg - 5000 kg. The containers are insulated and have an independent cooling system driven from the farm solar/ electric system.

The boxed produce will be stored in these containers, each container will hold a specific type of vegetables and is controlled with the right temperature for this type.

When loaded, a trailer with a generator to drive the cooling system, will transport the container to the market.

The produce will always arrive fresh, even if there are unforeseen delays.

The movable container-cold-store system developed by SESEA will allow the following to be done:

- Keep each vegetable at its best temperature;
- Minimize handling;
- Delivery to multiple customers without loss of produce quality;
- Minimise energy requirements (only the space used for storage is cooled);
- Minimise cost (a conventional system needs cold storage at the farm, refrigerated transport facility and storage at the receiving end).

4.1.9 'Mastermeter' Control Panel

The 'Mastermeter' control panel is designed to control larger areas of Nutrient Film grown crops to the highest standards of control and reliability. The panel includes:

- 'Mastermeter' Controllers for pH, conductivity and temperature. These controllers are designed to the highest specification and are housed in an enclosure. They have fully adjustable high and low alarms and all major functions are on 'plug-in' modules. In addition, the temperature unit has connections for high and low level water probes in the main circulation tank to warn of extreme water conditions. A computer output is available for these units if required.

- A pH 'Mastermeter' guard unit for early warning of probe failure or drifting. This is interlocked with the pH control unit. In the event of the two units failing to agree all acid dosing is stopped and an alarm registered.

- A 3 phase changeover unit designed such that a standby pump will automatically start up should any pump trip out on overload. Any pump or pumps can be selected for running with the remainder on automatic standby. The unit is complete with 3 phase and single phase fuses and switch gear plus visual indication of pump running and failure conditions. All wiring connections for the control panel are housed in this unit, in an ecnlosure enabling easy connection on site. All alarm functions on the panel are terminated in a single pair of normally open contacts rated at 24 V.AC/DC for connection to the automatic alarm system. The alarm can be inhibited for early season intermittent watering.

All the control and monitoring probes are housed in an in-line manifold system i.e. 2 pH probes and 1 conductivity probe with temperature compensation.

The flow cell is wired into the changeover unit so that should solution fail to flow through the manifold for any reason an alarm is activated and dosing stopped.

The manifold is supplied from a small branch off the main flow line.

The three 'Masterpump' control units are mounted and prewired into the controllers complete with air connection to the 'Masterpumps' mounted in the nutrient tanks.

4.1.10 Hydroponic Pumping Unit

The unit will consist of:

- One fibreglass tank suitable for sinking into the soil to form a nutrient circulation tank for the system. Included in the unit will be a ball valve for fresh water inlet with an in-line water meter. Suitable overflow connections to the tank and necessary overflow pipe and fittings will be provided.

- Two circulating pumps, one as standby, capable of delivering 2-3 litres per minute to each row of plants.

- Suction pipework system in PVC, consisting of pump inlet screens, check valves and flow control valves plus 25mm recirculation loop to provide splash-back aeration.

- 12 mm take off point, for connection to measuring manifold in hydroponic control panel.

- Pump water level control switch. This float switch cuts out the circulation pumps should the water level fall to a point where the pumping system may loose its prime. The pumps automatically start when the water level returns to normal.

- Supply pipes to troughs, in 50mm low density polyethylene pipe with outlets in 6mm flexible LDPE tubes.

- Return pipe, of 150mm PVC.

4.1.11 Data Recording

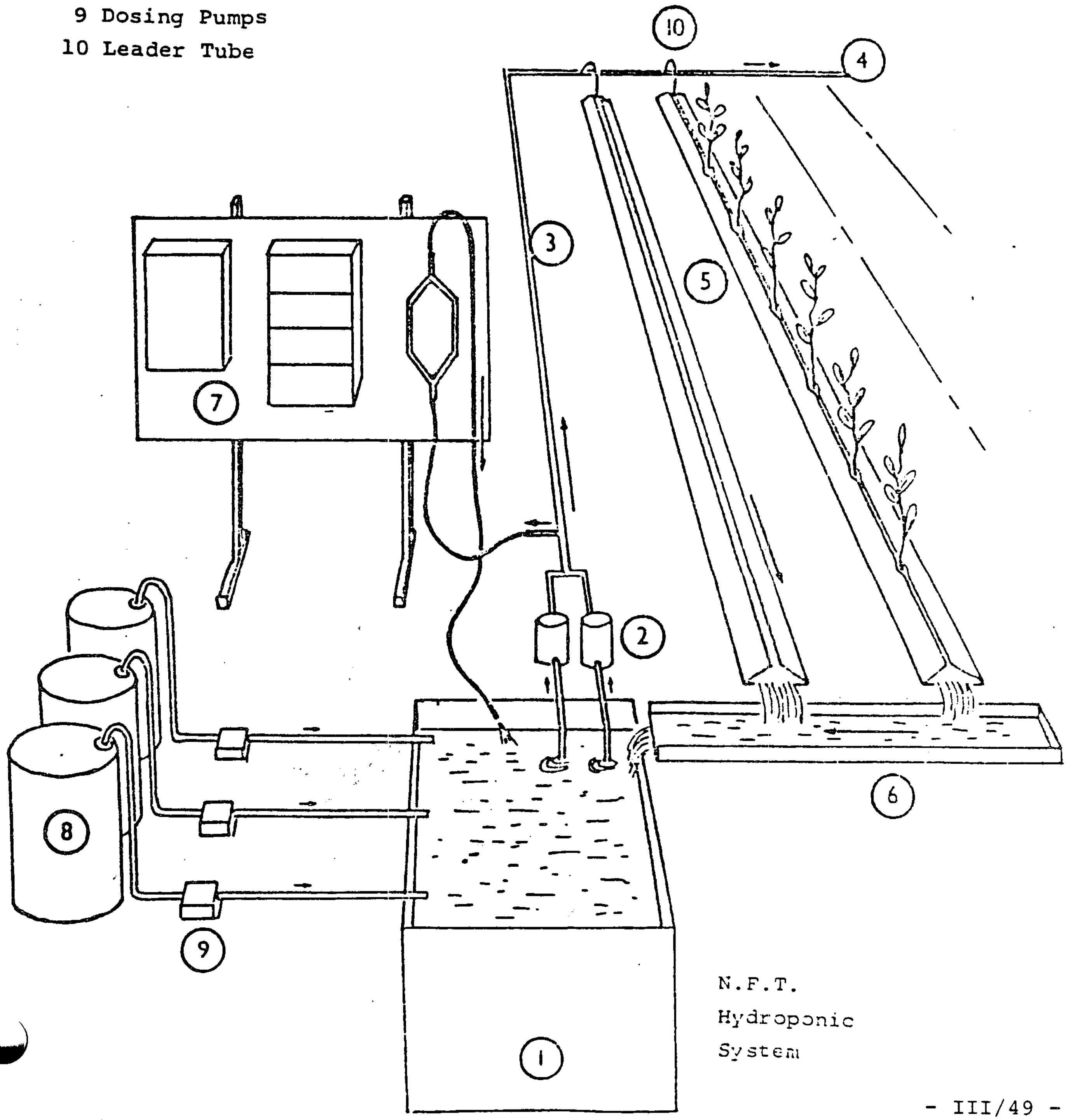
All the instrumentation provided will be capable of interfacing with a computer which will perform a data logging function.

The following parametres of the NFT system will be available for data logging:

- pH level of nutrient solution
- CF level of nutrient solution
- pH alarm level of nutrient solution
- Temperature of nutrient solution
- Water make up to each circulating tank
- Nutrient concentrate dose rate to each tank
- Nutrient circulation rate
- CF level of make up water

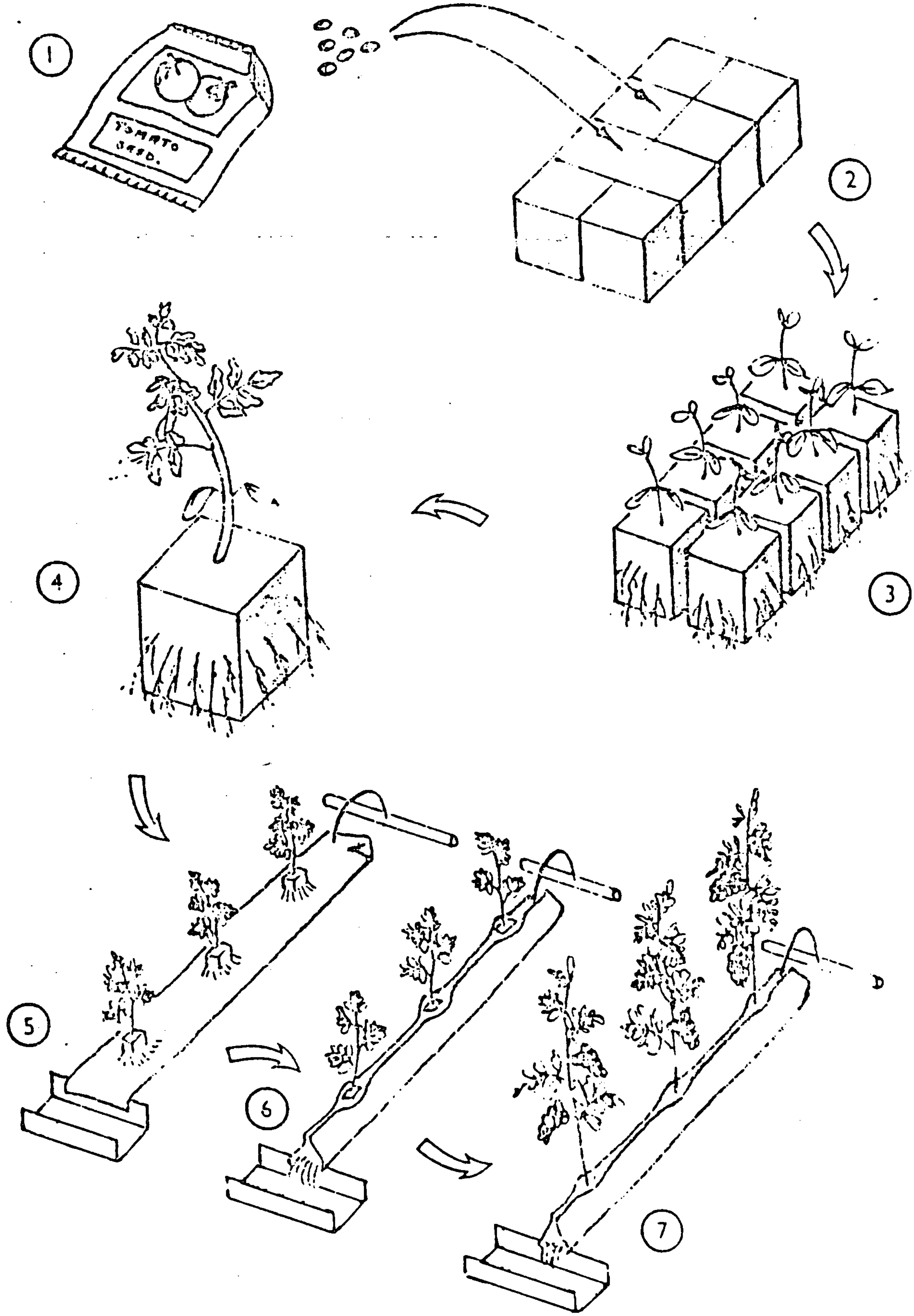
Fig. III-16

1 Nutrient Tank
2 Nutrient Pump
3 Nutrient Supply
4 Nutrient Header
5 Growing Channel
6 Nutrient Return
7 Control Unit
8 Nutrient Concentrates
9 Dosing Pumps
10 Leader Tube



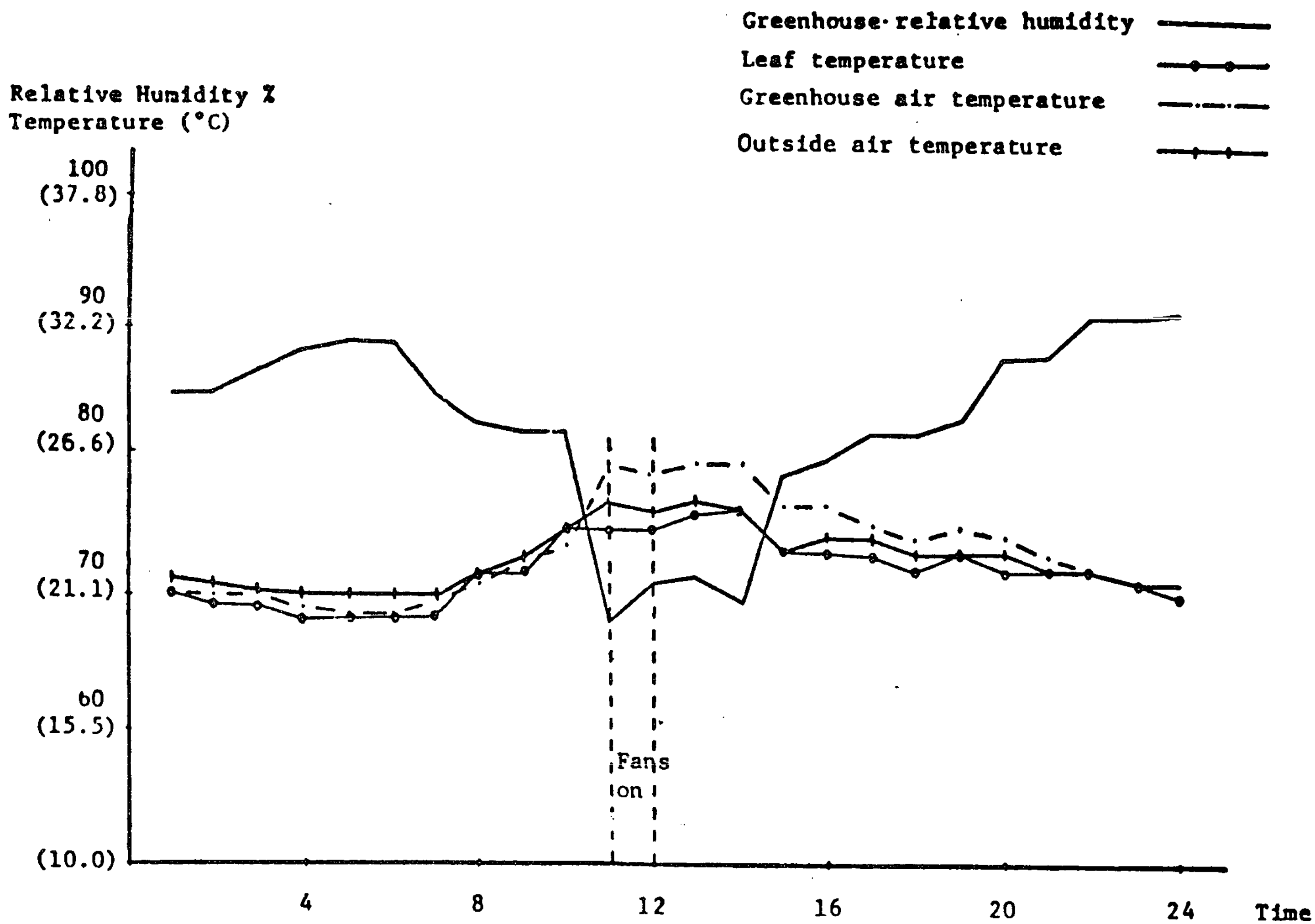
N.F.T.
Hydroponic
System

Fig. III-17



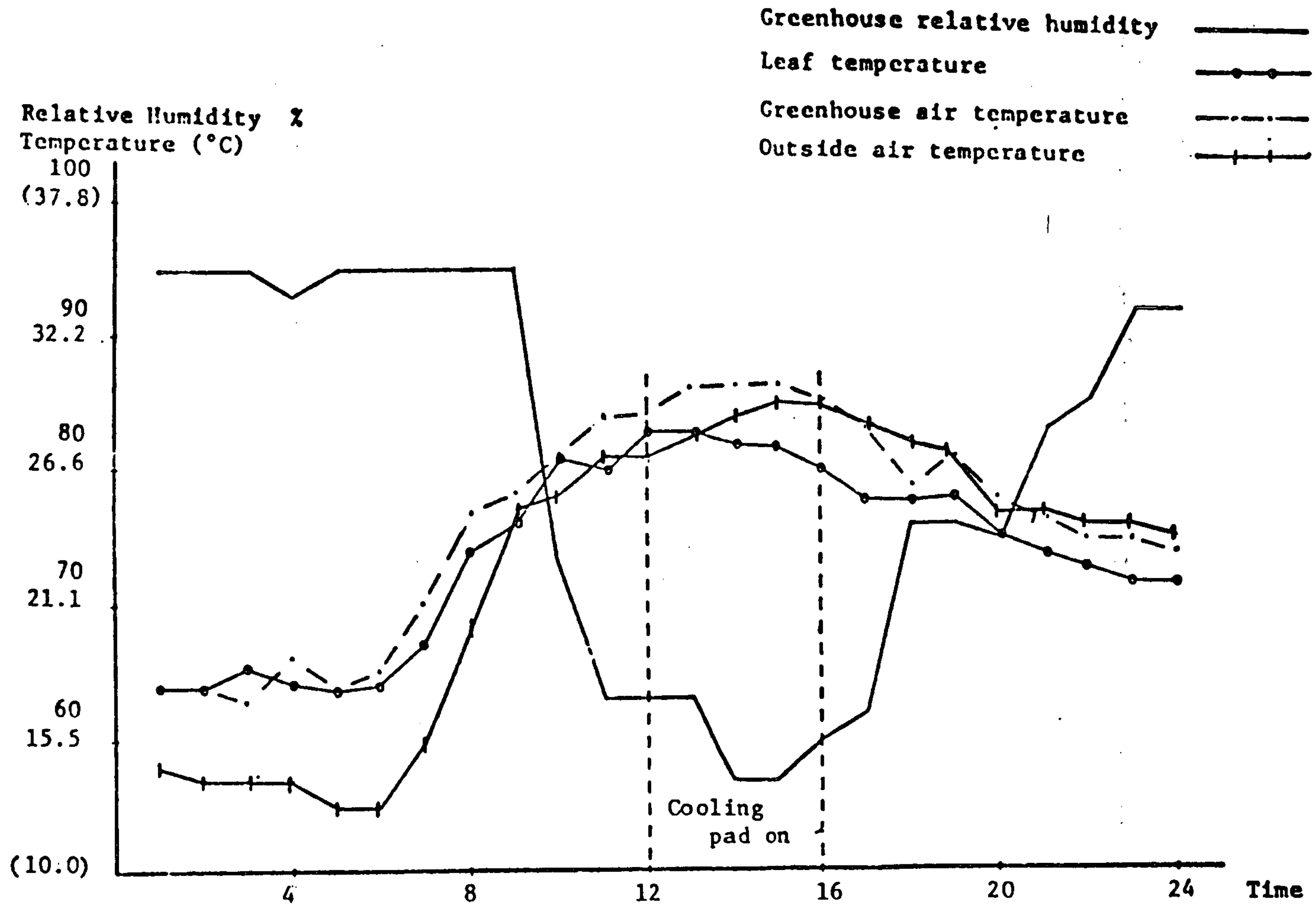
N.F.T.cycle

TYPICAL PERFORMANCE OF FAN & PAD COOLING



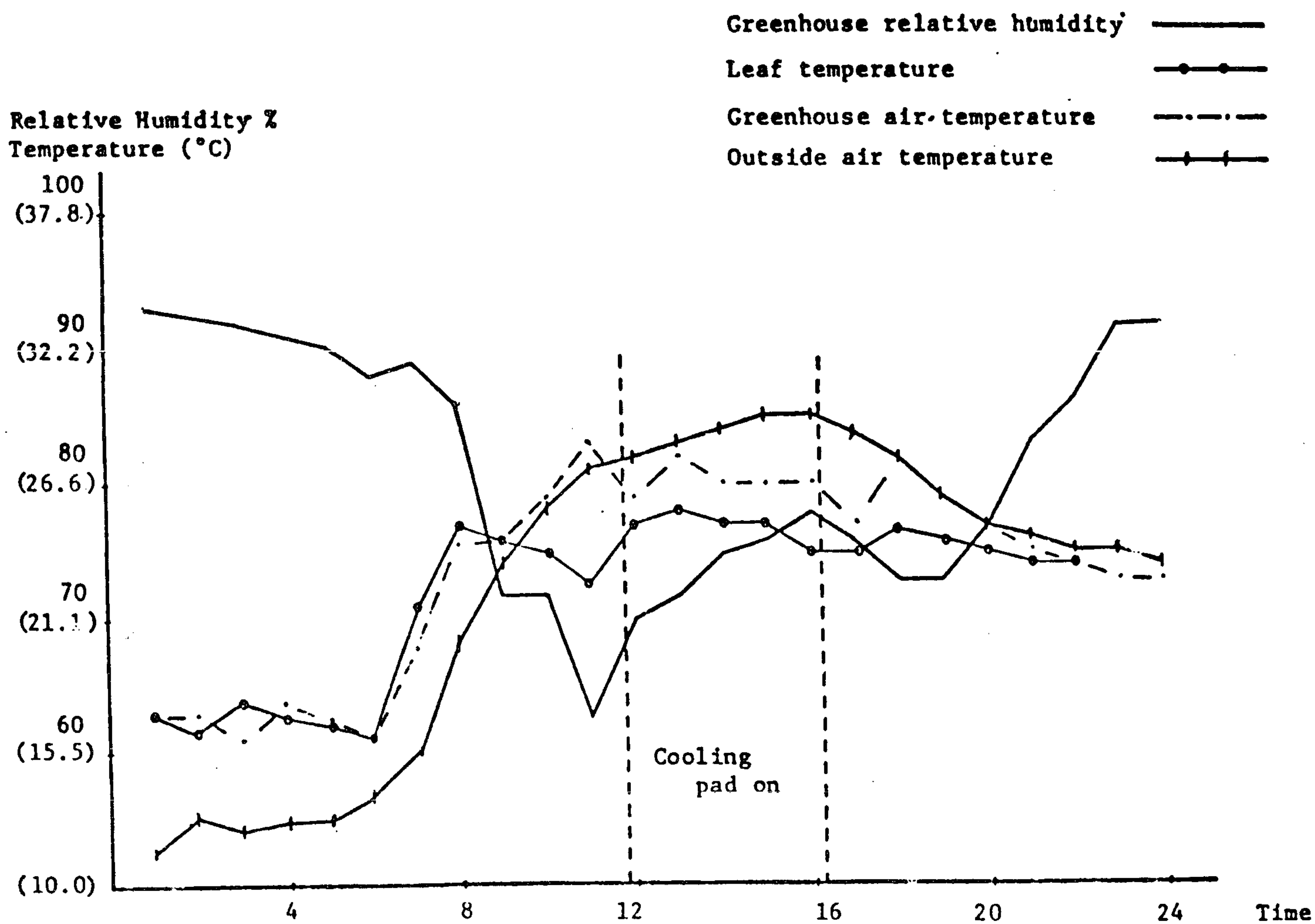
Greenhouse temperature and relative humidity.
The evaporative cooling systems were not on duty this day.

Fig. III-18



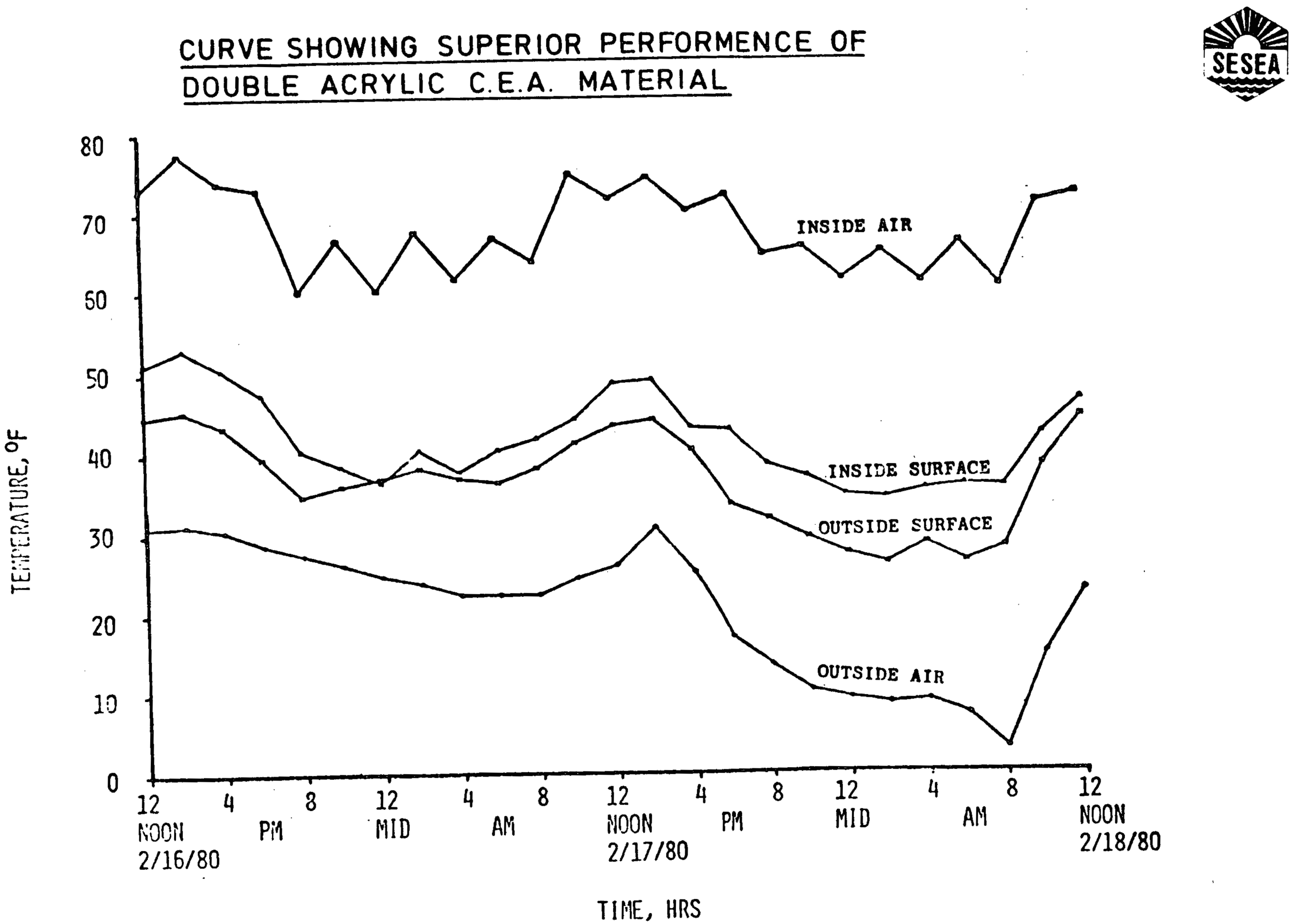
Cooling pad. Temperature and relative humidity
at 27m from the cooling pad.

Fig. III-19



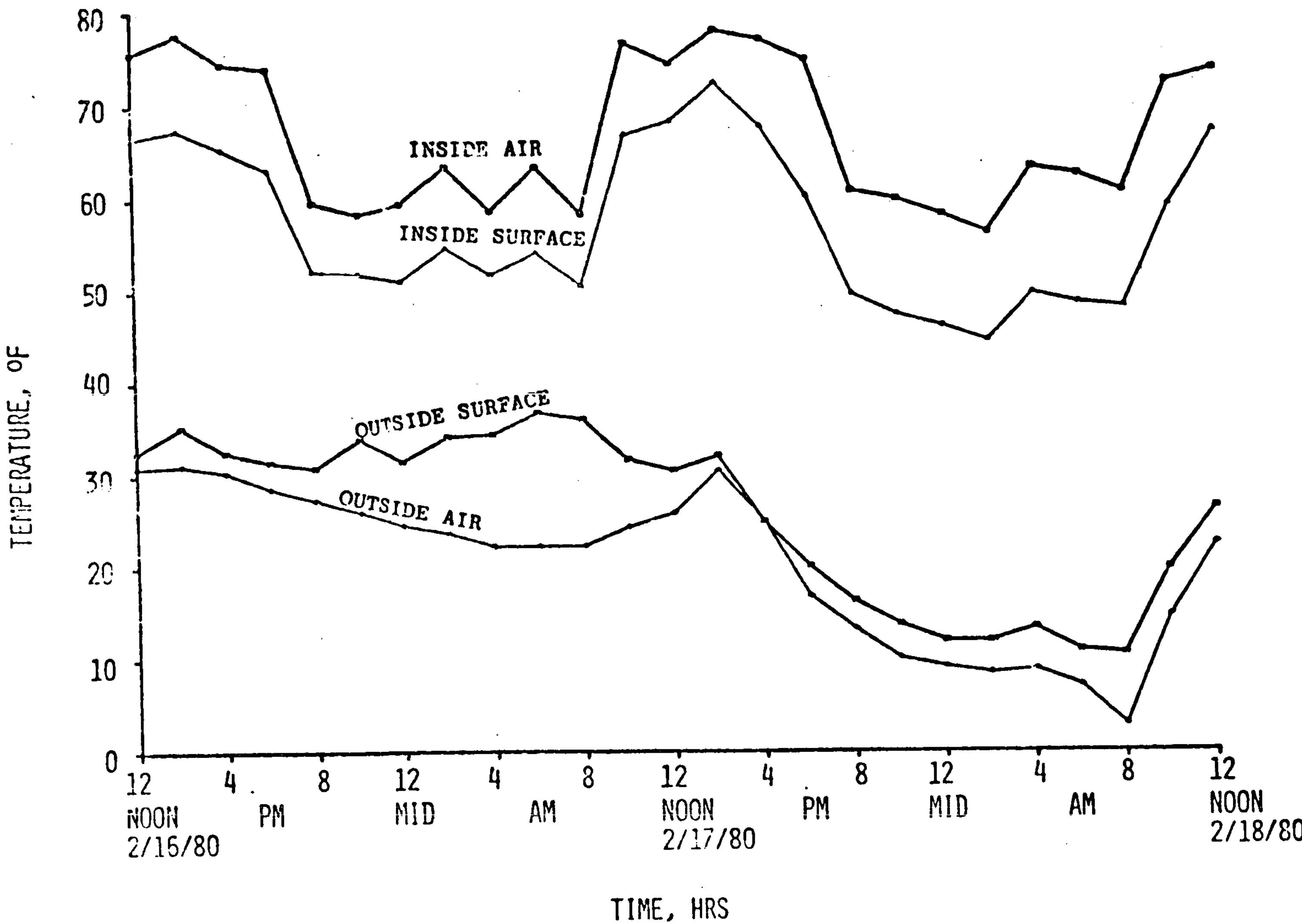
Cooling pad. Temperature and relative humidity
at 60m from the cooling pad.
Fig. III-20

CURVE SHOWING SUPERIOR PERFORMENCE OF DOUBLE ACRYLIC C.E.A. MATERIAL



A typical daily profile of the temperature gradient from the plant growing area to the outside air for a conventional glass greenhouse

Fig. III-21



A typical daily profile of the temperature gradient from the plant growing area to the outside air for a rigid-double-wall-acrylic greenhouse

Fig. III-22

Fig. III-23

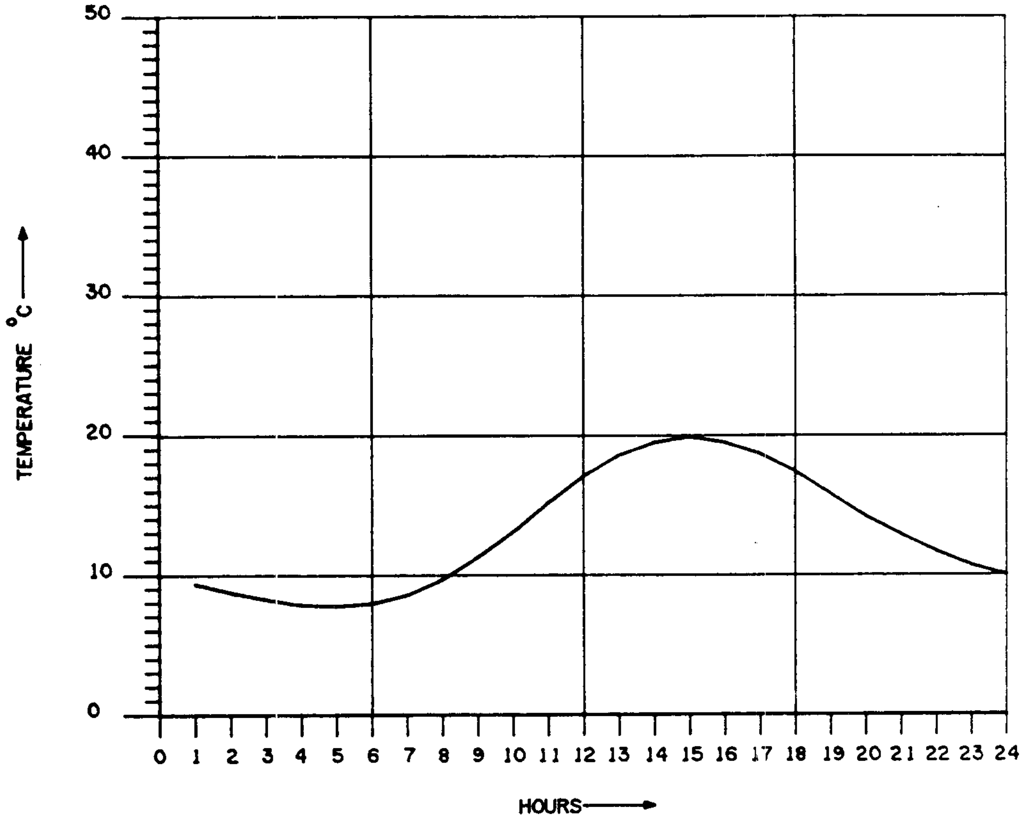
The evaporative effectiveness of a horizontal cooling pad as measured experimentally on five different days with relation to the leaftemperature.
Temperatures are indicated in °C.

		1	2	3	4	5
Ambient dry bulb	T_a	26.1	30.6	25.6	27.2	30.6
Leaf temp.	T_L	24.4	27.2	22.2	26.1	27.2
Ambient wet bulb	T_W	22.8	26.1	20.0	25.0	25.6
Leaf emissivity of long wave radiation	ε	0.52	0.76	0.61	0.50	0.68

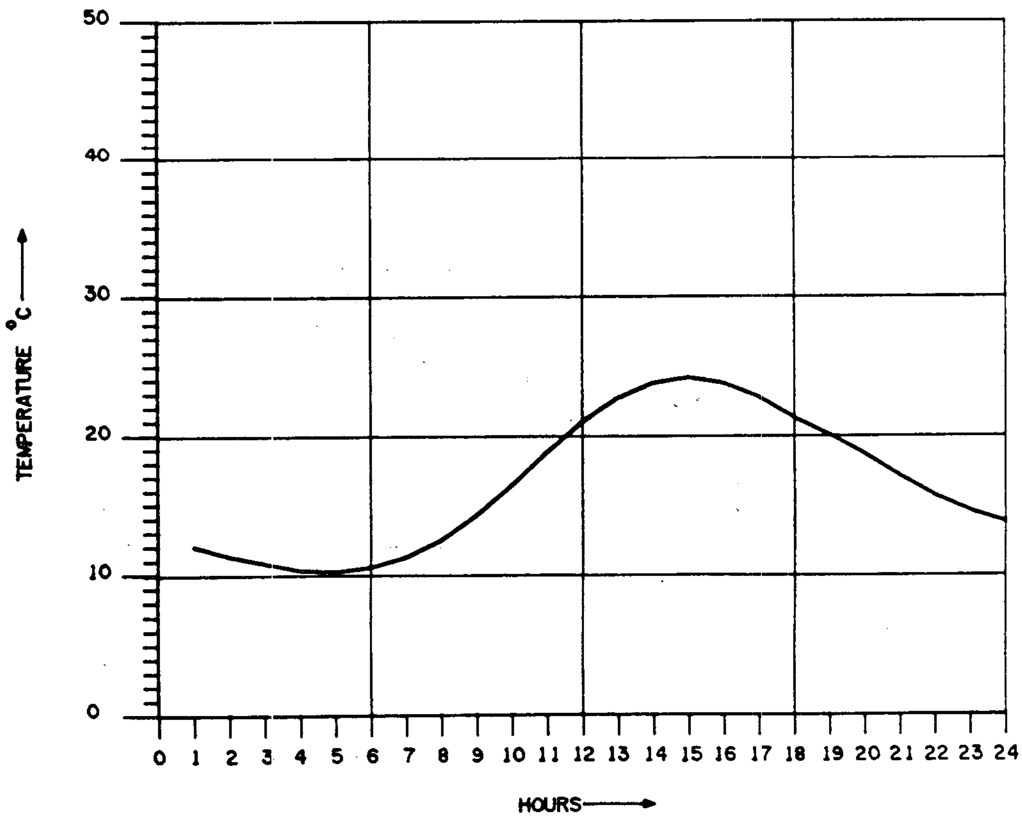
RIYADH AREA SAUDI ARABIA

Fig. III-24A

TYPICAL DIURNAL DRY BULB TEMPERATURE: JANUARY



TYPICAL DIURNAL DRY BULB TEMPERATURE: FEBRUARY



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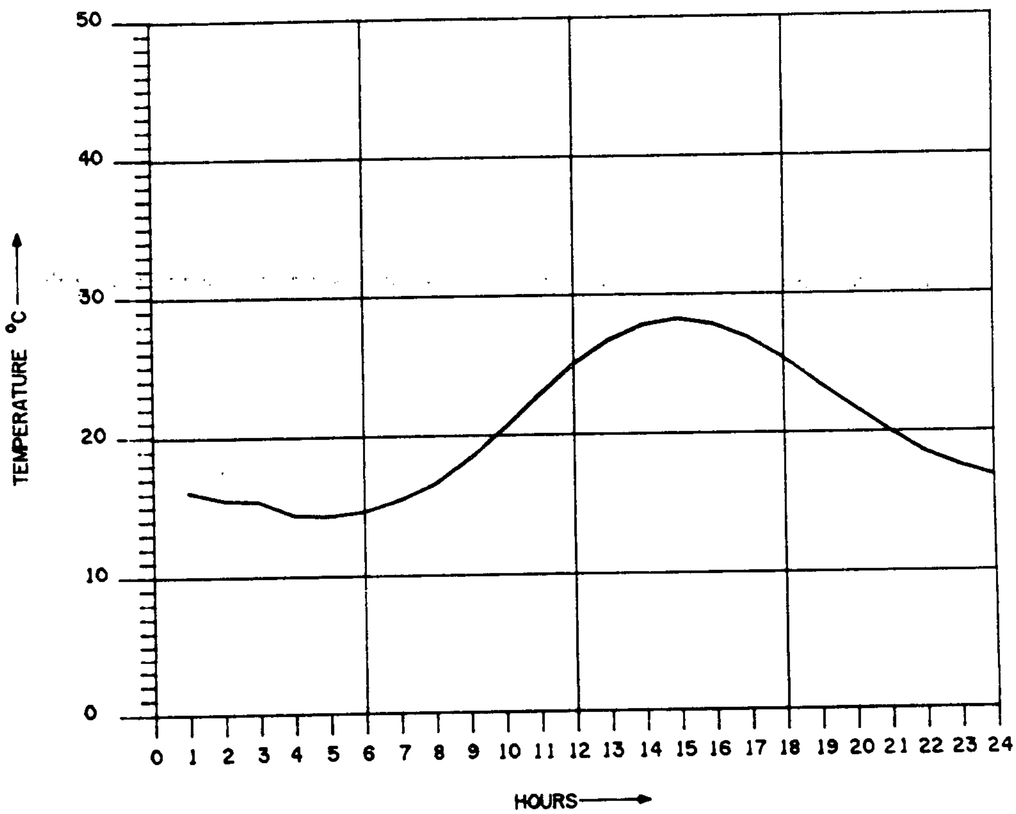
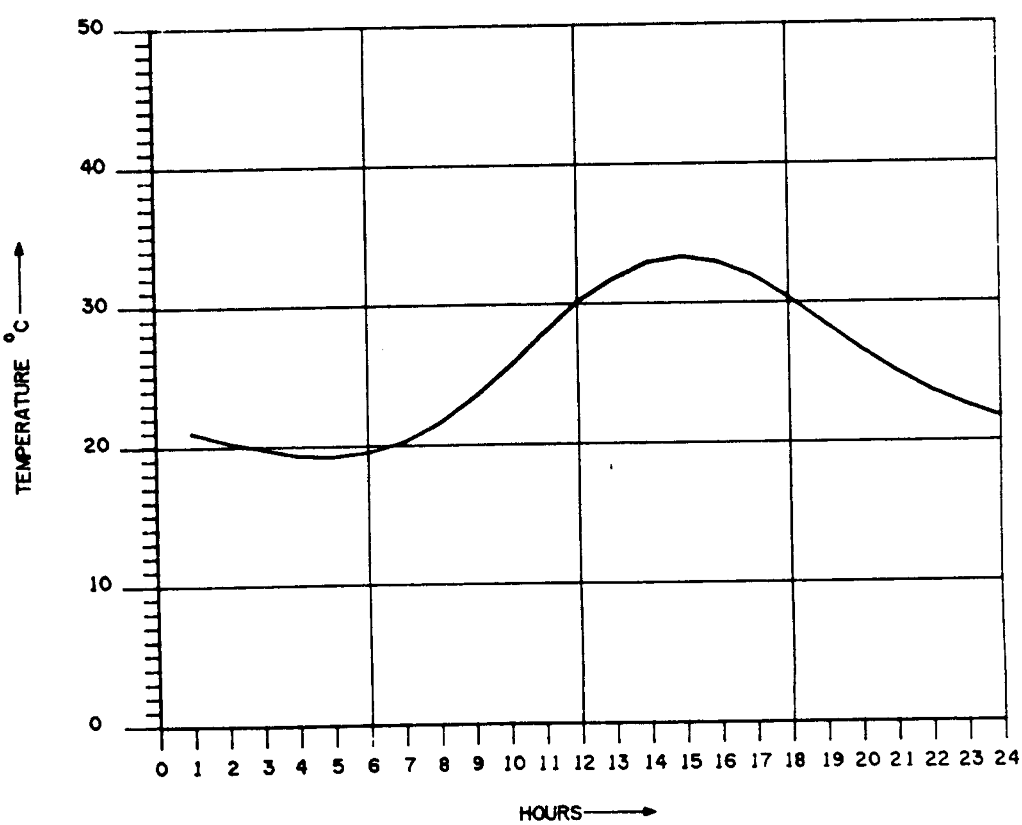
RIYADH AREA SAUDI ARABIA

Fig. III-24B

TYPICAL DIURNAL DRY BULB TEMPERATURE: MARCH



TYPICAL DIURNAL DRY BULB TEMPERATURE: APRIL



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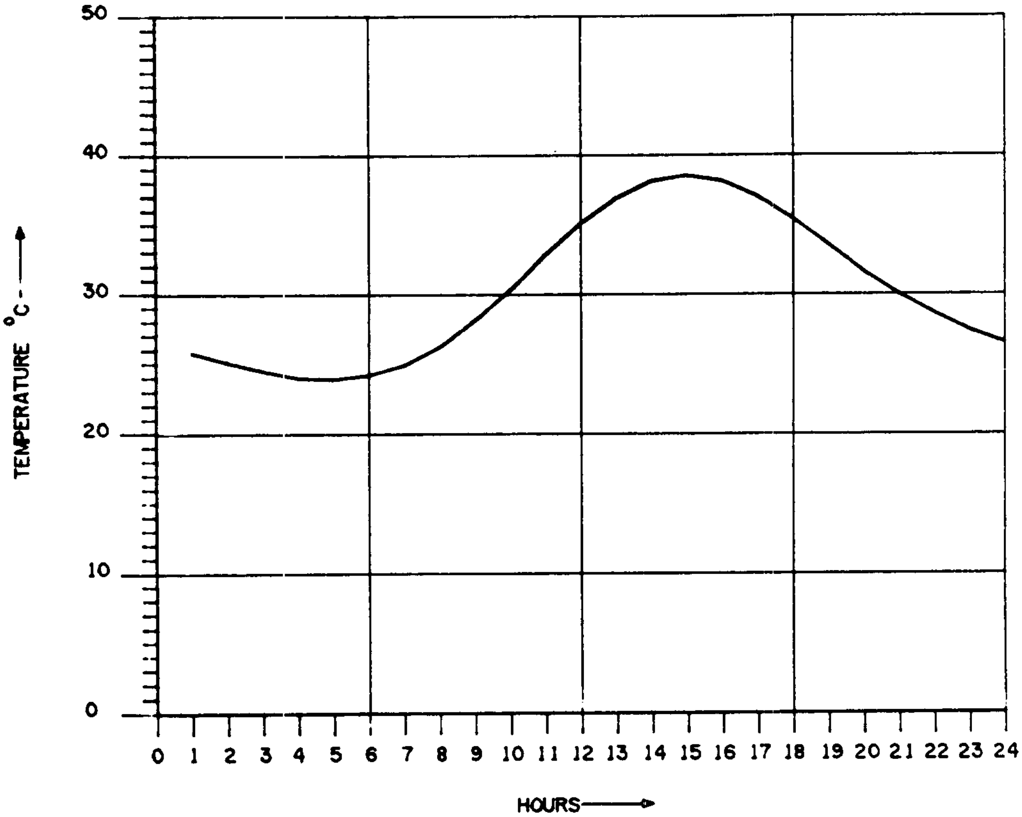
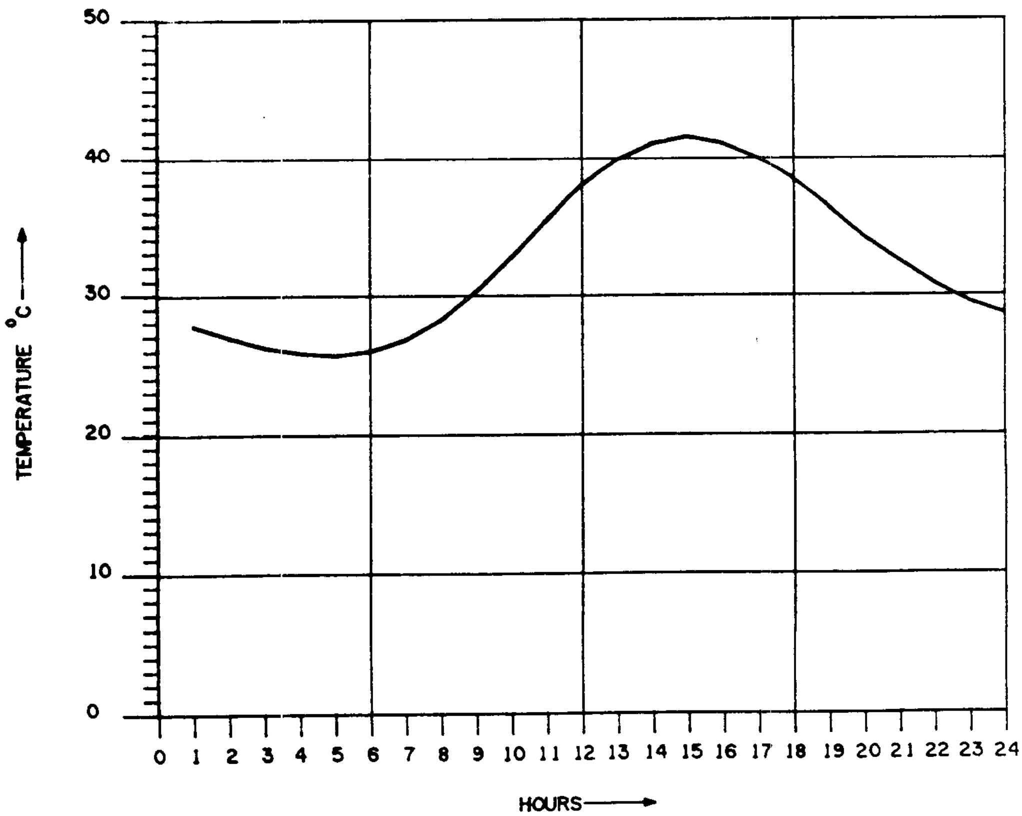
RIYADH AREA SAUDI ARABIA

Fig. III-24C

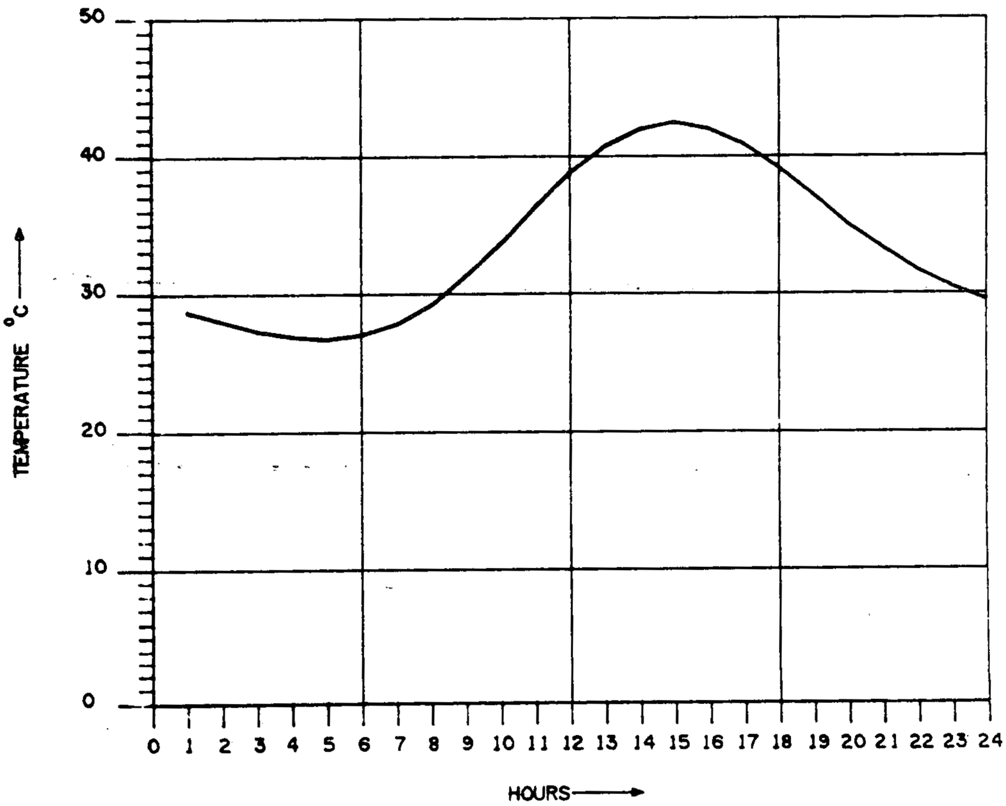
TYPICAL DIURNAL DRY BULB TEMPERATURE: MAY



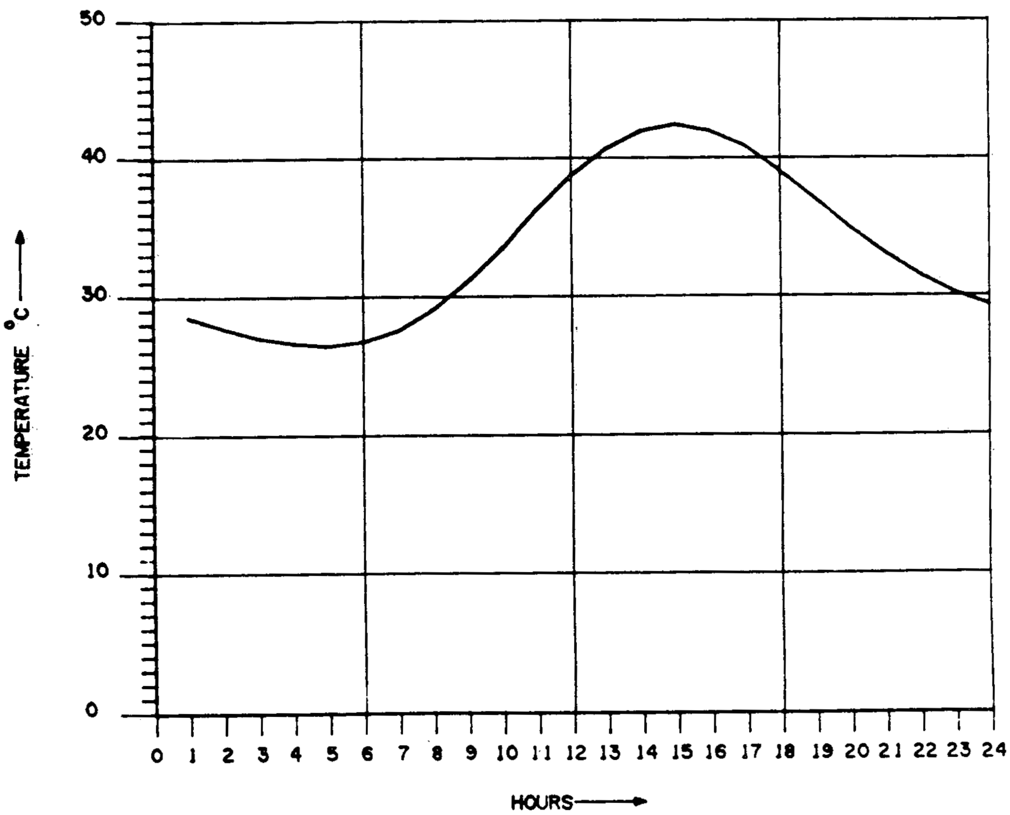
TYPICAL DIURNAL DRY BULB TEMPERATURE: JUNE



TYPICAL DIURNAL DRY BULB TEMPERATURE: JULY



TYPICAL DIURNAL DRY BULB TEMPERATURE: AUGUST



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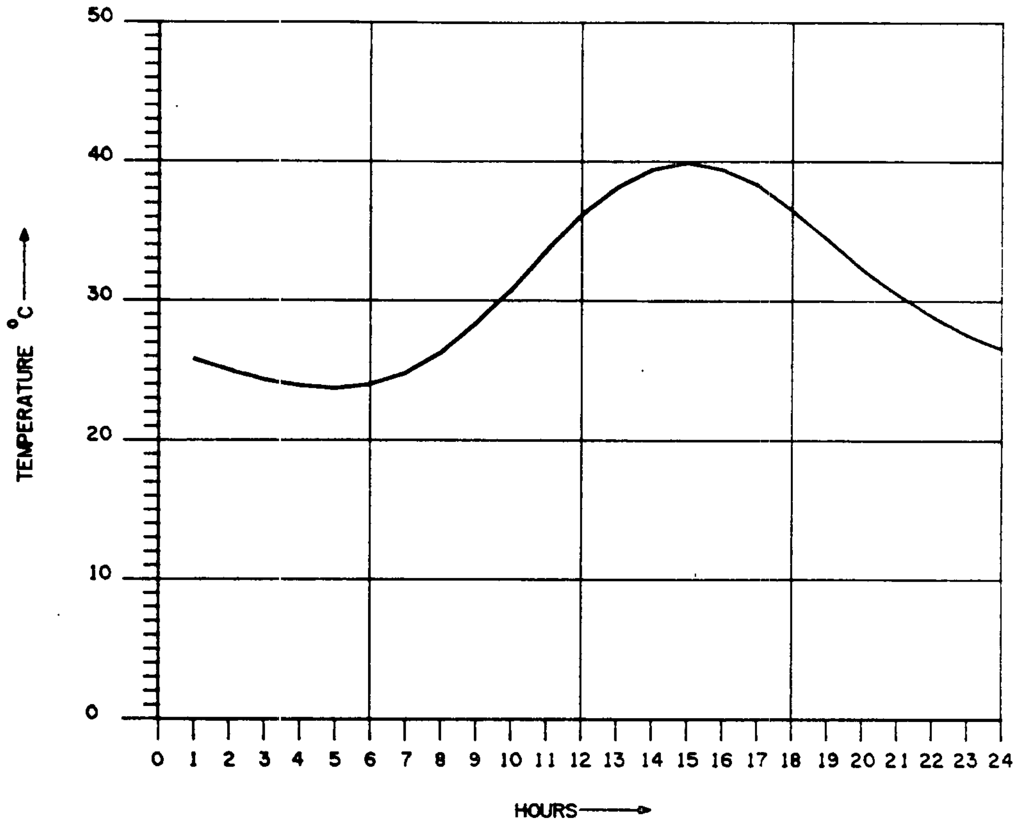
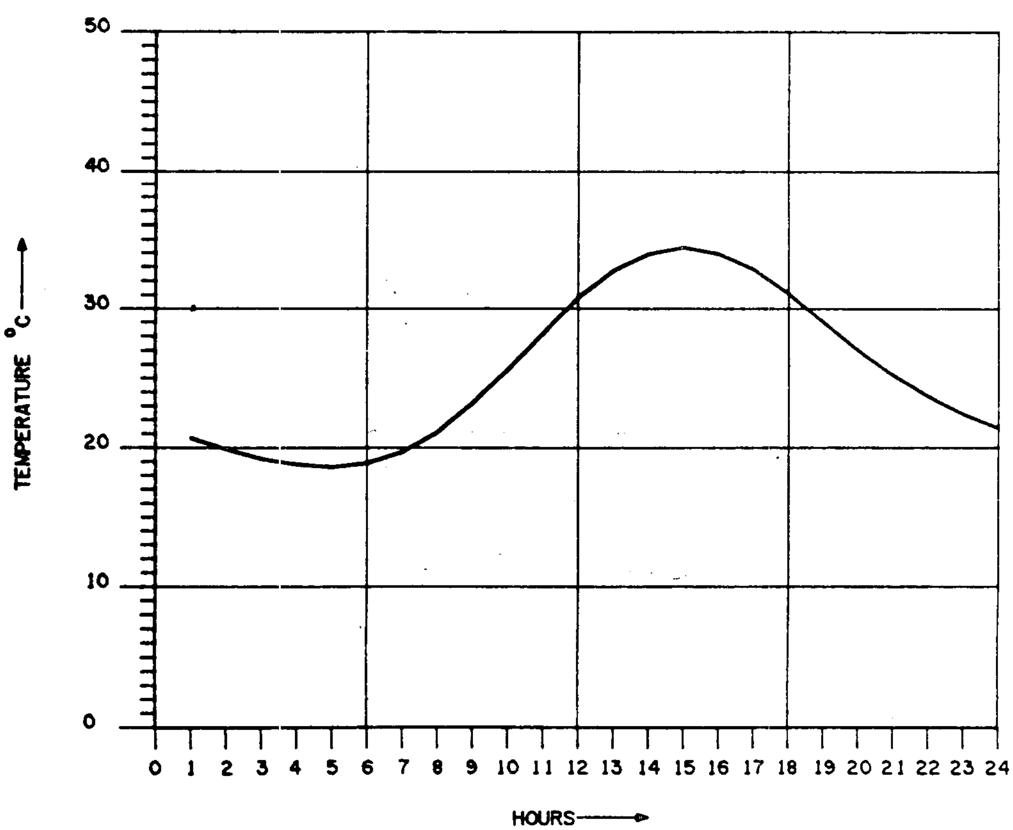
TYPICAL DIURNAL DRY BULB TEMPERATURE: SEPTEMBER



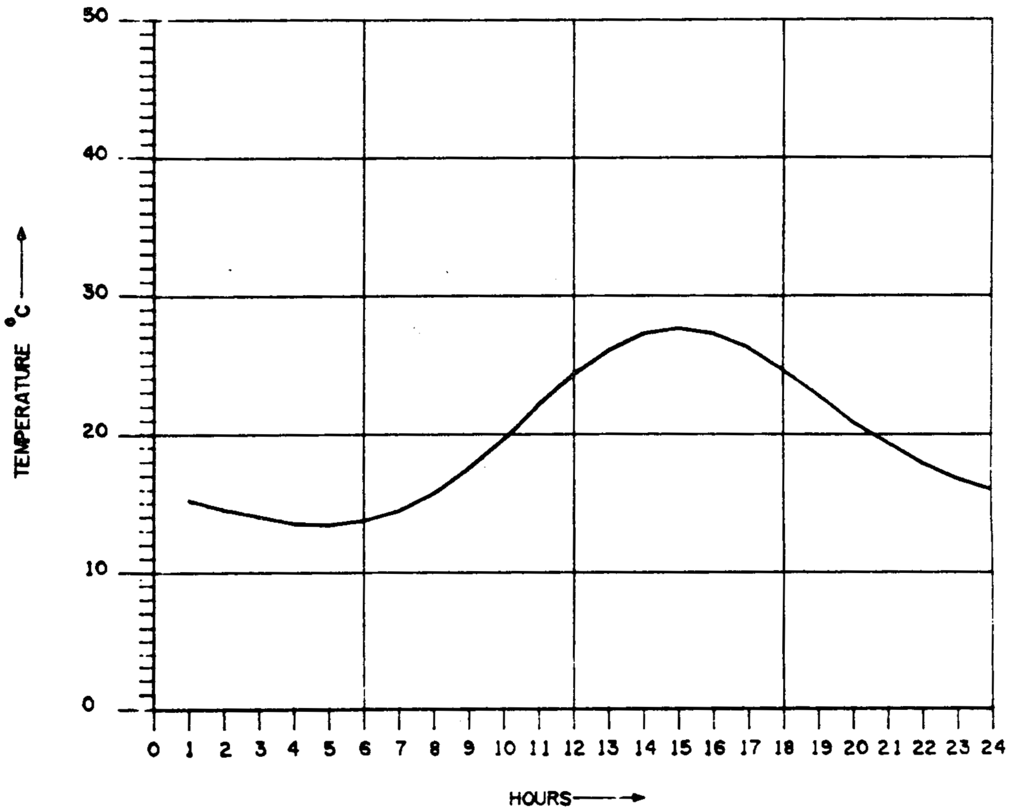
TYPICAL DIURNAL DRY BULB TEMPERATURE: OCTOBER



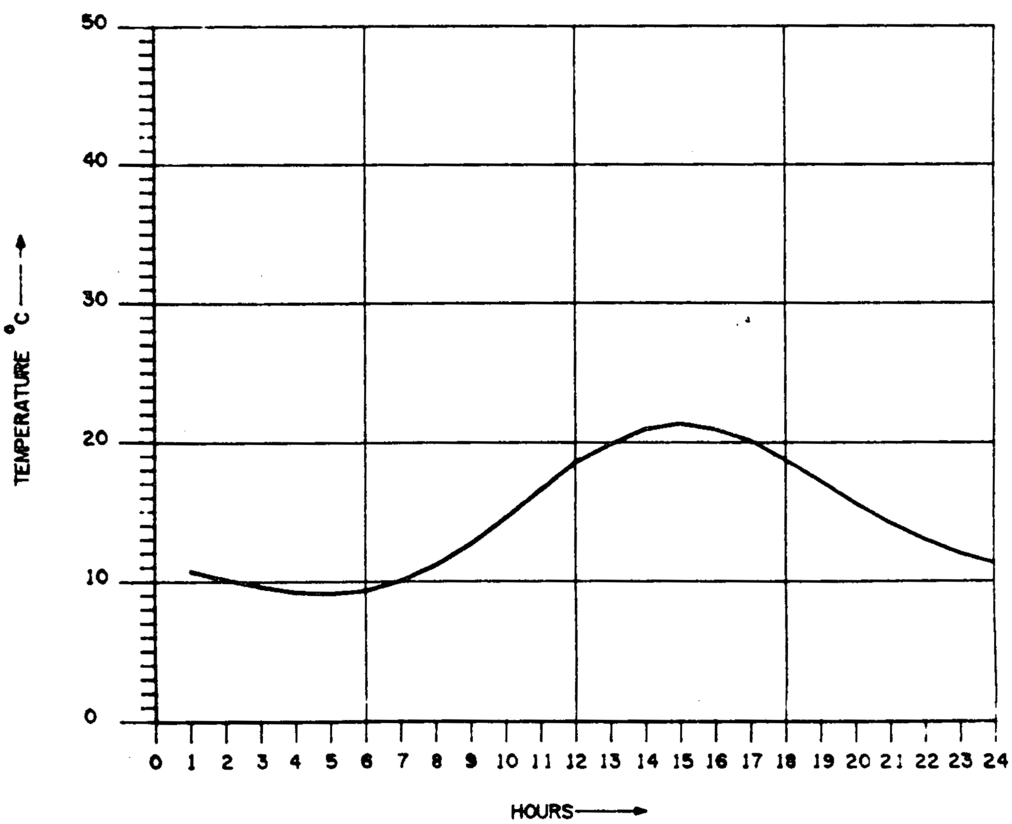
RIYADH AREA SAUDI ARABIA

Fig. III-24F

TYPICAL DIURNAL DRY BULB TEMPERATURE: NOVEMBER



TYPICAL DIURNAL DRY BULB TEMPERATURE: DECEMBER



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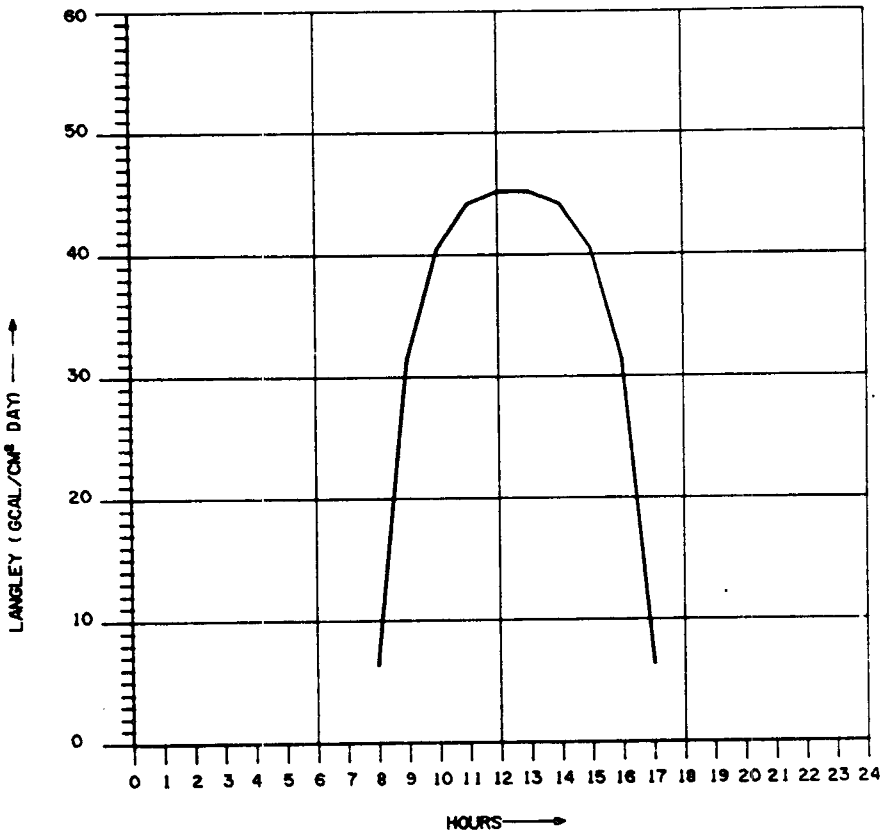
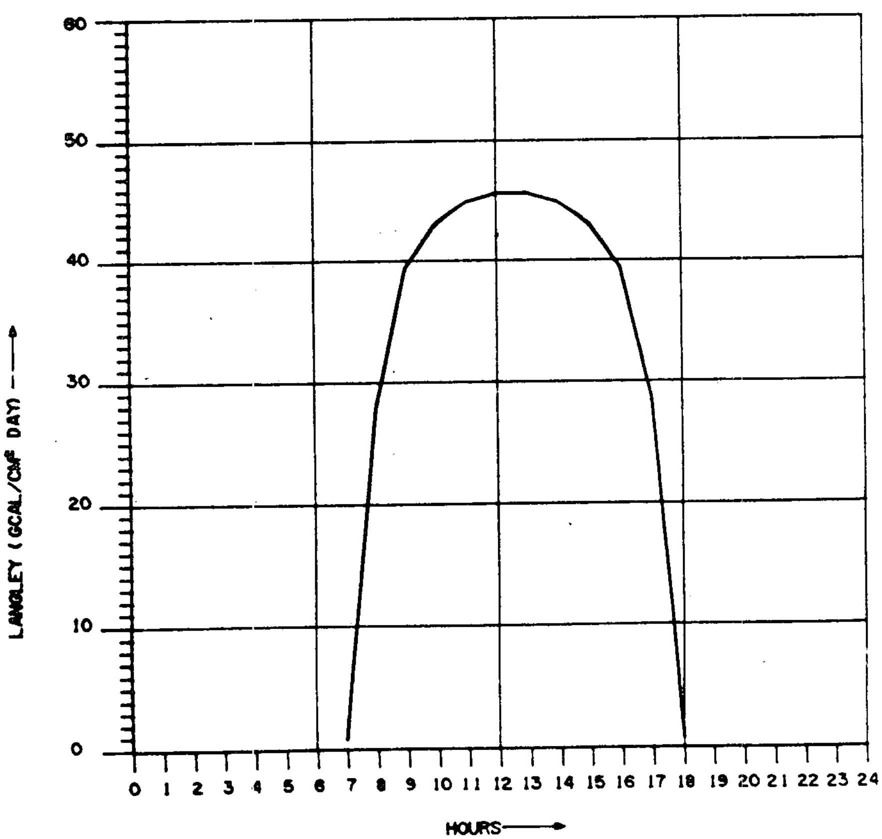
RIYADH AREA SAUDI ARABIA

Fig. III-25A

TYPICAL DIURNAL RADIATION: JANUARY



TYPICAL DIURNAL RADIATION: FEBRUARY



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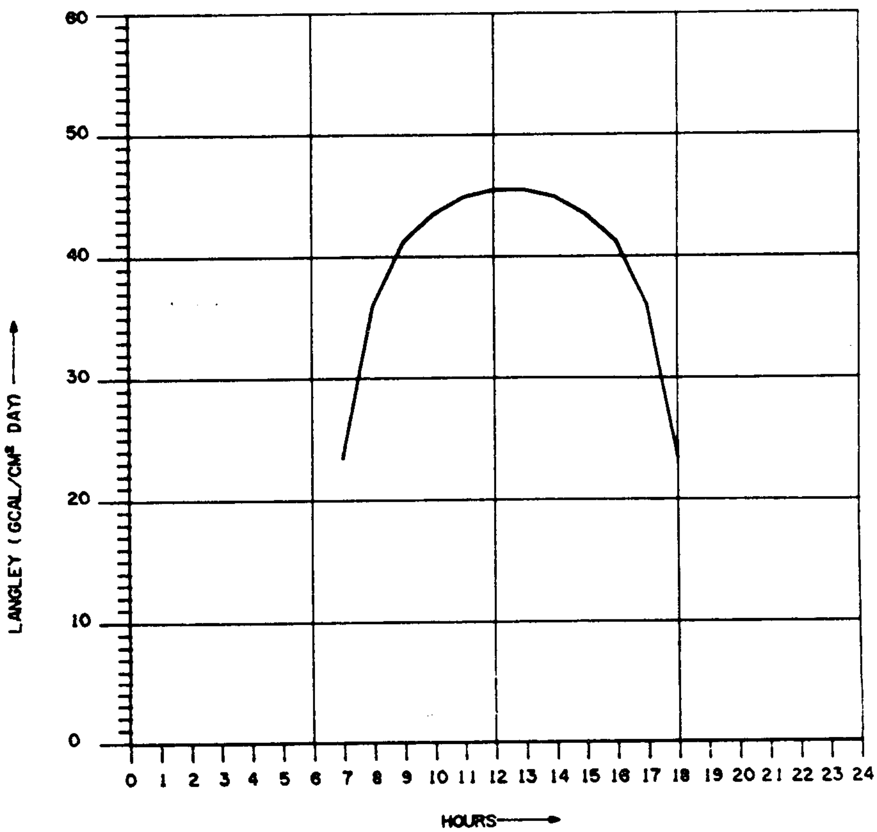
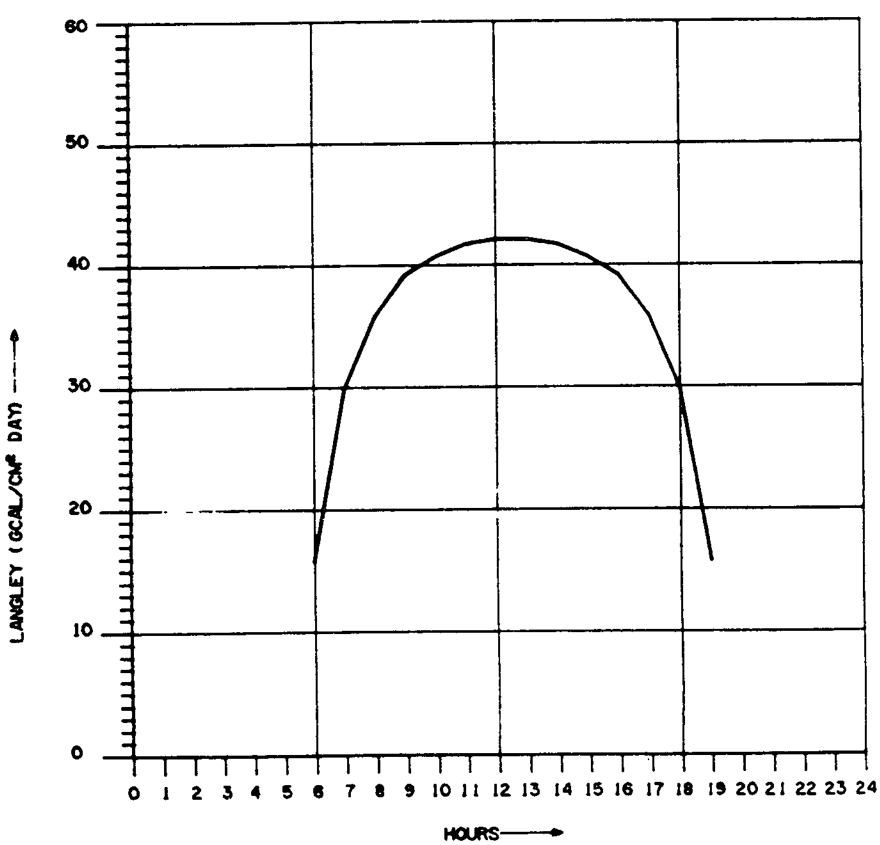
RIYADH AREA SAUDI ARABIA

TYPICAL DIURNAL RADIATION: MARCH



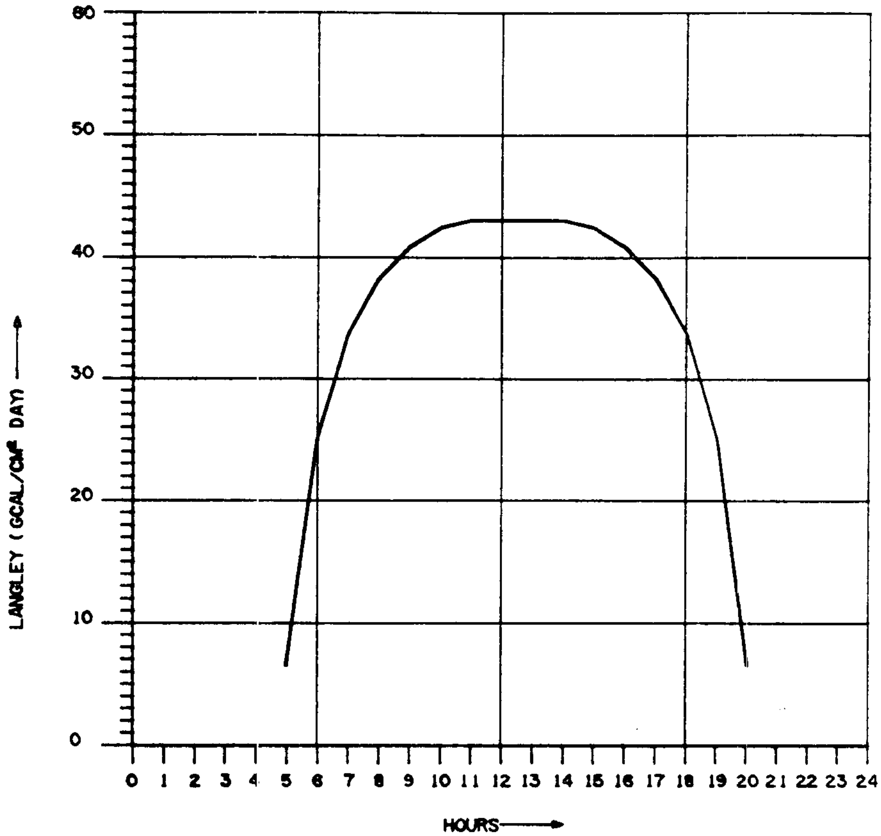
TYPICAL DIURNAL RADIATION: APRIL



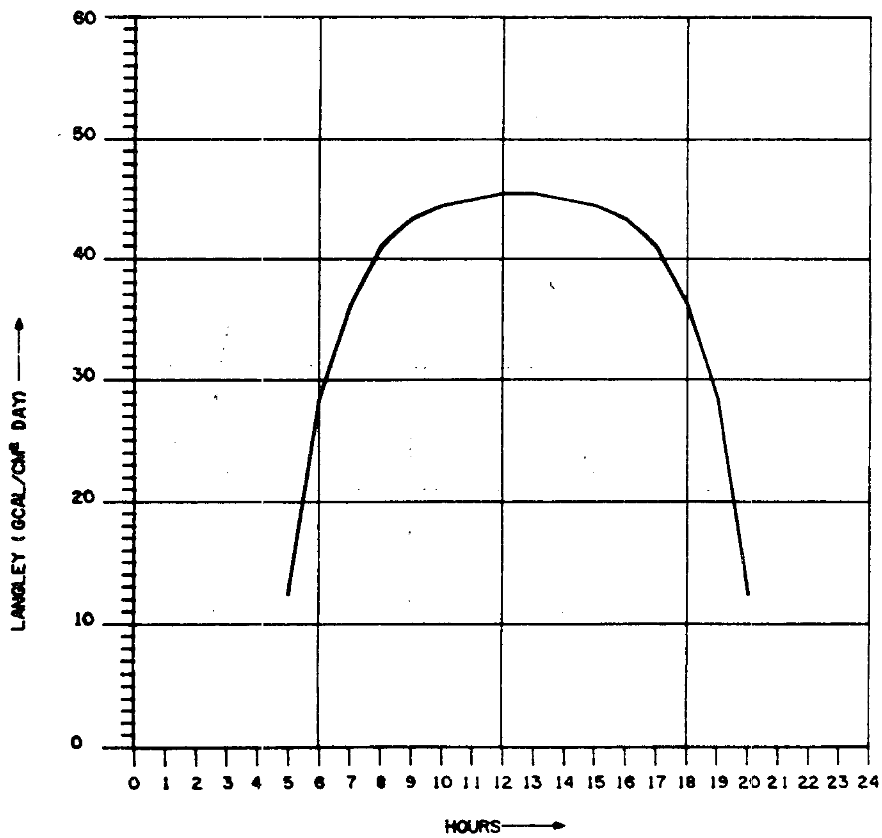
RIYADH AREA SAUDI ARABIA

Fig. III-25C

TYPICAL DIURNAL RADIATION: MAY



TYPICAL DIURNAL RADIATION: JUNE



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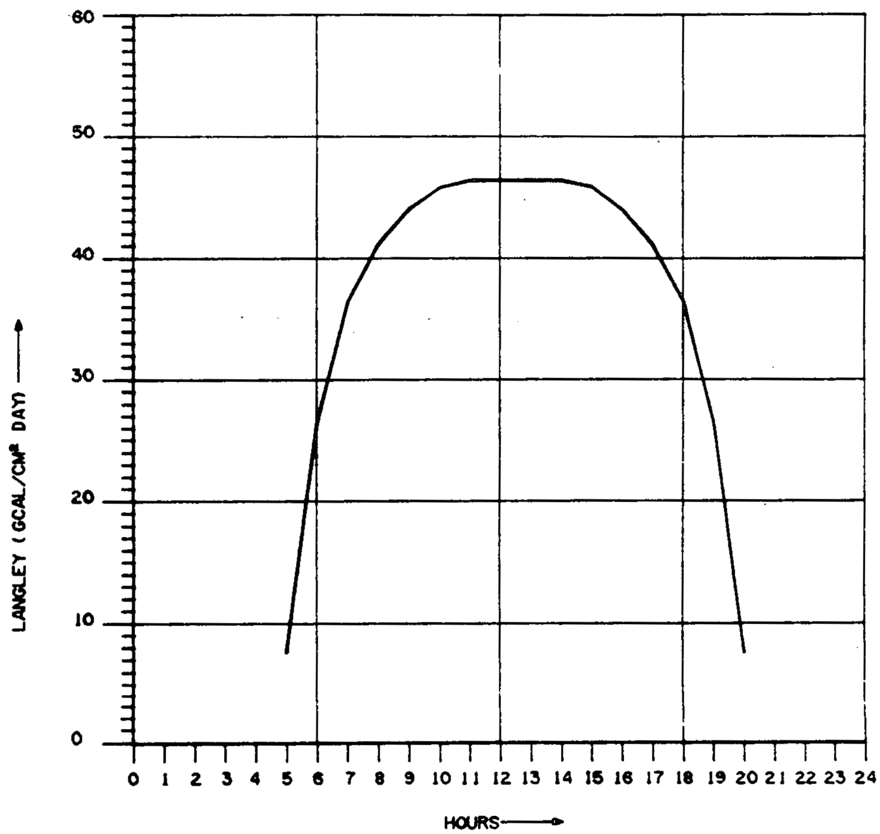
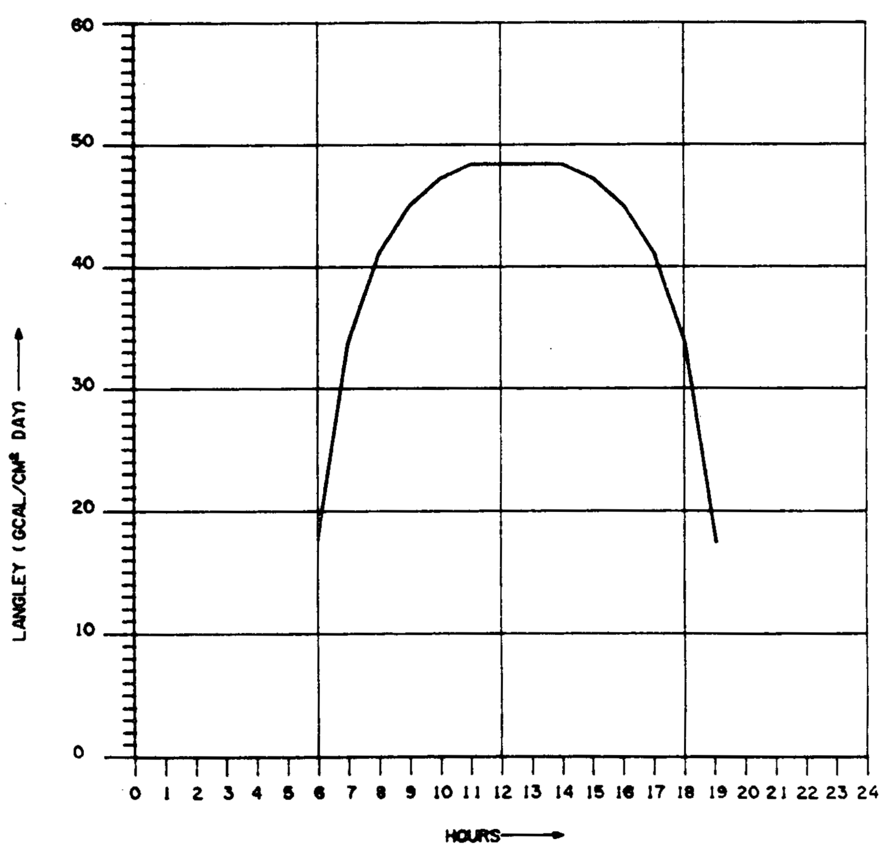
RIYADH AREA SAUDI ARABIA

Fig. III-25D

TYPICAL DIURNAL RADIATION: JULY



TYPICAL DIURNAL RADIATION: AUGUST



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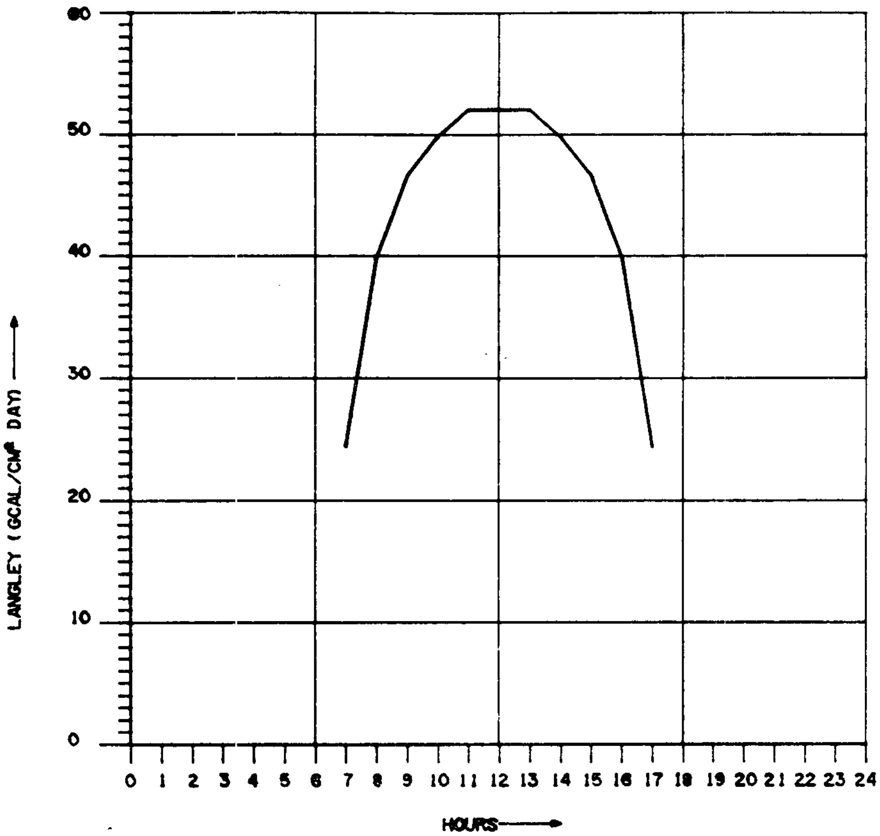
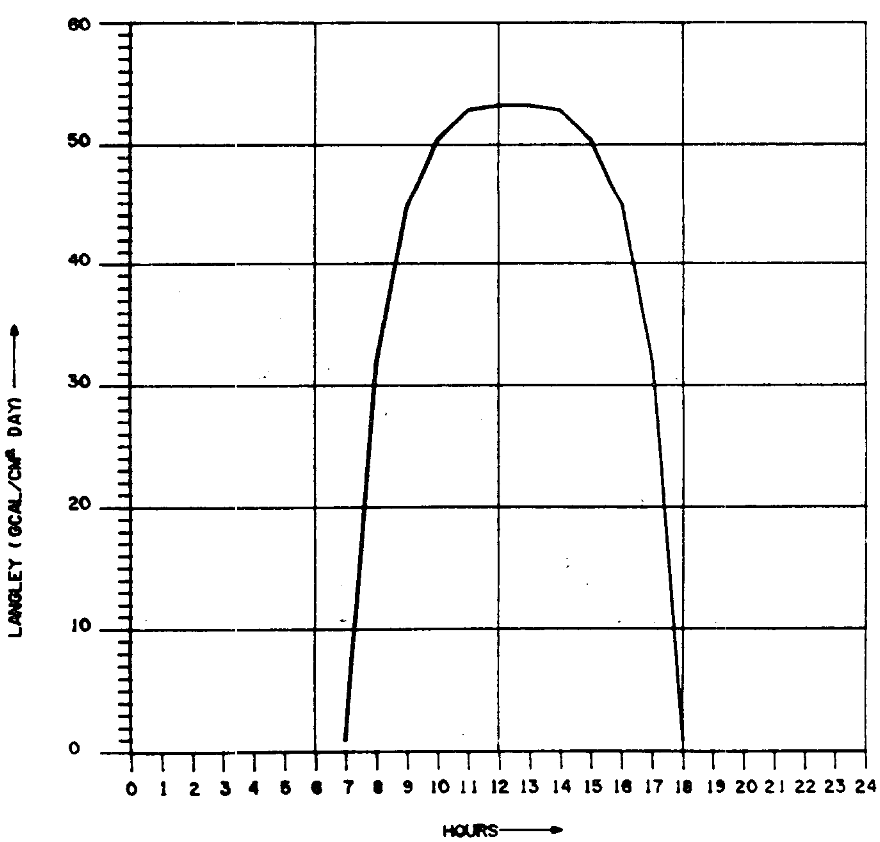
RIYADH AREA SAUDI ARABIA

Fig. III-25E

TYPICAL DIURNAL RADIATION: SEPTEMBER



TYPICAL DIURNAL RADIATION: OCTOBER



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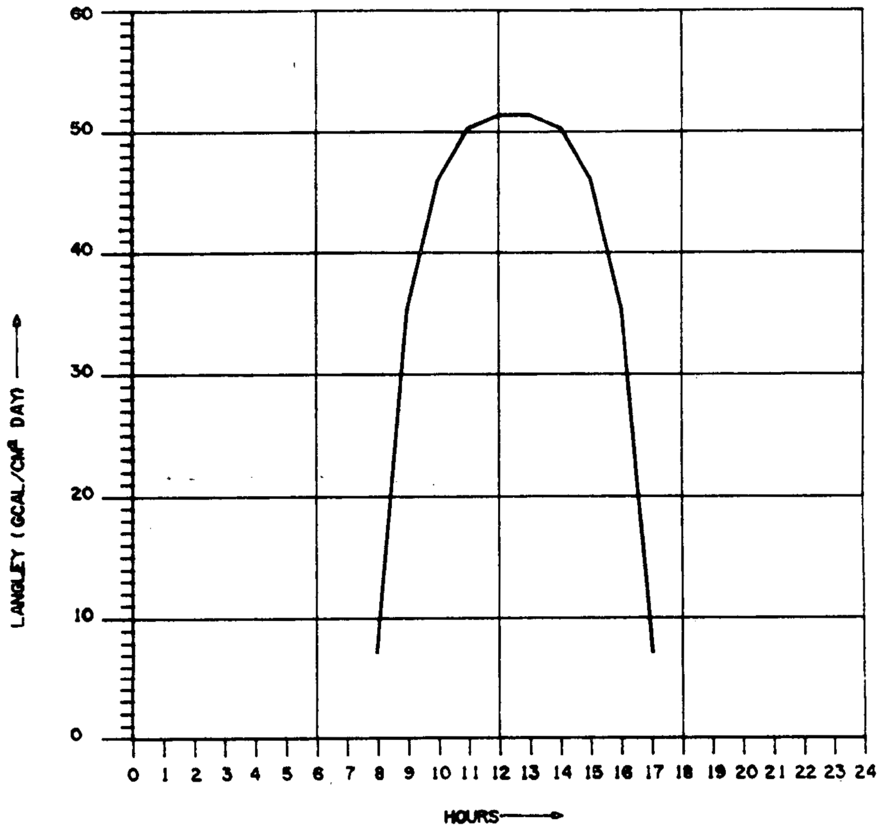
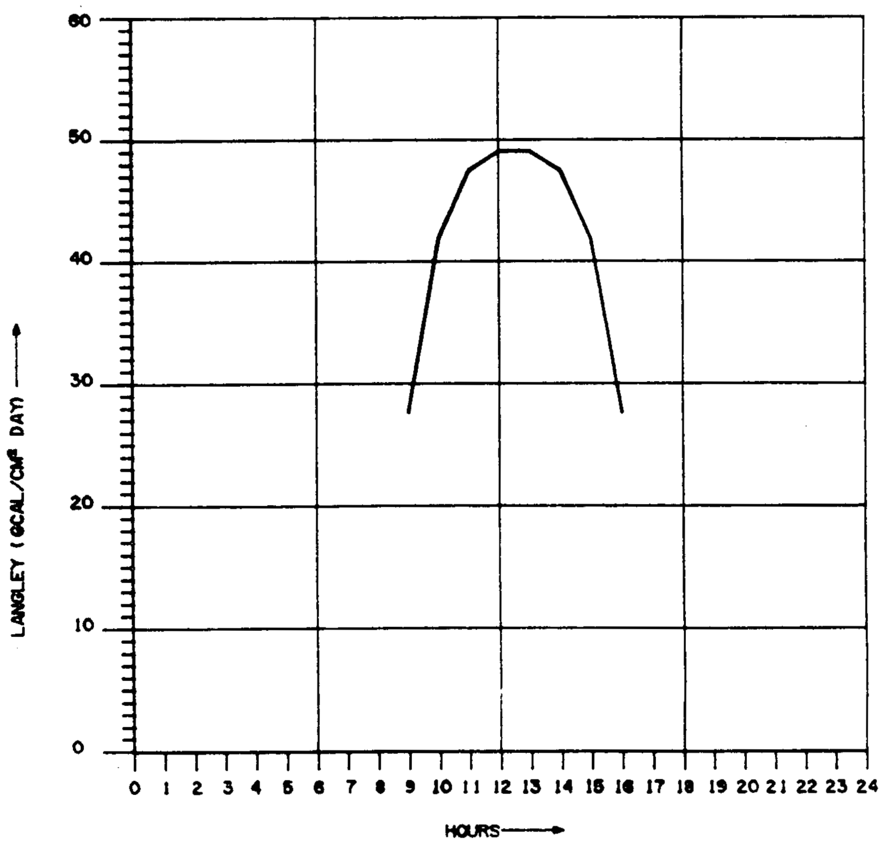
TYPICAL DIURNAL RADIATION: NOVEMBER



TYPICAL DIURNAL RADIATION: DECEMBER



4.2 UNIT 200, WATER SUB-SYSTEM

4.2.1 Introduction

In this section the overall water flow sub-system is described. As shown in Fig. III-26 the water is pumped from the well into a storage tank. From there, the water is used to feed the desalination system and the CEA cooling water system. The CEA feedwater comes from the desalination system. The solar pond evaporation make-up flow consists of desalination reject flow and cooling pad circulation blow-down.

4.2.2 Overall Description of the Desalination System

For desalination of wellwater with 2000-5000 ppm total dissolved solids (TDS) various systems have been considered but the most economic and reliable system is that of reverse osmosis (RO).

RO is a membrane process that acts as a molecular filter to remove up to 95-99% of all dissolved minerals, 95-97% of most dissolved organics and more than 98% of biological and colloidal matter from water. Osmosis, is the natural process whereby pure water flows through a membrane from a dilute solution into a more concentrated solution, thereby diluting the latter. Water flow continues until the pressure created by the osmotic head equals the osmotic pressure of the salt solution. If the osmotic pressure is overcome by the application of an external pressure, the flow is reversed from the concentrated solution. This is the process of reverse osmosis.

4.2.3. RO Membrane

For this system, the B-9 hollow fine fiber permeator of Du Pont is selecated. The fibers are such that they form a dense skin at the surface, thus inhibiting the passage of salts but allowing water to pass through.

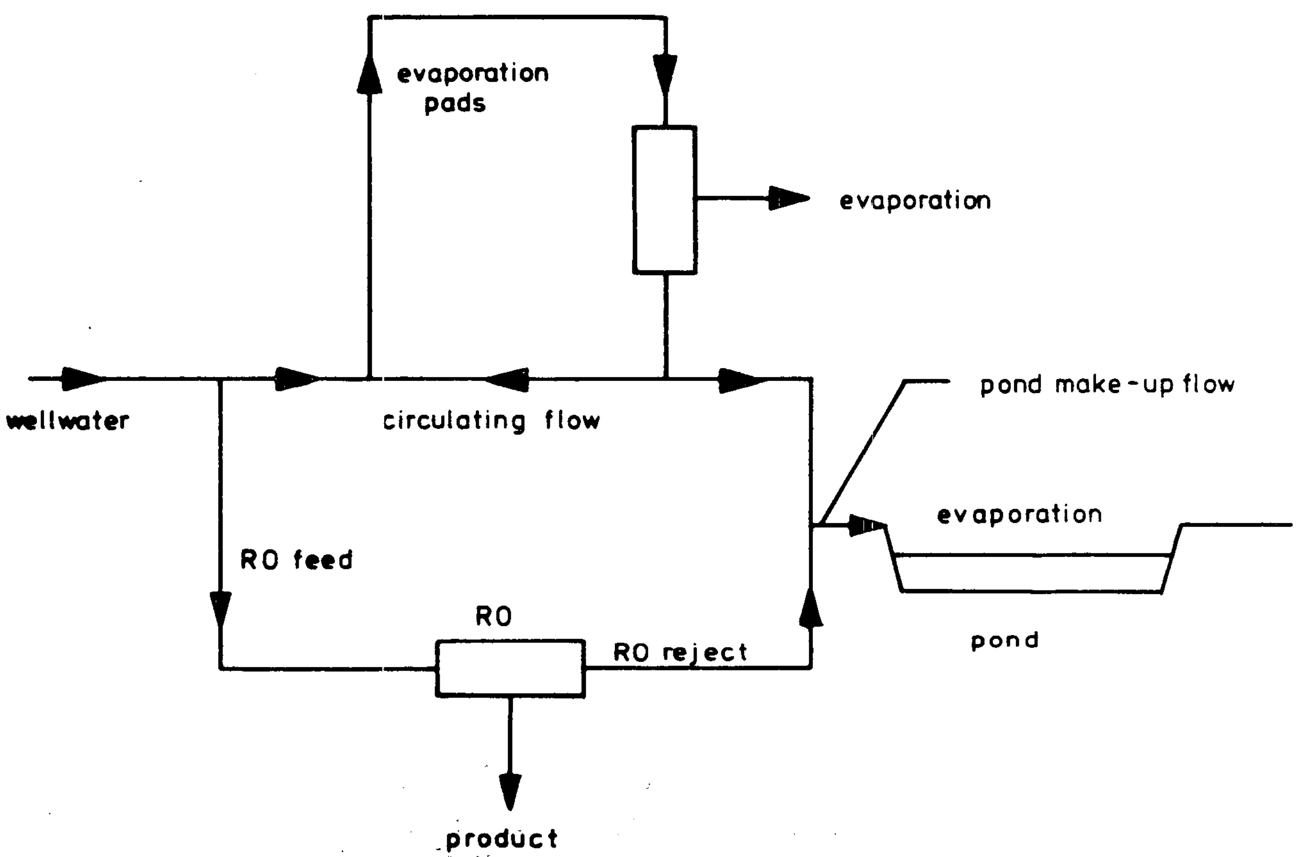
The hollow fibers, are selfsupporting membranes and are actually thick walled cylinears. Because the ratio of outside to inside diameter is 2 to 1, these fibers have the strength to withstand high operating pressures without collapsing. Their small dameter permits the development of an extremely compact device, having a large surface area for transport.

Fig. III-27A illustrates the principle of a hollow fiber reverse osmosis device. Frequently the analogy of a shell and tube heat exchanger is used to describe the permeator. If one visualizes the hollow fibers as the tubes in the heat exchanger, the feed water flow is around the outside of the tubes (shellside). Product water is driven through the fiber walls by the high operating pressure and flows down the tubes and out through the "tube-sheet". Reject or concentrate flow is taken off the "shell side".

Fig. III-27B illustrates a B-9 permeator. Feed water at 28 bar pressure enters the permeator through a highly porous distributor located at the center of the permeator. This distributor runs the entire length of the permeator.

Water moves radially from the distributor toward the outer shell of the device, still under 28 bar pressure. The pressure forces the pure water through the fiber walls thus moving it along the bore of each fiber to the "tube-sheet", where the fibers have been cut to allow the exit of pure water. The salts, minerals and other contaminants move to the outer perimeter and are takne out of the permeator via the reject stream.

Fig. III-26



WATERHOUSEHOLD SYSTEM

Fig. III-27A

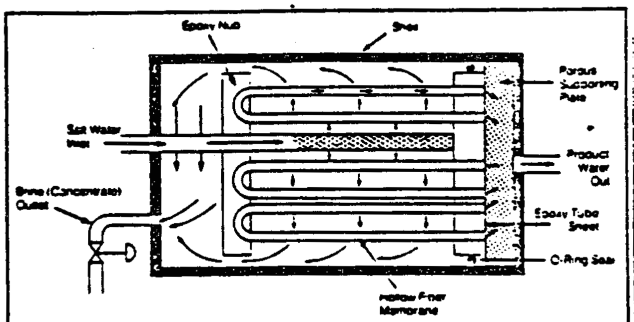
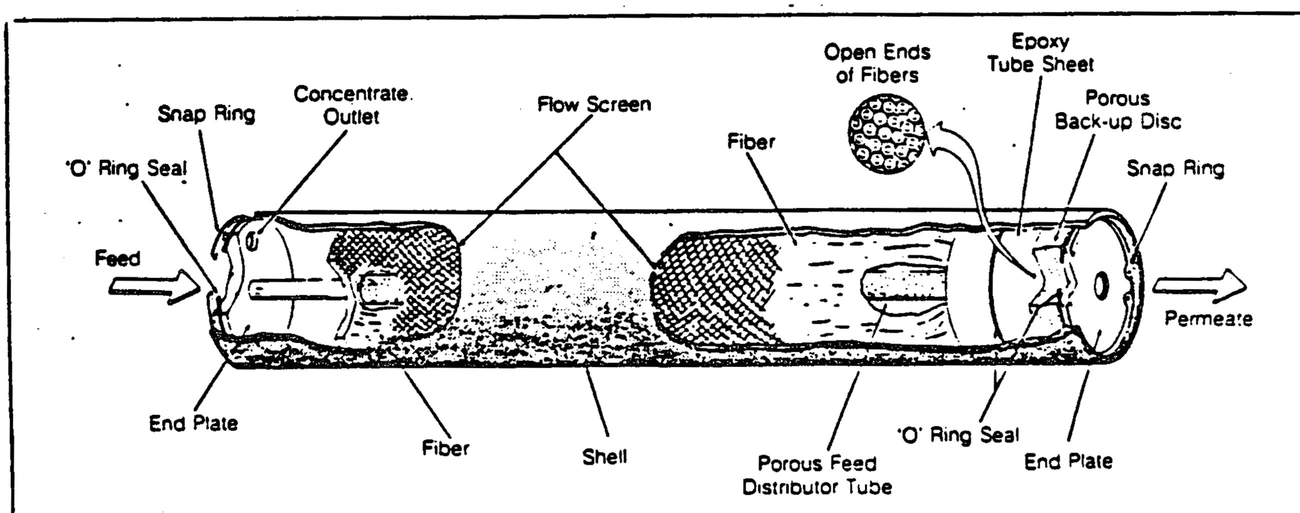


Illustration of Hollow Fiber Reverse Osmosis Process.

Fig. III-27B



Cut Away Drawing of Permasep® Permeator

4.2.4 RO Permeator Requirements

The reverse osmosis system is based on pretreatment requirements and max. conversion rate. To achieve the max. product water specification of 60 ppm NaCl, the max. possible conversion in one stage, will be 65%.

Because each permeator needs a minimum brine rate that approximately equals the product rate, the maximum conversion that can be achieved by one permeator is approx. 50%. Therefore, to obtain higher conversion rates, staging of permeators is necessary. This is done by using first stage reject as second stage feed.

Because the reject flow from the first stage is almost half the feed flow, a normal staging is done by using half of the number of first stage permeators in the second stage. The feed flow of the second stage is more concentrated than the feed flow of the first stage and its pressure is lower by about 1 bar. This reduces the conversion rate of the second stage in comparison with the first.

4.2.5 Pretreatment Requirements

It is imperative that adequate consideration be given to the pretreatment needs of reverse osmosis systems.
The major pretreatment requirement for any RO device is the prevention of membrane "fouling". Fouling affects all types of membranes although the degree of severity may vary. All aspects of fouling involve the trapping of some type of material within the reverse osmosis itself or on the surface of the membrane. The well water to be used for this project, contains very low levels of colloidal matter or metal oxides and therefore fouling due to these causes can be ignored. Suspended solids will be trapped in a 10 micron cartridge filter prior to entering the RO unit, thus the only concern will be fouling due to membrane scaling. This is caused by the precipitation of some of the salts dissolved in the feed water. Since these salts are usually concentrated by a factor of two to four (50 to 75% conversion) in the reverse osmosis process, their solubility limits can be exceeded and thus precipitation can occur. The most common scales encountered in RO water treatment are $CaCO_3$ and/or $CaSO_4$.

Pretreatment for the prevention of the carbonate scale will be required with most natural feed waters if the RO system is to operate at any reasonable conversion level. Pretreatment for prevention of the sulfate scale is usually necessary only for feed water with TDS of 1500 ppm or above.

The pretreatment method to be adopted for this project, is the chemical conversion of $CaCO_3$ to $CaSO_4$ by the addition of sulphuric acid followed by the inhibition of sulphate scaling by the addition of hexametaphosphate.

With normal feed supply B-9 permeator will not suffer from biological fouling. B-9 permeators which are shut down for any extended period of time may be treated with a formaldehyde solution to prevent the growth of bacteria in the stagnant environment.

4.2.6 Product Water

The aromatic polyamide membrane used for B-9 permeators is very stable and in the absence of membrane fouling, salt passage may be expected to remain relatively constant.

In general, passage of mono-valent ions will be greater than passages of bivalent ions and bivalent ions greater than trivalent. The passage of bicarbonate ion $(HCO_3)^-$ is pH-dependent, and the effect is shown in fig.III-28, which may be used to estimate the passage of various ions.

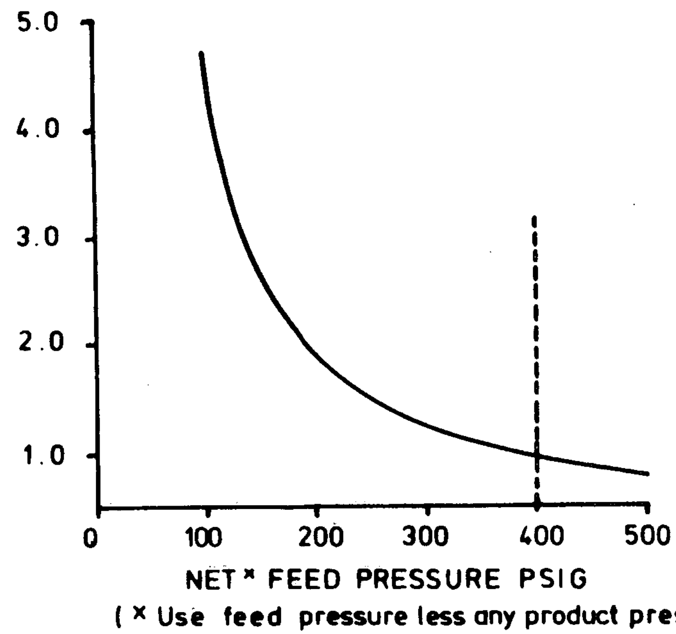
Fig. III-29 shows the salt passage as a function of feed pressure. A maximum feed pressure of 400 psig delivers minimum salt passage. A feed pressure of 406 psig is chosen to deliver a product water pressure of 6 psig.

Fig. III-28

APPROXIMATE ION PASSAGES AT 75% CONVERSION 400 PSI FEED PRESSURE AND ABOUT 1500 PPM TDS

Ion	Suggested Design Basis*	Probable Initial Passage**
Calcium Ca^{++}	4%	1.5%
Magnesium, Mg^{++}	4%	1.5%
Sodium, Na^{+}	10%	5%
Potassium, K^{+}	10%	5%
Phosphate, $PO_4^{\equiv}$	2%	1%
Sulfate, $SO_4^{=}$	4%	2%
Chloride, Cl^{-}	10%	5%
Nitrate, NO_3^{-}	15%	5%
Silica, SiO_2	15%	5-15%
Carbon Dioxide, CO_2	100%	100%

*Based on 10% salt passage under standard test conditions.
** Based on 5% salt passage under standard test conditions.



CORRECTION FACTOR FOR SALT PASSAGE AS
A FUNCTION OF FEED PRESSURE *

(This correction chart applicable only for feed
concentrations up to about 2500ppm NaCL.)

Fig. III-29

4.2.7 Greenhouse cooling requirements

The greenhouse is cooled by evaporative cooling. Hot, dry ambient air passes through cooling pads over which water is sprayed by means of pumps. As a result of passage through a water curtain the air reaches the wet bulb temperature of the water by evaporation of part of that water.

In the table below, the average daily evaporation in the cooling pads is listed for each month.

Month	Cooling Pad Evaporation m^3/day	Monthly precentate of time the cooling pumps will be running
Jan	0	0
Feb	43	10
March	137	30
April	254	55
May	371	82
June	430	95
July	450	100
Aug	446	100
Sept	383	85
Oct	259	57
Nov	122	26
Dec	0	0
Avg. (Annual)	241	53.3

The cooling water requirements will be supplied from the well. For cooling water circulation through the pads, a 20 kW pump will be installed that will only run if cooling is needed. The monthly percentage of time these pumps are running is also listed in the above table.

4.2.8 RO Feedwater requirement

Because the climate in the greenhouse is completely controlled, the water need of the greenhouse will be independent of the time of the year i.e. outside climate. This leads to an unchanging product water need from the reverse osmosis system of 207 m^3/day and also to an unchanging feedwater need of 318 m^3/day in case of 65% conversion.
The RO reject flow sent to the solar pond for evaporation make-up, will also not change and will equal 111 m^3/day.

4.2.9 Solar pond evaporation requirements

To calculate evaporation make-up of the solar pond the evaporation data of fig. III-30 are used. Evaporation data are very difficult to obtain and the local situation has an important influence on real evaporation.
Main items of influence are:

1) Wind direction and speed
2) Depth of the pond i.e. surface temperature
3) Presence of a salt gradient
4) Top layer fouling
5) Dimensions of the pond, also referring to waves in case of high winds.

For fig. III-30 the Derab pan evaporation figures are used to calculate monthly variations, but the absolute level is lower by 25%, based on literature data.

The solar pond will have lower evaporation than normal pan evaporation due to the salinity and lower surface temperature. Real data will probably result in lower well water requirement than that indicated in Figure III-31.

Figure III-30 Pond evaporation for 60000 m^2 Solar pond and 6000 m^2 evaporation pond

Month	Evaporation mm/day	Solar pond m^3/day	Evaporation pond m^3/day	Total Evaporation m^3/day
Jan	3.3	198	20	218
Feb	4.9	294	29	323
March	6.4	384	38	422
April	8.8	528	53	581
May	11.1	666	67	733
June	13.0	780	78	858
July	16.1	966	97	1063
Aug	12.7	762	76	838
Sept	8.0	480	48	528
Oct	6.1	366	37	403
Nov	4.1	246	25	271
Dec	3.2	192	19	211
Average	8.2	492	50	542

Figure III-31 Well water requirements for, RO, cooling pad and solar pond.

Month	RO Product m^3/day	Cooling Pad Evaporation m^3/day	Pond Evaporation m^3/day	Well Water Supply m^3/day
Jan	207	0	218	425
Feb	207	43	323	573
March	207	137	422	766
April	207	254	581	1042
May	207	371	733	1311
June	207	430	858	1495
July	207	450	1063	1720
Aug	207	446	838	1490
Sept	207	383	528	1118
Oct	207	259	403	869
Nov	207	122	271	600
Dec	207	0	211	418
Avg. (Annual)	207	241	542	990

4.3 UNIT 300, ORGANIC RANKINE CYCLE (ORC)

4.3.1 Introduction

The essential function of the Organic Rankine Cycle as defined in this Section is to convert the energy, accumulated in the Solar Pond, into the energy demand of the key-sub-system, (the CEA-Sub-system) in the most effective way. This is achieved by applying the heat pump principle whereby an organic fluid is pumped and heated in the liquid state to the vaporization temperature, vaporized at constant pressure and temperature, expanded isentropically to condenser pressure, and condensed at essentially constant pressure. About 90% of the theoretical enthalpy drop on isentropic expansion is recovered as "work" in the expander. Coupled with mechanical losses in the expander, gear reducer, and generator, the net overall efficiency is about 75 to 85 percent of the theoretical enthalpy drop.

4.3.2 Sub-System Description - Basic Flow Scheme

In the description of the Organic Rankine Cycle, reference is made to the Basic Flow Scheme, Fig. III-32, which is added to this section. The main equipment item of the Organic Rankine Cycle is the expansion (T) machine, in which the organic cycle fluid is expanded from a high to a low pressure. During this expansion, mechanical energy is released which drives an electrical generator (G) directly coupled to the expander machine. The expanded cycle fluid is condensed in a combination of condensers (E-2, E-3, E-4) designed for optimum conditions in the following way:

4.3.2.1 Base condenser is E-4, a finned tube type condenser utilizing the single largest heat reject source available, this being air. As the detailed Process Flow Diagram of the CEA-Sub-system shows, the condenser is located in the exhaust airstream of the ventilators supplying either inside air from the CEA-system, or outside air, or a mixture of both to the condenser. To a certain extent the resulting condensing capacity is set by the operational modes of the CEA-Sub-system.

4.3.2.2 A shell and tube condenser E-3 is located downstream of E-4, condensing cycle fluid against raw water from the raw water storage in the CEA-Sub-system, which is partly used for make-up of the solar pond. During the major part of the year, this water is of lower temperature than the outside air or the air inside the CEA-Sub-system because it is obtained from the well and it is therefore ideal for downstream trim cooling in order to achieve the lowest possible condensation temperature.

4.3.2.3 A shell and tube condenser E-2, is installed in parallel with E-4, utilising the preheated raw water from E-3, which contributes to the overall system efficiency by partially replacing The condensing capacity of E-4, when certain ventilators will only be running to satisfy the condensing duty of the cycle fluid and by returning heat to the solar pond, which otherwise would have been rejected to air.

The condensed cycle fluid is collected in a storage vessel V, which serves also as the pump head-tank.

The liquefied cycle fluid is pumped from the storage vessel V, to the evaporator E-1, by a motor-driven pump P.

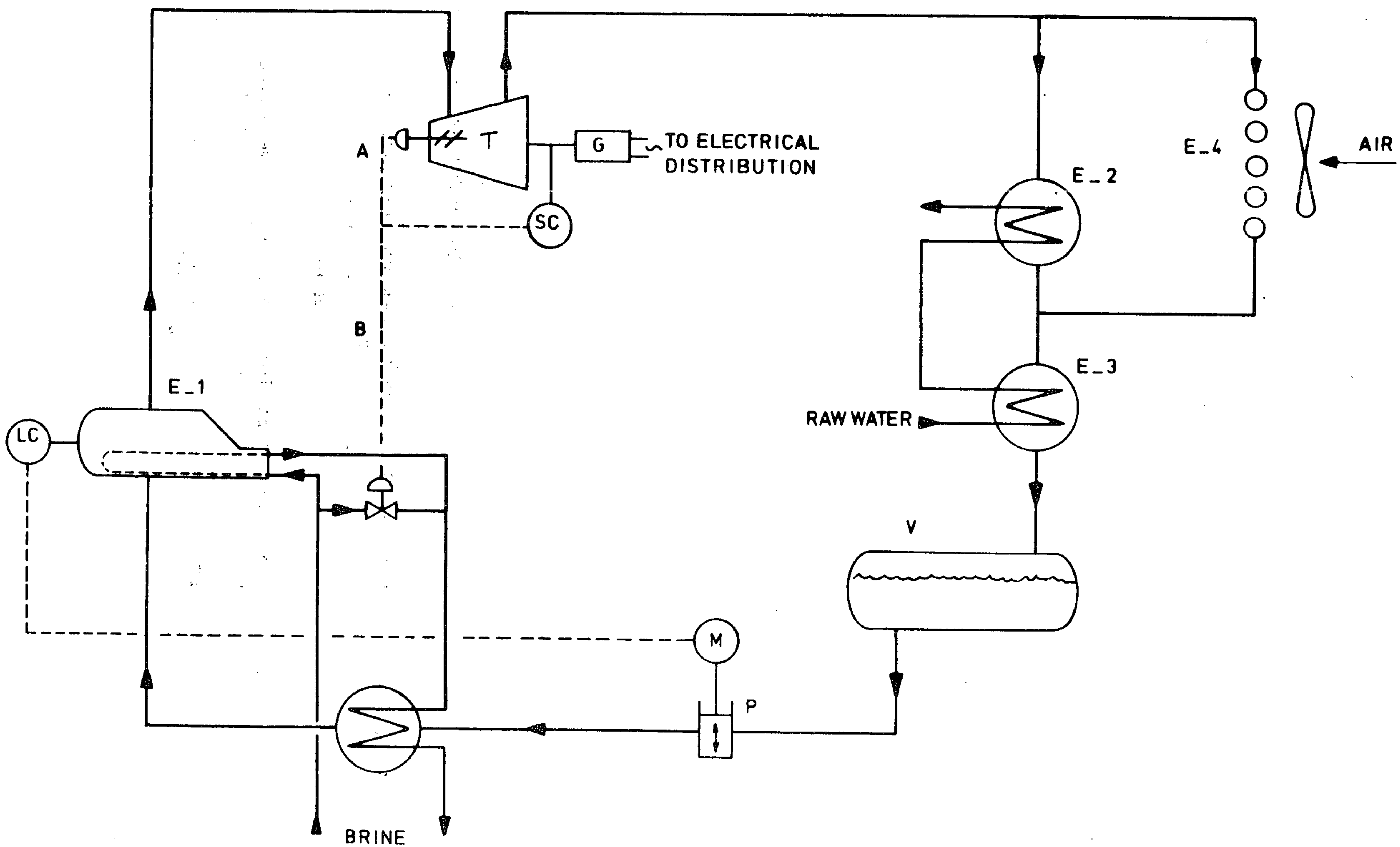
Given the flow, the fluid and the differential pressure to be handled by the pump, a positive displacement pump (diaphragm type) is selected to optimise on efficiency. The pump will be provided with stroke adjustment for capacity change.

The cycle fluid is first preheated and then evaporated in a kettle type shell and tube exchanger E-1 driven by the hot brine stream from the solar pond.

The saturated vapour of cycle fluid from the evaporator E-1, is fed to an expansion machine T, where mechanical energy is released to drive the generator G. The selected type of the expansion machine is of the rotary type to optimise on onergy recovery.

The base control applied in the Organic Rankine Cycle is a speed control on the expander-generator combination which adjusts the inlet vanes of the expander. To optimise the cycle, as well as minimize on energy requirement of the solar pond, a reduction of the heat input into the evaporator E-1 is provided by throttling a bypass valve around the evaporator which is master controlled by the expander speed controller. The level of the cycle fluid in the evaporator E-1 is controlled by adjusting the capacity of the cycle fluid circulation pump P.

Fig. III-32 **BASIC FLOW SCHEME O.R.C.**



4.3.3 Cycle Fluid Selection

The choice of the fluid in the Rankine Cycle is of utmost importance to the attainable efficiency of the power generation system. Prime parameters influencing the choice of the fluid are:

- available high temperature level source for fluid vaporization. In this system, there is only one source available and that is the lower convective zone of the solar pond.

- available low temperature level source for fluid condensation. Here, the best available source with respect to minimum overall water-consumption is the exhaust air from the greenhouse during the summer, and the outside air during the winter, as well as nighttime during certain transition periods.

The selected design conditions are:

- Summer:

  T vap. = 89-5 = 84^{o}C, taking into account
  Δt = 5^{o}C for brine/fluid exchange

  T cond. = 29+5 = 34^{o}C, taking into account
  Δt = 5 C^{o}for greenhouse air/fluid exchange

- Winter:

  T vap = 68-5 =^{o}63 C, taking into account
  Δt = 5^{o}C for brine/fluid exchange

  T cond. = 20+5 = 25^{o}C, taking into account
  Δt = 5^{o}C for ambient air/fluid exchange

Taking into consideration the above temperatures, the selected fluid must be able to satisfy the following parameters:

- To reach saturation vapor pressure at the lowest of the high temperature levels available.

- To reach saturation liquid phase at the highest of the low temperature levels available.

- Saturation vapor pressure to be above atmospheric at all condensing conditions. Vacuum, will create design and operating problems.

- High ratio of external work over total heat absorbed, i.e. minimum latent heat.

- Critical point to be sufficiently removed from operating conditions.

- Produce the same pressure ratio during the summer as well as the winter, in order to optimize on expander efficiency.

- Low viscosity, in order to minimize system pressure drop.

- Maximum heat transfer properties in order to minimize heat exchange equipment cost.

An evaluation of several candidate fluids against the above parameters has led to the conclusion that flourohydrocarbon fluids commonly known as freons are the most suitable, amongst which freons R-11, 113 and 114 are the best with R-114 being the most suitable fluid, fulfilling all of the above conditions.

4.3.4 Capacity Determination

The function of the Organic Rankine Cycle is to provide the total system with the required amount of electrical energy. The required capacity of the sub-system is in this way fixed by this requirement, utilizing the avialable optimum heat input and reject sources.

It should be noted that at this stage of the project (Task III) the base-line concept for the total system is fixed, but no complete detailed engineering has as yet been performed.

Hence, the underlying information for electrical energy requirement is preliminary and can be modified during the detailed design work to be performed in the following Report. However, no major deviations are envisaged, which would invalidate selections laid down in this Report.

4.3.5 Electrical Consumption

As indicated above, the capacity of the sub-system is determined by the total electrical energy demand of the total integrated system, inclusive of the parasitic power consumption of the sub-system itself. For this purpose, a preliminary electrical power list is prepared (See Fig. III-33). As can be seen from the balance, the following figures apply:

- Maximum hourly load : 240 kW
- Average daily load : 183 kW

4.3.6 Maximum Electrical Power Generation and Battery Storage

In order to allow for minor changes in the electrical power consumption, the sub-system will be designed for 200 kW output. (i.e. two parallel sets of 100 kW each).

With a minimum battery storage requirement to safeguard instrumentation, control and datalogging, it is calculated that additional installation of batteries to balance the electrical power requirement during the day (24 hours basis), will reduce the maximum sub-system capacity and prevent short-term load fluctuations on the solar pond.

Based on a design output of 200 kW and maximum hourly load of 240 kW, the theoretical battery-capacity for a peak demand of 8 hours per day = 8 x (240 - 200) = 320 kW. Based on the application of 12 V - 60 Amp.hr batteries, the required number of batteries are:

$$n = \frac{320 \times 103}{12 \times 60} = 444 \text{ batteries}$$

With an added safety margin, a storage of 500 batteries is to be provided, representing:

$$500 \times 12 \times 60 \times 10^{-3} = \underline{360 \text{ kW.hr.}}$$

This indicates that in the event of one or both ORC power generation sets failing, a battery power back-up of $\frac{360}{183} \times 2 = 4$ hrs will be available.

4.3.7 Minimum Electrical Power Generation

The minimum electrical power requirement will occur during the "winter" period when the cooling ventilators will be stopped as well as the cooling water circulation.

The anticipated minimum power requirements under these conditions are approx. 100 kW. Hence, the sub-system is designed for a turn down ratio of 50%.

4.3.8 Maximum Freon Circulation Capacity (Summer Condition)

In order to perform the detail engineering for the sub-system, the following basic-calculations are performed:

Brine draw temperature = 89°C = 192°F
Brine-Freon approach = 5°C = 9°F

Freon at inlet of the expander:

- temperature = 89 - 5 = 84°C = 183°F
- pressure: for saturated vapor at outlet of the evaporator
  p = 146.2 psia = 10.3 kg/cm²a.
  p vaporizer - expander = 1.5 psi
  hence pressure at expander inlet = 144.7 psia = 10.2 kg/cm²a.
- enthalpy : H = 96.2 BTU/LB = 53.4 kcal/kg

Condensing air temperature = 29°C = 84°F
Air-Freon approach = 5°C = 9°F

Freon at outlet of the expander:

- temperature = 29 + 5 = 34°C = 93°F
- pressure: for saturated liquid at outlet of the condenser-receiver
  p = 40.85 plia = 2.9 kg/cm²a.
  p expander outlet-condenser receiver = 4 psi
  hence expander outlet pressure = 44.85 psia = 3.2 kg/cm²a.

On the assumption of isentropic expansion in the expander, the enthalpy at outlet of the expander = 88.9 BTU/LB = 49.4 kcal/kg
H isentropic = 96.2 - 88.9 = 7.3 BTU/LB = 4.1 kcal/kg
Required power production = 200 kW
Expander efficiency at 100% load = 85%
Electrical generator efficiency = 98%
Amount of freon circulated =

$$\frac{200 \times 3{,}413}{0.85 \times 0.98 \times 7.3} = 112{,}253 \text{ Lbs/hr} = \underline{50{,}920 \text{ kg/hr}}$$

Fig. III-33

ELECTRICAL CONSUMPTION (kW)

DESCRIPTION	HOURLY MAX.	DAILY AVERAGE
Nutrient Circulation	14	7
Cooling Water	12	11
Well Water	22	13
Acid Dosing	0.5	0.5
SHP Dosing	0.5	0.5
RO Feed	13	11
Freon Circulation	27	20
Brine Circulation	18	18
Brine Leak	2	-
Solar Pond Maint.	5	1
Cooling Fans	110	90
Lighting	10	5
Instrumentation	6	6
Total	240	183

4.3.9 Equipment Selection

The following main equipment items to be incorporated in the sub-system are considered:

- The expansion machine
- The power generator
- The fluid evaporator
- The fluid condenser
- The fluid circulation pump
- The fluid storage vessel

4.3.9.1 Expansion Machines

The expansion machine is the heart of the sub-system and as such, requires full attention to evaluate its optimum selection. The prime parameters to be set for the selection are:

- Efficiency
- Reliability
- Flexibility

Taking the above parameters into account, the first selection to be made is rotary versus positive displacement. In view of the fact that efficiencies of positive displacement machines are lower than rotary, the choice will be the latter.

In the rotary machines, choice can be made between turbine and screw type. With efficiency and flexibility as prime considerations a turbine-type machine is selected.

The potential suppliers of a turbine-expansion machine, in the required operational range and with experience are rather limited.

Potential suppliers considered were:
- Atlas Copco
- Rotoflow Corporation
- MTI
- Sofretes
- Mycom
- LInde

Further investigation into the potential supply market has led to the (preliminary) selection of Rotoflow Corporation, as the optimum choice.

4.3.9.2 Power Generator

The power genertor, coupled to the expansion-turbine, will be selected on the basis of:

- high efficiency at the whole range of loadfactors.
- reliability.

Since sufficient potential suppliers are available for this type of equipment, final selection will be made in detailed engineering phase.
For further details reference is made to the section 4.5, dealing with electrical sub-system.

4.3.9.3 Fluid Evaporator

A variety of evaporator-types exist. However, the most suitable type for this application is a kettle-type shell and tube heat exchanger. Due consideration must be given to the selection of materials of construction because of the corrosivity of the hot-brine stream.

4.3.9.4 Fluid Condenser

The selection for the equipment to be used in the condensation of the Rankine Cycle Fluid can be split into two parts:

- Part one, using the greenhouse ventilation air for condensation, will be a series of finned-tube heat exchangers which will be located in the unit 100.

- Part two, uses the solar pond make-up water stream which is taken from the cooling water storage. The condensers used in this section will be either shell-tube types or finned-tube double-pipe.

4.3.9.5 Fluid Circulating Pump

Of the various types of pumps examined for this service, the best is a diaphragm-type positive displacement pump. These pumps show the highest efficiency, require lower NPSH, are reliable and economical in service. Capacity adjustment can be achieved by the change in stroke length thus avoiding wastage of energy in a control valve.

4.3.9.6 Fluid Storage Vessel

For the fluid storage, a horizontal vessel is selected. This is due to the fact that the condensed fluid must return by gravity, thus limiting the elevation at which the vessel can be located with rspect to the fluid return line and the NPSH requirement of the pump.

4.4 UNIT 400, SOLAR POND

4.4.1 Introduction

This sub-section presents the analysis, design, construction, operation and maintenance details for the solar pond sub-system for a commercial 5ha, CEA installation.

For the optimum application of Solar Technology, it is important to consider the following factors:

- Application
- Climatic conditions
- Site conditions
- Cost

In certain areas, e.g. Saudi Arabia, Solar Ponds fulfill all of the factors set above.

The application of Solar Ponds include CEA facilities, water desalination for urban useage, water desalination for drip irrigation systems for agricultural production and sand stabilization, and others.

Climatic conditions are excellent in Saudi Arabia, with its high radiation regimes and minimum cloud cover.

Site conditions and costs are both very favorable. Large land areas, called Sabkhas, are available often with consierable salt on site. These salt flats are contoured to the desired shape, have water readily available, are often close to urban areas (labor and market) and are currently unutilized.

Converting a sabkha into a Solar Pond requires detailed studies regarding site thermal and hydrologic characteristics.

4.4.2 Description of solar pond

The solar pond is a device for trapping and storing the solar thermal energy. The temperature-gradient in a solar pond is achieved by means of a salt-concentration gradient, increasing from low salinity near the pond surface to high salinity a meter or two below the surface. Hence, deeper waters are heavier than the water above them. Thermal buoyancy convection is suppressed, impeding that upward movement of warmed water that is the principal mechanism of heat loss in an ordinary pond.

In practice, the salt-gradient solar pond has three layers or zones (Fig.III-34):

- the upper convective zone (UCZ), a thin layer of low salinity water;
- the non-convecting or salinity gradient zone (NCZ), in which salt concentration increases with depth, and
- the lower convective zone (LCZ), an area of uniformly high salt concentration that is used for heat storage.

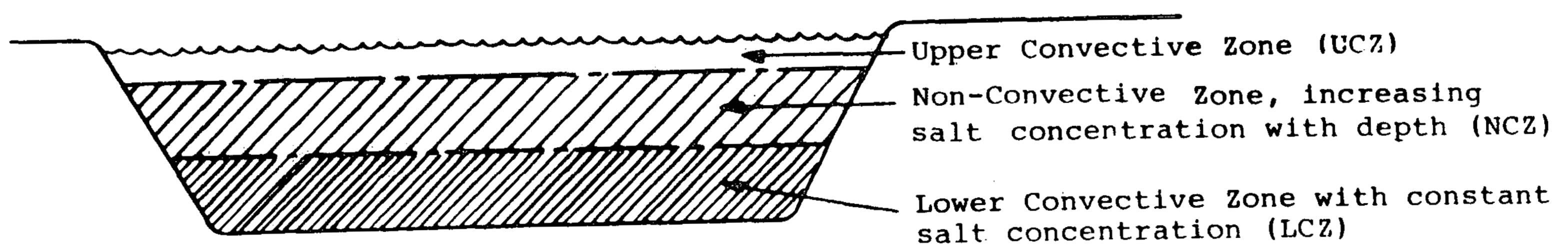


Figure III-34
SCHEMATIC OF SALT-GRADIENT SOLAR POND

In operating salt-gradient solar ponds in the United States, and elsewhere, temperatures as high as the boiling point of saline water have been achieved in the storage zone.

4.4.3 Solar Pond Design Requirements

Interface Requirements of the Solar Pond are:

- Climate
- Insolation
- Water supply (unit 100, 200 and the well)
- Organic Rankine Cycle (unit 300)
- Evaporation Ponds

The climate and insolation characteristics of the site are defined in the task II report of this project. The primary data of interest for the purposes of analysis of the solar pond are:

- Average Ambient Temperature	25.6 °C
- Average Insolation	230 w/m^2
- Minimum Average Monthly Temperature	13.5°C (January)
- Minimum Average Monthly Insolation	16 w/m^2 (Dec.)

Evaporation rate of the solar pond is conservatively assumed to be 3.0 m^3/m^2,yr. The Task II report documents the pan evaporation at the site as being 4.1 m^3/m^2,yr. Based on the practice reported by ORMA* and Kalecsinky**, here a conservative (high) pan to pond transfer coerricient of 75% is assumed in order to obtain the assumed evaporation rate.

* ORMAT TURBINES Ltd., A study of the feasibility of a solar salt Pond Generating Facility in the State of California, U.S.A. P. 9-7.

** A.V. Kalecsinky - "Ungarische Warme und Heisse Kochsalzeen" Ann D. Physik (4) 7 P; 408-416, 1902.

Based on mass and salt balances for the CEA and RO system, the solar pond receives the following streams:

unit 100	433	m^3/day, water
	434	Kg/yr, salt
unit 200	108	m^3/day, water
	202	MT/yr, salt

The solar pond system in turn furnishes to the organic rankine cycle (unit 300) brine at the following conditions:

- Average flowrate: 631 m^3/hr.
- Average hot brine temperature: 77°C.
- Min. acceptable hot brine temperature: 68°C.
- Average thermal load supplied by the solar pond: 2324 kWth.
- Maximum thermal load supplied by the solar pond: 2962 kWth.

The solar pond also produces a brine overflow of 51 m^3/day to the evaporation pond which in turn produces 636 MT/yr of salt from this brine. This salt is available for make-up to the solar pond, if needed.

4.4.4 Design Criteria

The solar pond system must satisfy the following design criteria:

- Supply electrical and thermal energy at minimum cost.

- Exercise minimum impact on the environment.

- Meet the interface requirements specified above.

4.4.5 Analysis and sizing of Solar Pond

Considerable pond simulation work for the Engineering Field Test (EFT) system has been carried out. This work employed the RI/UPM proprietary model with input from the SESEA team and it has culminated in three reports being submitted for each stage of the work.

Stage 1, gave SESEA s strong feel for the model and explored the effect of subsoil conductivity, pond depth, load sharing and load variation.
Stage 2, focused on identifying preferred LCZ depths.
Stage 3, incorporated a revised heat withdrawal histogram and, with the inclusion of previously gained results, iterated on pond size. Additional work has investigated pond energy depletion with time and with no solar input.

Some of the points derived from this work are:

- Subsoil conductivity significantly affects the temperatures obtained.
- A depth of 1.9 m. for LCZ is sufficient to meet the project requirements.
- A surface area of 60000 sq.m. is necessary for the commerical size pond.
- The solar pond becomes inoperative in 31 days (T = 65°C) under summer conditions with no solar input.

SESEA intends to present a complete discussion of the simulation work in a future report to SERI. A brief summary of the results are given below.

The model inputs for the pond cases studied, are listed in Figures III-35 and III-36 for the thermal load profile representative of the Engineering Field test system. The results of this study may be used for scale-up of the commerical size pond.

In order to satisfactorily match the computer model output data to the monthly variations in heat load, the time step of the model was changed from 20 days to 15.25 days. It is immediately apparent from Figure III-37 that the revised load profile is more compatible with the yearly variations of solar input to the pond; i.e. lower loads in winter, higher loads in summer.
Three different pond areas were run (6000 m^2, 7000 m^2, 8000 m^2) and the results are shown in Figure III-38. The impact of having the load in harmony with the solar input is illustrated in Figure III-38.

In all three cases, the amplitude of the yearly fluctuations in storage zone average temperature is decreased when compared to the stage 1 and 2 report results. The preferred pond area was specified as having a maximum quasi-steady state temperature of approximately 90°C. This condition is best met by the 7000m^2 pond. The 6000m^2 pond cannot meet the required temperature value under the specified conditions whereas the 8000m^2 pond overshoots the temperature and is continuing to increase in average yearly temperature after four years. It must be emphasized that an operating pond will deviate from the results obtained with the mathematical model and consequently it is necessary to be conservative in sizing the actual pond area.

To further aid the design process, the results of calculations of the efficiency and the yearly average quasi- steady state* temperature are presented in Figure III-39. In cases where quasi-steady-state was not achieved, the results were calculated on the basis of the last year of the run for the particular pond configuration and conditions. The yearly efficiency was defined as the ratio of yearly average heat removal to yearly average solar input. The average temperature was calculated as the mean of the maximum and minimum temperatures for the final year of a given run.

*Quasi-steady-state refers to the situation where the pond temperature cycle repeats itself over a year with the same maximum and minimum temperatures.

Figure III-39 efficiency values reflect the fact that, since the radiation input per unit area is the same for all cases, the efficiency is simply a function of the heat load per unit area once quasi-steady-state conditions are approached. The temperatures obtained, vary depending on the pond configuration. Figure III-40 shows that the <u>relative</u> improvement (increase) in the average storage zone temperature decreases as one goes to deeper, and therefore more costly, ponds. This is apparently a case of diminishing returns.

In conjunction with the above EFT simulation study a series of calculations for the commercial unit were made using the technique developed by Edesess et.al*. The results of the calculations using this programme are shown in Figure III-41.

Using the values given in Figure III-41 a series of runs were made for various thermal loads to investigate the effect of load variations on pond size. Figure III-42 presents the results of this effort.

Based on these results and the desire for a safety factor at this preliminary design phase, a total pond size of 60000 m^2 was selected.

The next point investigated was the effect of pond depth on performance, for the selected pond area. Figure III-43 presents the assumptions used in the SERI technique for this investigation.

As expected, a 60000 m^2 pond results in a reasonable depth requirement to meet the maximum load while maintaining a 68°C minimum allowable LCZ temperature. For maximum flexibility and allowing for a safety factor SESEA has selected a LCZ depth of 1.9 m. It is anticipated that these values will be refined, based on results from the EFT system.

This depth will ensure that the solar pond power system will be capable of meeting the thermal load requirements of the project, even if the turbine-generator system should fail to be as efficient as anticipated. This depth will also allow the pond to perform satisfactorily for 20% variation in insolation.

Aside from the depth and area specifications for the solar pond, there are three major design considerations:

- Liner selection
- Pond configuration
- Salinity control

Figure III-35

Salt	Sodium Cloride
Pond Bottom absorptivity factor	0.5
Pond top surface transmissivity factor	0.9
Initial temperature of pond and earth	25°C
Start up time for pond	January 1
Start of heat removal	Average LCZ temperature, 85°C
Location of heat removal	10 cm from bottom
Pond surface boundary temperature	Ambient wet bulb temperature
Concentration profile*	UCZ: Uniform at 2%
	NCZ: Linear from 2% to 20%
	LCZ: Uniform at 20%
Depths (UCZ/NCZ/LCZ)	0.25m/1.25m/1.5m
Thermal load	See figure III-36
Surrounding earth	Dry sand
Areas	$6000m^2/7000m^2/8000m^2$

* UCZ = Upper Convecting Zone, NCZ = Non convecting Zone, LCZ = Lower convecting Zone.

Figure III-36

Thermal Load Profile

Month	Load (KWth)
January	190.1
February	228.1
March	266.2
April	304.2
May	342.2
June	380.2
July	380.2
August	342.2
September	304.2
October	266.2
November	228.1
December	190.1

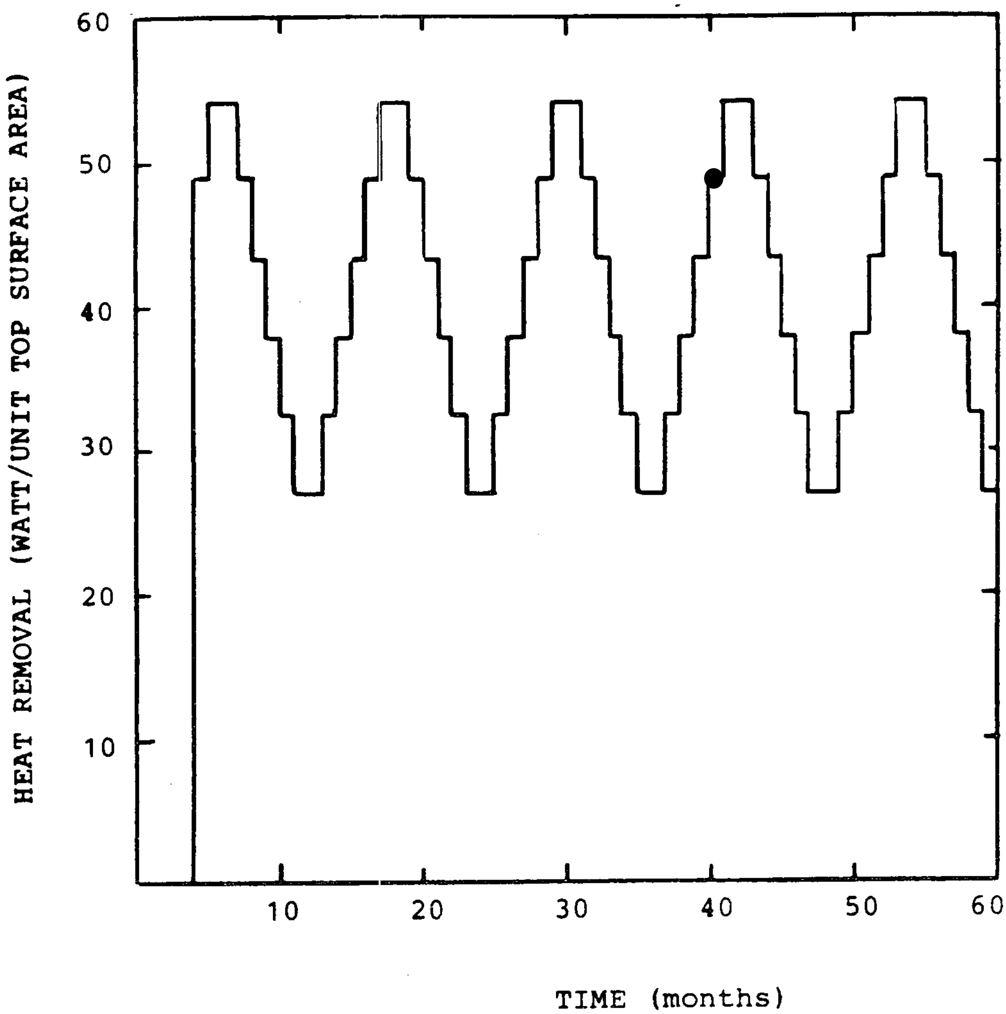


Fig. III-37 VARIATION OF HEAT REMOVAL PER UNIT TOP SURFACE AREA WITH TIME FOR THE POND WITH TOP SURFACE AREA OF 7000m².

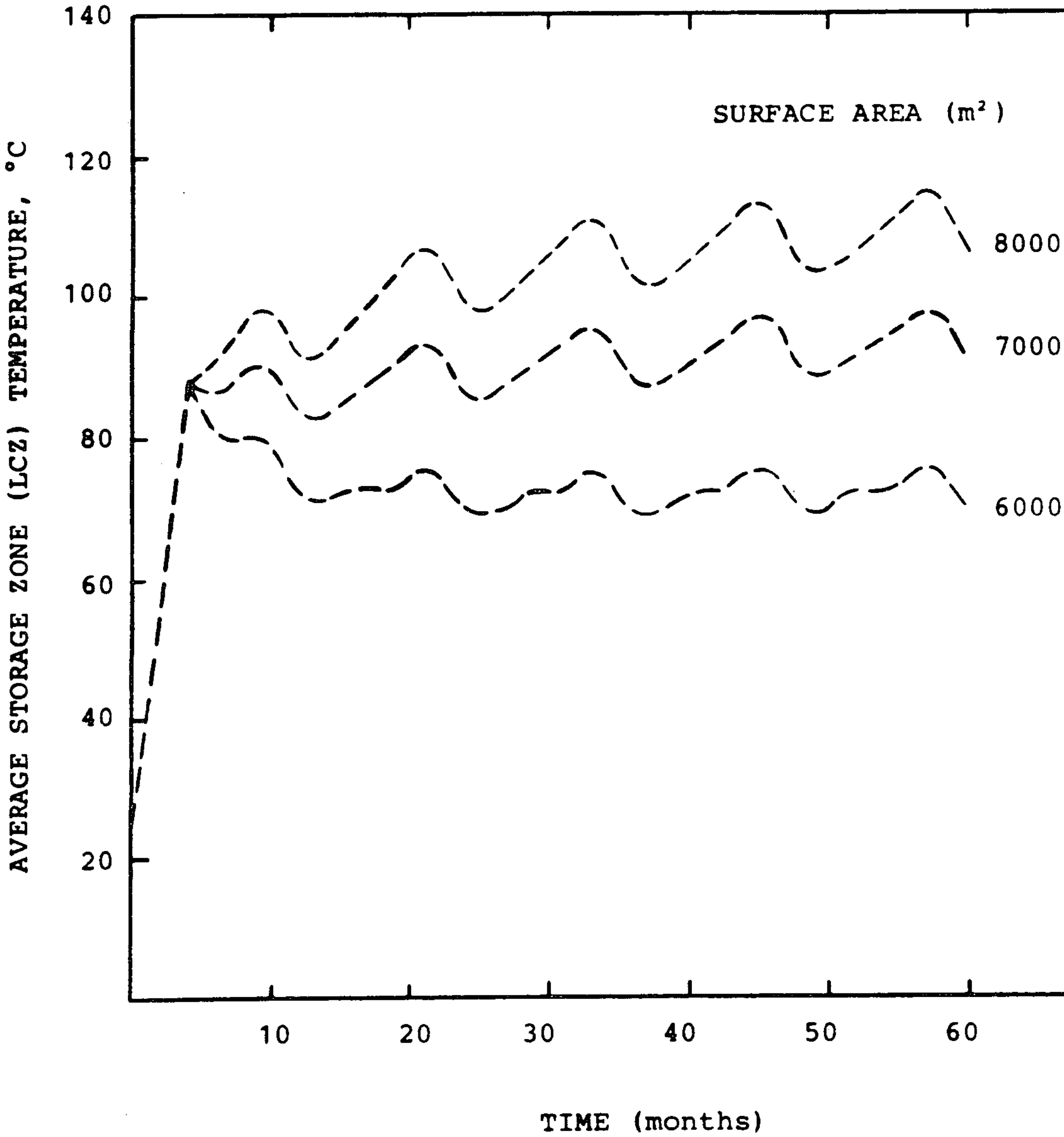


Fig. III-38 AVERAGE STORAGE ZONE (LCZ) TEMPERATURE RESPONSE WITH TIME FOR PONDS WITH DIFFERENT TOP SURFACE AREAS.

Figure III-39

Efficiency and Average LCZ Temperature
as calculated from Stage 1 and Stage 2 Results.
(Quasi-steady state cases)

Stage 1 Cases.

Pond Code	Efficiency (%)	LCZ average temp. (°C)
A	19.5	89.2
B	19.5	63.0
C	19.5	87.6
D	19.5	70.8
E	17.1	105.6
F	17.1	83.2

Stage 2 Cases.

Pond Code	Storage Zone depth (m)	Efficiency (%)	LCZ average temp. (°C)
A	1.0	17.1	101.0
B	1.5	17.1	104.8
C	2.0	17.1	107.5
D	2.5	17.1	109.1
E	3.0	17.1	110.1

Figure III-40 is a plot of the temperatures from Figure III-39 (Stage 2) as a function of the storage depth of the pond (the LCZ thickness).

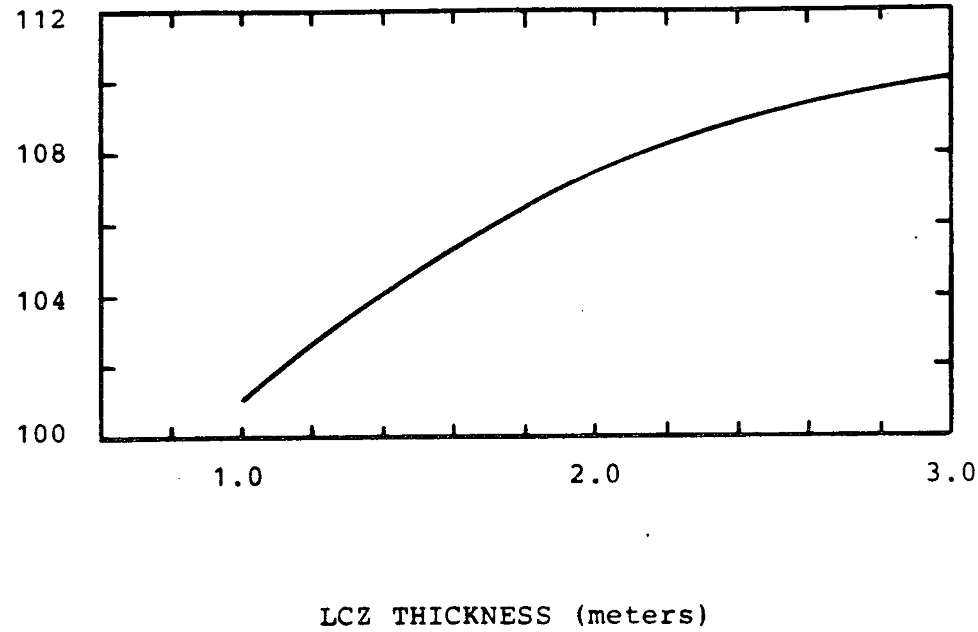


Fig. III.40 DEPENDENCE OF LCZ QUASI STEADY STATE AVERAGE TEMPERATURE ON STORAGE ZONE DEPTH; TASK 2 PONDS.

Figure III-41

Parameters for simplified Pond Model Area Calculations

Desired annual average LCZ temperature	77°C
Annual Average Ambient temperature	25.6°C
Annual Average Insulation	230 w/m^2
Average Thermal load to be supplied	varied
Latitude of pond	25^o
Average "Tau" "Alpha" (for UCZ+LCZ=1.5m)	0.31
Surface loss coefficient	4 w/m^2°C
Edge loss coefficient	2.5 w/m^2°C
Bottom loss coefficient	0.1w/m^2°C
Reflection loss coefficient	0.98

*Edesess, M., Henderson J., Jayadev, T.S., "A Simple Design Tool for Sizing Solar Ponds" SERI/RR-351-347, December 1979.

Figure III-42

Pond area vs Average Thermal load
(Electrical output = 183.5 KW_e all cases)

Overall Rankine Cycle Efficiency (%)	Average Thermal load (electr.equiv. + 60) (KW_t)	Pond area (m^2)
7	2681	63285
8*	2354	55725
9	2099	49818
10	1894	45065

* design point

Figure III-43

Parameters for Simplified Pond Modal Depth Calculations.

Minimum Monthly Average Ambient	13.5°C (Jannuary)
Minimum Monthly Average Insolation	161w/m^2 (December)
Maximum load	varied
Month of maximum load	7 (July)
Minimum Tau Alpha	0.3
Minimum reflectance coefficient	0.96
Minimum acceptable LCZ temperature	68°C

Using the values in Figure III-43 the pond depth was calculated assuming:

- Pond area = 60000 m^2
- Average Thermal Load = 2099 Kw_t
- Rankine cycle efficiency = 8%

The resulting LCZ thickness for a 68°C minimum LCZ temperature was 1.9 m resulting in a total pond depth of 3.4 m.

4.4.6 Liner and Configuration Selection

Several pond liner concepts and configurations have been identified as being suitable for this application. They are listed and characterized in Figure III-44.

An evaluation of each of the liners for the pond configurations of interest with regard to capital cost, leakage probability, reliability, cost of installation and life expectancy, indicated that the thick plastic liner yielded the minimum LCC for this component.

Based on this finding, a survey of pond liner manufacturers was made to identify a suitable solar pond liner material. Figure III-45 a, b summarize the results of this effort.

Fig. III-44 Pond Configuration and Liner Selection

POND DESIGN PARAMETER	OPTIONS	COMMENTS
LINE TYPE	1) CONCRETE	. NOT INERT TO CHEMICAL
	2) CONCRETE & LINER	. SATISFIES REQUIREMENT BUT LINER MUST BE REPLACED AFTER CLEANING - MAY BE DIFFICULT TO PREVENT LEAKS
	3) ASPHALT	. SATISFIES REQUIREMENTS BUT SEAMS PRESENT LEAKAGE PROBLEM
	4) THIN PLASTIC	. CANNOT BE CLEANED MECHANICALLY - LEAKAGE PROBLEM PROHIBITIVE
	5) THICK PLASTIC	. SATISFIES REQUIREMENTS
	6) CLAY	. PERCOLATION PROHIBITIVE, DOES NOT SATISFY REQUIREMENTS
	7) DIRT	. DOES NOT SATISFY REQUIREMENTS - PERCOLATES
POND CONFIGURATION	1) PARTITIONAL COMBINED EVAPORATION AND SETTLING	. SATISFIES 20 YR LIFE CONSTRAINT . PRECIPITATE BUILDING AT INLET REDUCES UTILITY . PRODUCTION INTERRUPTED OR PONDS NEED TO BE OVERSIZED
	2) SEPARATE INLET SETTLING AREA WITH LARGE EVAPORATION AREA	. SATISFIES 20 YR LIFE CONSTRAINT . CONTINUOUS OPERATION WITHOUT OVERSIZING . EVAPORATION AREA WOULD NOT HAVE MUCH STRENGTH CONSTRAINT WHICH WOULD ALLOW LESS EXPENSIVE LINING
NUMBER OF POND SEGMENTS	1) SOLAR - 2 OR 4 2) EVAP - 1	. TRADEOFF EXISTS BETWEEN DOWN TIME AND CLEANING COSTS AND CAPITAL COST

MANUFACTURER	PRODUCT	COMPOSITION	COST ($\$/m^2$)
BURKE INDUSTRIES	HYPALON -- 36 MILS (INDUSTRIAL GRADE)	SYNTHETIC THERMO-PLASTIC RUBBER	6.46
CARLISLE TIRE & RUBBER	EPDM, NYLON REINFORCED 60 MILS	EPDM	10.23
KENNECOTT CORPORATION	TEFLON	TEFLON	430 - 538
STAFF INDUSTRIES	XR-5, SPECIAL 30 MILS	OIL REISTANT PVC	8.07
WATERSAVER COMPANY	PVC -- 20 MILS	PVC	2.15
	HYPALON -- 36 MILS	SYNTHETIC THERMO-PLASTIC RUBBER, REINFORCED WITH POLYESTER	5.38

INSTALLATION COSTS ARE ESTIMATED TO BE $ 2.70 ≈ 3.75/m²

- Figure III-45A Survey of Pond Liner Manufacturers -

MATERIAL	LIFE EXPECTANCY	INSTALLATION	PROBLEM AREAS	RANKING
PVC	20 YEARS EXPECTED	- PAINTED SEAMS OR FACTORY SEALED SEAMS	WICKING OF BRINE INTO REINFORCING FIBERS	3
		- MUST BE DRY & CLEAN FOR REPAIR	COLD CRACKING EARTH COVER (.3m)	
EPDM	15 YEARS WRITTEN	- CEMENT & GUM TAPE SEALING	FIELD SEAMS ARE DIFFICULT	2
	20 YEARS EXPECTED	MUST BE DRY FOR REPAIR	PATCHING AFTER BRINE EXPOSURE REQUIRES SKILL	
HYPALON	20 YEARS* WRITTEN	- NO FIELD SEAMING NECESSARY**	BLOCKING CAN OCCUR IF MISHANDLED	1
	40 YEARS* EXPECTED	- MUST BE DRY FOR REPAIR	COST	
TEFLON	-	-	COST PROHIBITIVE	4

* ONE COMPANY
** ONE COMPANY 2000 m² TO 6000 m², OTHER COMPANY WOULD SEAM

- Fig. III-45B Solar Pond Liner Ranking -

4.4.7 Salinity Control System Selection

Salt diffuses from the LCZ to the UCZ on a continuous basis, driven by the salinity difference between them. This migration must be countered if the pond is to remain operational. Tabor * identifies two basic methods of controlling the diffusion, they are:

- Falling Pond
  In this approach, water is extracted from the LCZ at a rate sufficient to overcome the upward diffusion rate of the salt. In effect, the salt stands still. This technique can be integrated into the energy extraction system. Low salinity water is added to the top of the pond to offset evaporation losses.

- Surface Flushing
  This approach uses fresh water to flush the UCZ clear of high salinity water. This also serves to clean the surface of the pond. This technique can be used to cool off condensing water via evaporation. Typical flushing rates are of the order of $2m^3/m^2yr$ of pond surface.**

The major design requirements for salinity control are:

. minimize salt and water consumption (blow down)
. maintain good thermal performance by maximizing NCZ
. maximum reliability consistent with cost
. control of extraneous salts contained in make up water.

Upon examining the two basic salinity control concepts the SESEA team has evolved an unified approach which combines both concepts in an optimum manner. Figure III-46 presents the basic feature of all three approaches.

*"Solar Ponds", Solar Engergy vol.27 no. 5, PP 181-194, 1981.
** A study of the Feasibility of a solar salt pond generating facility in the state of California, USA by ORMAT TURBINES Ltd see also SERI /TR-731-1202 June 1981.

The unified approach (curve C in Figure III-46) controls both the composition of the salt and the salinity gradients and concentrations within the various zones. For preliminary sizing purposes, SESEA has assumed a salt diffusion rate of $30kg/m^2yr$. This rate is based on an extensive review of the literature* which abounds with estimates ranging from $10kg/m^2yr$ to $45kg/m^2yr$. The molecular diffusion rate alone is approximatly $20kg/m^2yr$, being primarily dependant upon salt properties, brine temperatures, and salinity gradient. However, experience with operating solar ponds has shown that the net salt transport to the surface has consistently been higher than that attributable to molecular diffusion alone. Causes for the enhanced salt transport are not well understood at this time. The safest approach is to assume a net salt transport equivalent to 1.5 times the molecular diffusion rate leading to the value selected by SESEA. This value should suffice until more definitve data are available from the Engineering Field Test System.

The salt that has migrated to the surface must be replenished in the storage layer by addition of dry salt or near-saturated brine, as discussed below.

In brief, the salinity and gradient control problems can be posed as follows:

Control of the UCZ concentration is accomplished by washing the zone with make-up water while extracting relatively weak saline water at a rate such that the diffused salt is removed continuously. At the same time the intermediate non-convecting zone salt concentration gradient which provides stability to the non-convecting zone must be maintained. Generally a concentration gradient of at least 200 kg/m^3 is required for stability. Salt diffusion occurs across the concentration gradient in accordance with the diffusion equation where:

$$q = -k_s \, ds/dz$$

q = salt flux

k_s = diffusion coefficient

s = concentration

z = linear dimension of the gradient

Thus, a solar pond must be maintained in a dynamic state. Control of the LCZ concentration requires replenishing the salt in that zone at the same rate that it is removed from the UCZ. This may be accomplished by revovery of the salt from the wash solution and returning it to the LCZ. In as much as it is difficult to dissolve the added salt without stirring and stirring is undesirable in the solar pond, it is necessary to circulate the solution from LCZ to pick up the returned salt from the UCZ. This can be accomplished by mixing in an evaporation pond where the total water evaporated is determined by the net water added to the UCZ.

Apart from controlling the concentration of the preferred salt ($NaCl$ or $MgCl_2$) it is also necessary to control the concentration of extraneous (x) salt added to the system with the make up (wash) water. This (x) salt may be removed by taking a stream from the evaporation pond containing the same quantity of (x) as does the make up stream and evaporating or otherwise disposing of it as by-product of the system (figure III-47). It must be noted that NaCl and (x) are removed simultaneously from both the solar pond and evaporation pond in the same ratio. Thus, equivalent make up NaCl must be added to the system. Alternatively (figure III-48) the concentration of (x) may be allowed to build up to some point equal to or less than saturation in the solar pond.

Then the wash stream is split going to two evaporative ponds. The first stream is controlled such that the quantity of (x) is equal to the quantity of (x) in the make up stream. The remaining wash stream goes to the second pond and functions similarly to the evaporative pond in the first method above. The advantage is that the ratio of NaCl to (x) is much smaller in this stream and thus the make up NaCl required is less. The total water evaporated is the same in both cases.

The NCZ gradient is controlled to maximize the depth while meeting the minimum desnity gradient required to maintain stability under equilibrium conditions. Equilibrium is defined as a state where conditions at all points in geometric space remain constant with time. At equilibrium, the flux q is constant across the NCZ. That is, the net flow of salt across any point is constant and equal to the salt transported from the LCZ to the UCZ. Thus in equation 1 the product $k_s(^{ds}/dZ)$ is constant. Since k_s is inversely proportional to viscosity which is strongly related to temperature, it varies from bottom to top of the UCZ with k_s being larger at the bottom. Thus, at equilibrium the salt gradient takes the shape of curve (A) in figure III-46 and the limiting point for stability is at the bottom of the NCZ. An alternate approach to controlling concentration is to remove solution from the bottom of the pond at a velocity, V, such that q is zero in the equation

$$q = VS - k_s(^{ds}/dz) \qquad (2)$$

$$\text{and} \quad V = \frac{1}{s} k_s(^{ds}/dz) \qquad (3)$$

Since the velocity (V) is constant at all point the product $^{k}s/s\ (^{ds}/dz)$ is also constant. Also, while the value of k_s may change by a factor of 2, the concentration changes by a factor of 10.

Thus, at equilibrium $^{ds}/dz$ is much smaller at the top than at the bottom of the NCZ as shown by curve (B). In order to maximize the depth of the NCZ it is desirable to maintain a constant gradient, $(^{ds}/dz)$, over the depth of the NCZ as in curve (C).

This reasoning led the SESEA team to the concept of combining the two approaches to gradient control with a lesser wash stream used with the UCZ and a downflow less than that required to give q = 0.

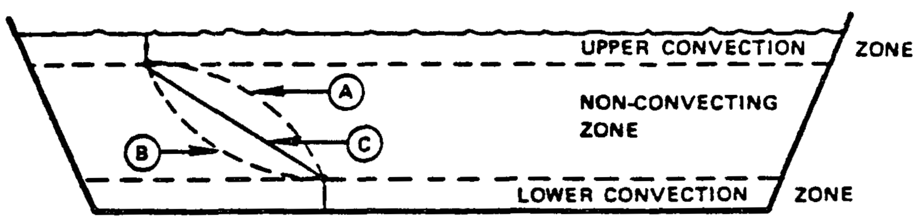
To illustrate the advantages of this approach consider figure III-49 through III-51. Figure III-49 presents the various water, salt and evaporation streams associated with only the washing of the UCZ as the control mechanism.

The salinity of the LCZ is maintained by extracting a quantity of brine at 23% salinity from the LCZ mixing it with concentrated brine in the evaporation pond to bring the salinity to 25% and reinjecting the same quantity of brine into the LCZ. The UCZ is washed by sufficient water to maintain it at 2% salinity.

Figure III-50 presents the case of using washing of the UCZ (at 2% salinity) combined with extraction of less concentrated brine (23% salinity) from the top of the LCZ and reinjecting higher sailinity brine (25% salinity) into the lower section of the LCZ. Fig III-50 also presents the case of a partial falling pond with extraction from the UCZ at a point where the salinity is 6% instead of 2% as in the prior case. Fig. III-51 illustrates the overall salt and water balance.

Figure III-52 summarizes the major performance characteristics of the three salinity control cases considered above.

The advantages of the combined approach in terms of water consumption and required evaporation pond area are obvious. It should be noted that the above cases have been presented to illustrate the apporach and are not necessarily optimum. An optimum design will be established in task IV. Anticipated trade offs include pond stability, pumping power and capital cost.



CURVE

A. TOP WASH GRADIENT CONTROL.
GRADIENT AT BOTTOM OF NON-CONVECTING Z ONE IS STABILITY LIMITATION. CURVATUE DUE TO $k_s = f(T)$

B. BOTTOM DRAW OFF GRADIENT CONTROL.
GRADIENT AT TOP OF NON-CONVECTING ZONE IS STABILITY LIMITATION. CURVATURE IS DUE TO CRITERIA $V = (\frac{1}{s})\, k_s\, (\frac{ds}{dz})$ = CONSTANT WHICH OFFSETS TEMPERATURE EFFECT.

C. CONTROLLED COMBINATION OF TOP WASH AND BOTTOM DRAWOFF TO PRODUCE CONSTANT GRADIENT FROM TOP TO BOTTOM OF NON-CONVECTING ZONE. ALLOWS MAXIMIZING ΔZ, HEIGHT OF N.C. ZONE, AND MINIMIZATION OF WATER CONSUMPTION.

Fig. III-46 .Solar Pond - Salination Gradient Control Concepts

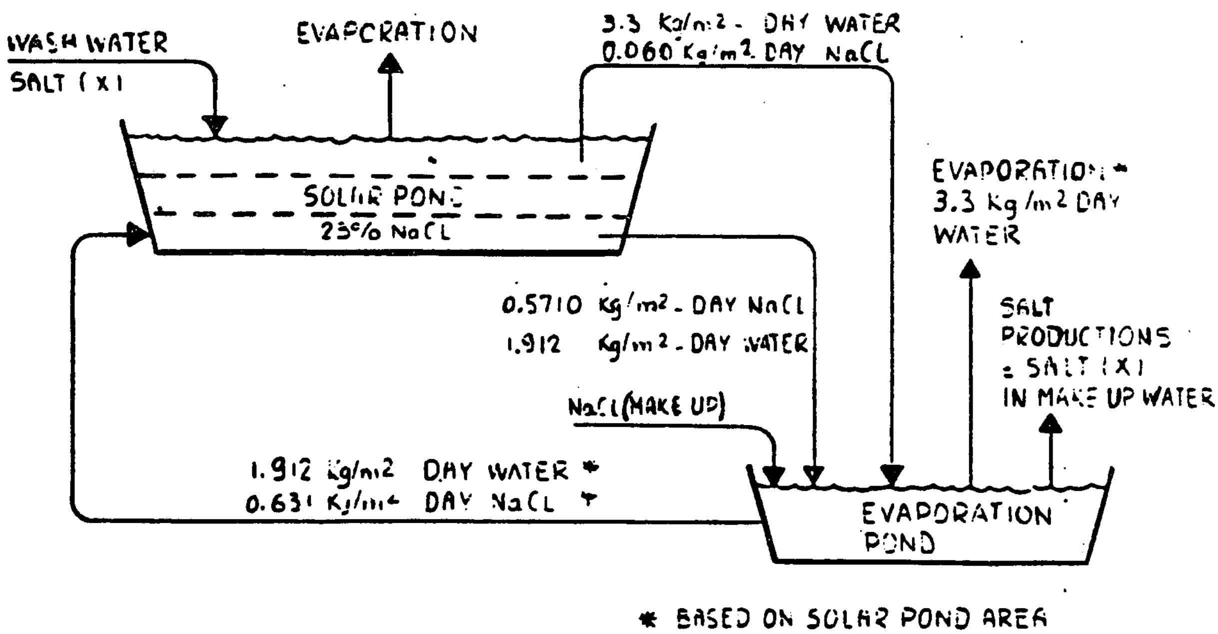
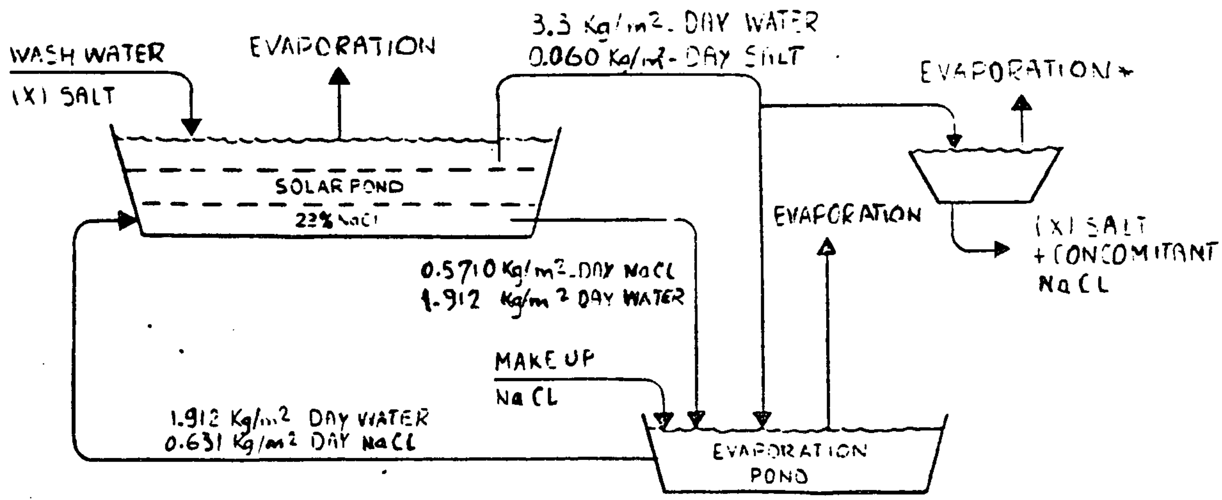


Fig. III-47 Extraneous Salt Concentration Control



* TOTAL EVAPORATION = 3.3 Kg/m2 DAY BASED ON SOLAR POND AREA IN GENERAL THE WASH WATER WILL CONTAIN VARIOUS SALTS AS DENOTED BY (X)

Fig. III- 48 Top Wash Salinity Control

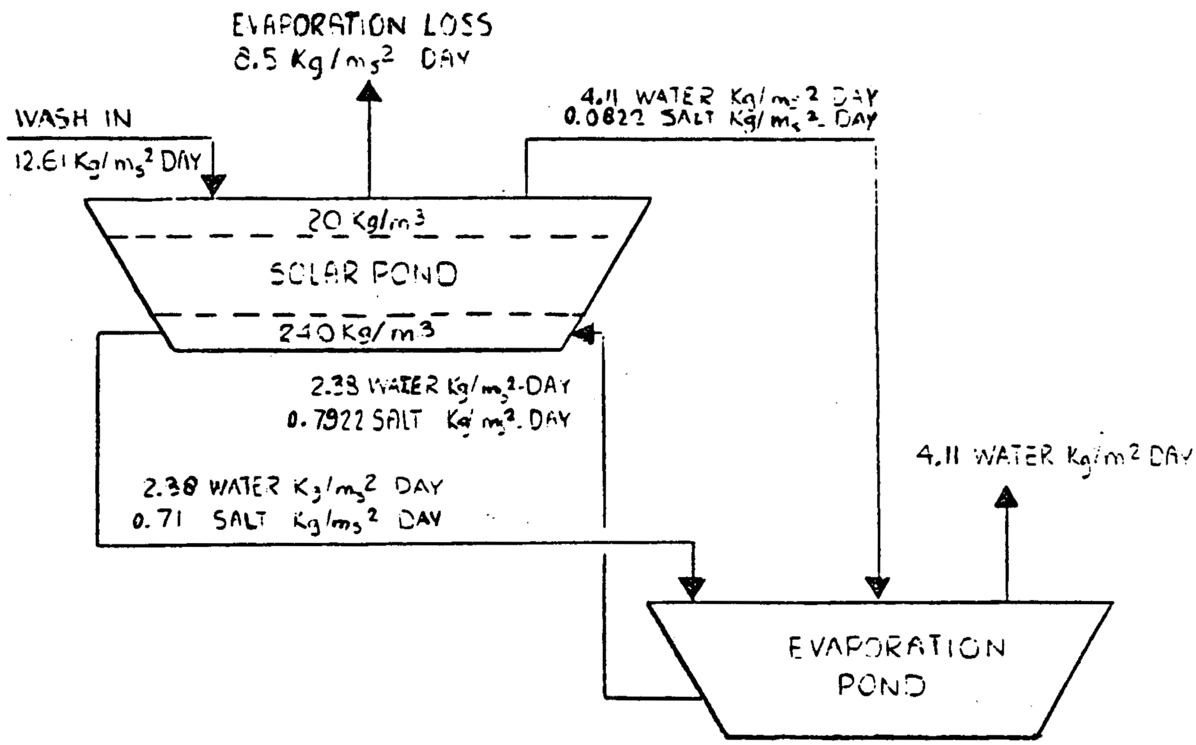
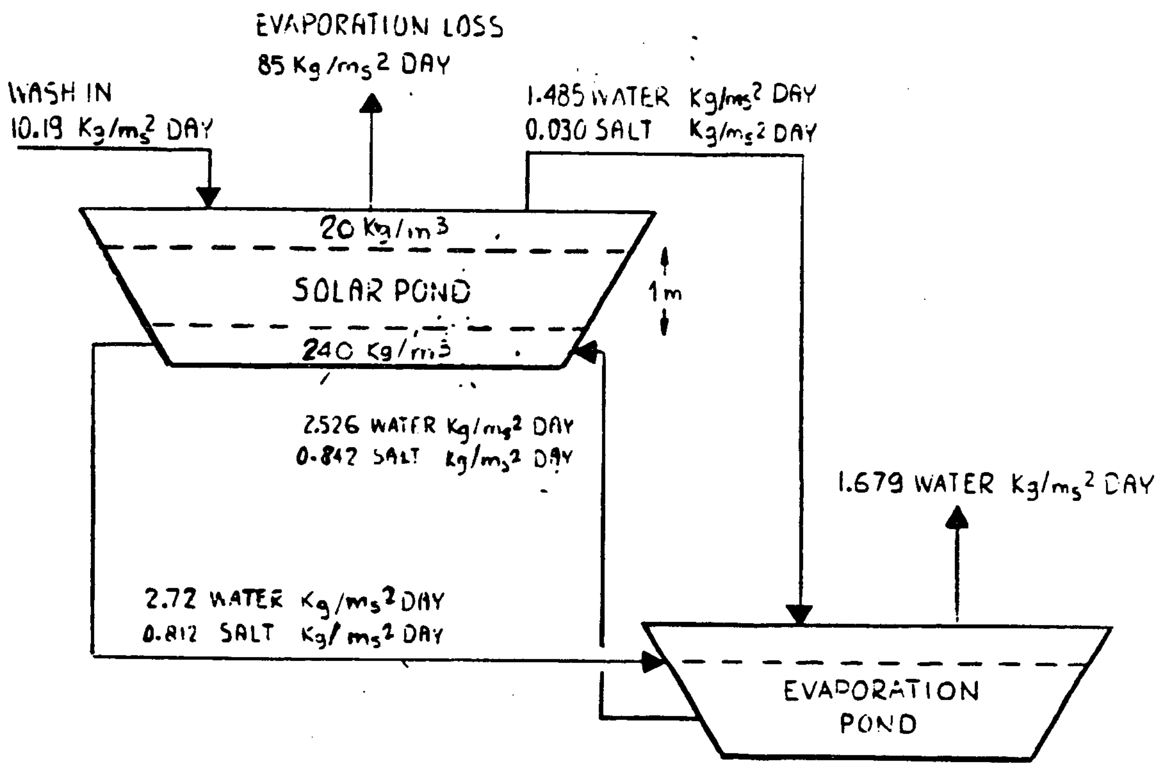


Fig. III-49 Alternate Extraneous Salt Concentration Control



ALL RATES NORMALIZED TO SOLAR POND AREA

Fig. III-50 SALINITY CONTROL USING WASHING PLUS FALLING POND

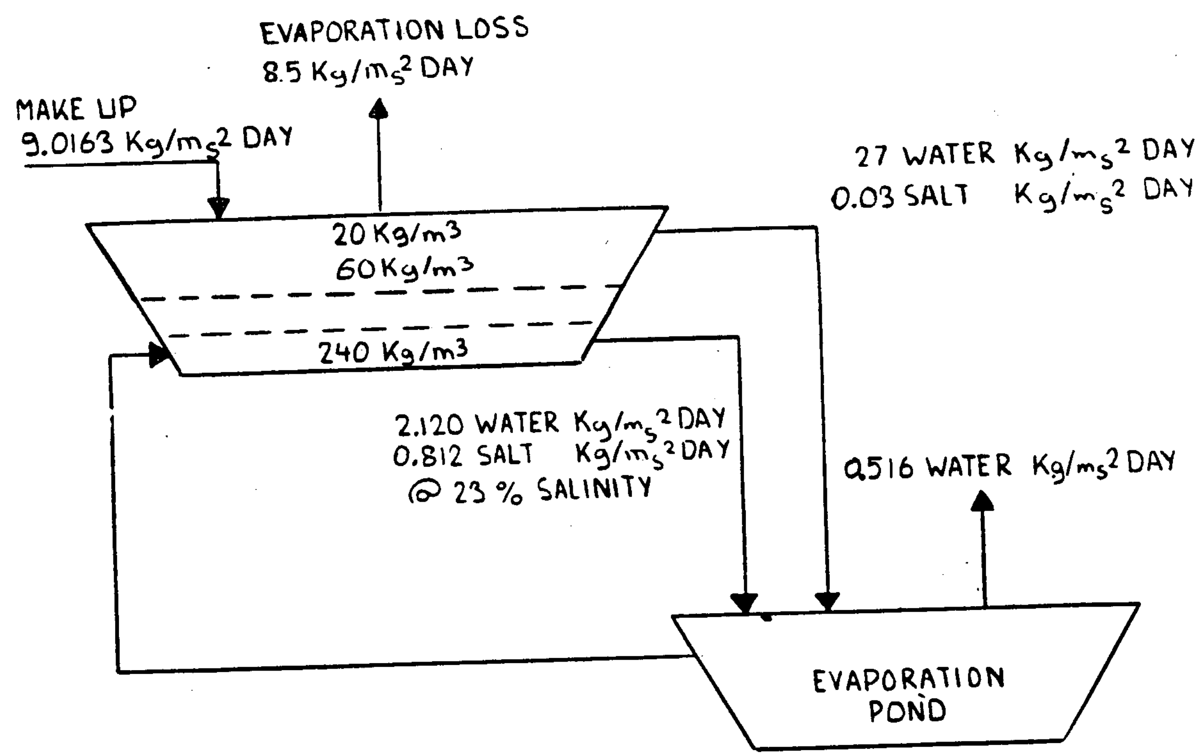


Fig. III-51 SOLAR POND SYSTEM; SALT AND WATER BALANCE
PARTIAL FALLING POND + V.C.Z. EXTRACTION

Figure III-52

Requirements of Salinity Control Concepts

(60000 m^2 nominal sized pond)

Concept	blowdown (m^3/m^2yr)	Evap/solar pond area ratio
UCZ washing + LCZ salt make up	1.5	0.48
UCZ washing + partial falling pond	0.613	0.2
UCZ extraction + partial falling pond	0.242	0.08

4.4.8 Summary of Pond Sizes

SESEA's recommendations for the size of the commercial (5ha) unit Solar Pond system are:

4.4.8.1 Main Solar Pond System

number of ponds: 10
size of ponds : 6000 m^2 each
dimensions : 150 x 40 m
(long dimension along nominal N-S direction)

depth	UCZ	0.25	m
	NCZ	1.25	m
	LCZ	1.9	m
Total		3.4	m.

height of pond sides above nominal pond level, 0.3 m

4.4.8.2 Evaporation Pond System

Number of ponds	: 2
Size of ponds	: 3000 m^2 each
Dimensions	: 30 x 100m

(long dimension along nominal N-S direction)

Depth (deep/shallow)	: 1m/0.3m

4.4.9 Construction Details and Specifications

The Solar Pond Sub-system will consist of ten adjacent, symmetric ponds, two evaporation ponds and supporting facilities. Ten ponds were chosen to permit leak management, ease of construction, and operational flexibility. An utility dike exists between the ponds for piping and controls. Figure III-53 is a cross sectional view of the solar pond, as envisioned for an actual site, and figure III-54 for the evaporation pond. Following is a discussion of the items as depicted in figures:

Solar Ponds:

Ten symmetric solar ponds will be installed to collect and store solar radiation energy as brine thermal energy.

Liner:

An impermeable liner will be provided throughout to contain the brine in the ponds. the liner material is Hypolon^{R} guaranteed for 20 years by Burke Rubber Company to 100°C operating temperatue. Pond Sides:

The pond sides are sloped:
. For ease of installation
. Cost minimization
. Control of subsoil gases

Pond subsoil:

The pond subsoil consists first of a layer of compacted sand (15 cm) to provide a base for the liner. Then approximately 15 cm of clean dry fill, again compacted to 90% of optimum. It is important to use dry soil in order to minimise heat transfer from the pond to the earth.

Brine Manifolds:

A pair of brine manifolds are required per pond to serve the ORC turbine-generation system. These diffusers also serve to control the salinity of the pond via the falling pond approach as discussed in sub-section 4.4.7. A third pair of diffusers will be used for pond salinity gradient control should the need arise. These diffusers will be designed to be portable so that only 2 sets will be needed for the commercial system.

Surface washing:

Two pairs of surface washing diffusers and skimmer drains as shown in Figure III-55 and III-56 are required per pond. The skimmer drains should be installed on the downwind side of the ponds. The surface washing diffusers are moveable to allow flexibility of operation.

Wave Suppression:

In order to prevent disturbances in the UCZ of the solar ponds by wind induced waves, it is necessary to provide a means of preventing wave formation and propagation. Methods of wave suppression that have been used on small ponds and have proven effective, are panels of floating nets or tubes across the surface.

Experiments have shown that effective suppression can be achieved by 2.5 m (8ft) panels spaced approximately every 15 m (50 ft), or by polyvinylchloride (PVC) pipes forming floating squares 3m x 3 m (10ft x 10ft). For solar ponds of the size anticipated, the use of net panels appears to be expensive. It is therefore proposed to use tubes of PVC with UV inhibitors that can be capped and floated on the surface. The ends will have to be anchored to maintain their position with the tubes mounted perpendicular to the prevailing winds at spacings of the order of 3 m (10ft). In this way, wave propagation is adequately prevented. Alternative wave suppression methods using pond shape and wind suppression or diversion via the pond banks will be investigated in task IV.

Utility dike:

The utility dike will be a large passageway between the two solar ponds. Its features include:

- All piping to and from the solar pond manifolds, the evaporation ponds, the mixing tanks, the ORC and the condensor;
- All electrical wiring for power and control in the Solar Sub-system area.

Evaporation Ponds:

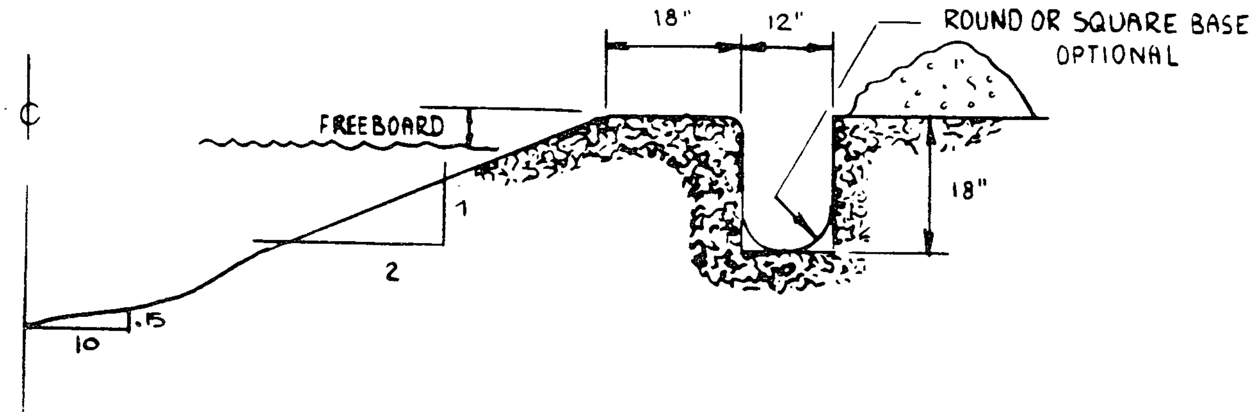
Two evaporation ponds will be used to evaporate brine as required to maintain the various salinity zones in the solar ponds. The evaporation ponds will be readily accessible for salt mining, as required for solar pond maintenance or disposal.

Mixing Tanks:

These tanks will serve as mixing receptacles for various fluids and for adding them to evaporation ponds or to the solar ponds.

Roadways:

Roadways are included all around the pond facility including dikes, for equipment and operator access.



PREFERRED SLOPE AND ANCHOR TRENCH CONFIGURATION

Fig. III-53 . OPTION 'A' **POND** CROSS SECTION

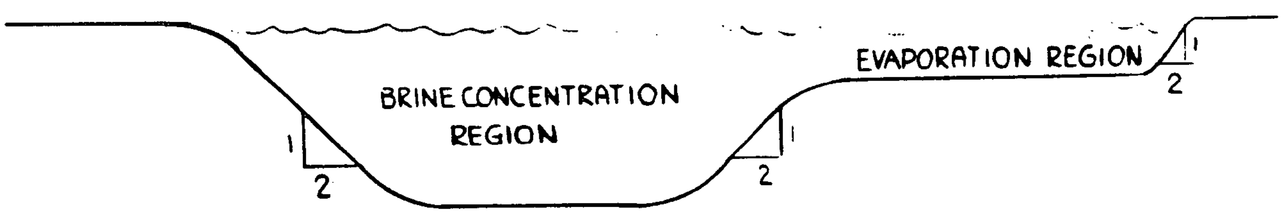


Fig. III-54 EVAPORATION POND CROSS SECTION

Note: 1) 2 units/pond required

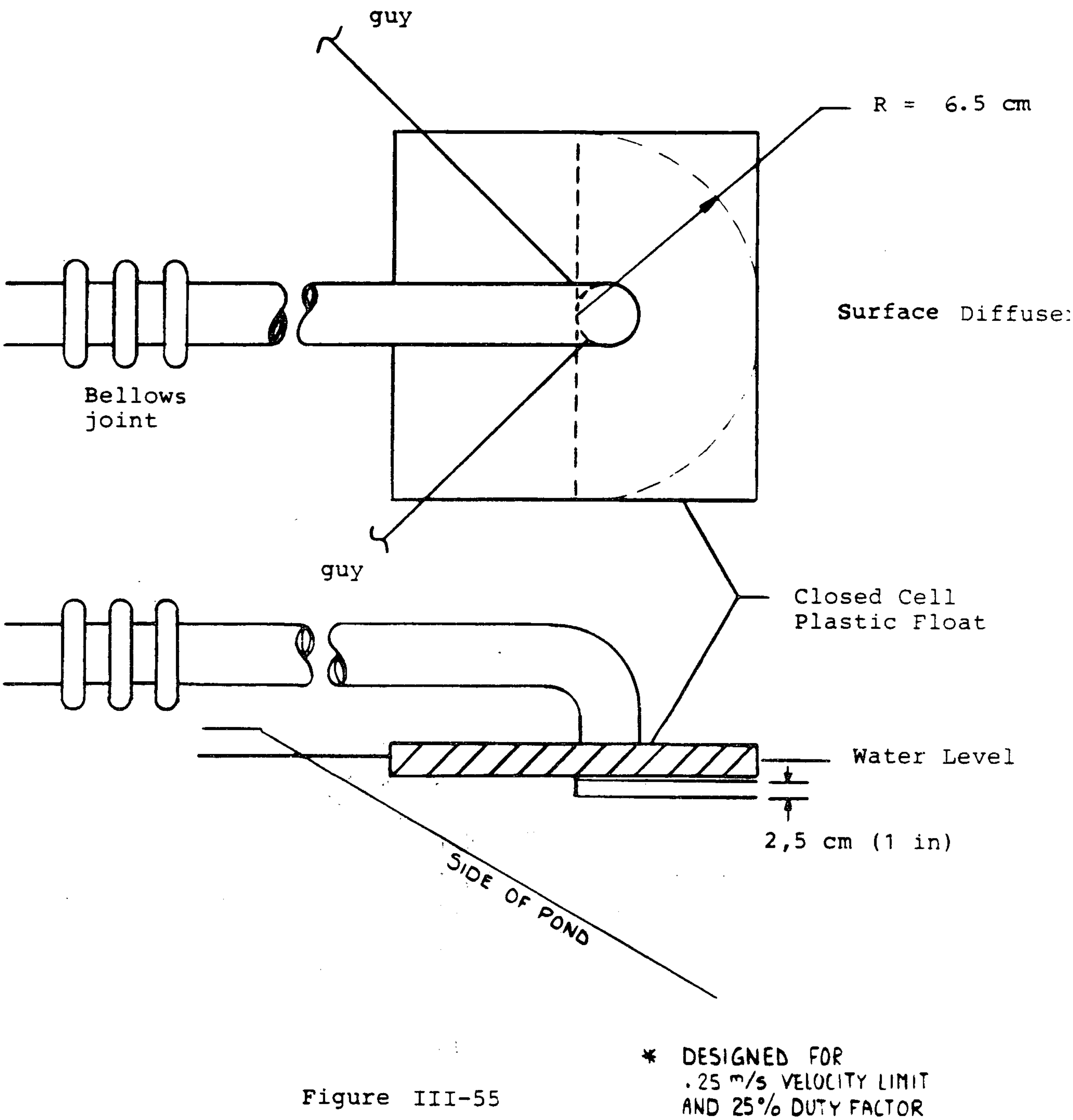


Figure III-55

FLUSHING DIFFUSER CONCEPT

from (SERI/TR-731-1201)

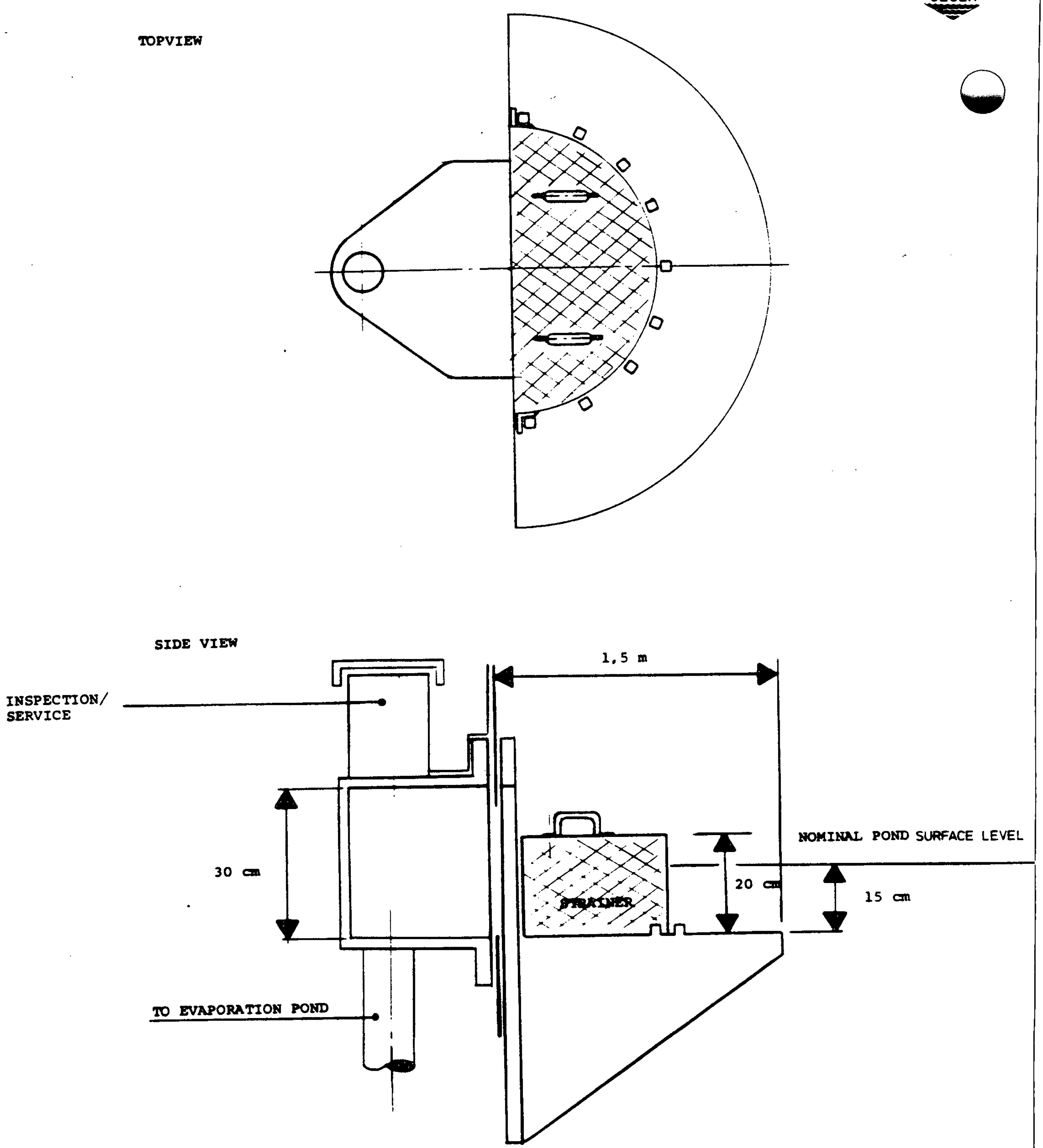


Fig. III-56 FLUSHING DRAIN DETAILS (2/POND)

4.4.10 Operation and Maintenance

Material used in this section is in part taken from the SERI Report TR-731-1201.

4.4.10.1 Pond Start-up

A solar pond should be filled as soon as possible once construction is complete. This will serve to protect the pond liner and to bring the pond system "on line" as quickly as possible by allowing each pond to begin collecting solar energy.

To start up a solar pond, the proper amount of salt for a pond will be placed in the bottom of the pond. Water will then be added to bring the depth to the middle of the NCZ. Experience has shown (Nielsen, Patel and Gupta*) that simply adding the water will dissolve a majority of the salt. The remaining salt will be dissolved by circulating the water via a floating portable pump. The non-convecting zone and UCZ will then be established as discussed below.

* Nielsen Chapter II Solar Energy Technology Handbook Part A, Edited by W.C. Dickenson and P.N. Cheremisinoff published by Marcel Dekker 1980.
Experimental Solar Pond, S.M. Patel and C.L. Gupta, Sunworld vol 5 number 4, p. 115, 1981

The non-convecting zone (NCZ) can be established in a satisfactory manner by following a procedure developed by Dr. Zangrando of SERI. The method is termed redistribution and consists of first partially filling the solar pond with high salinity brine as discussed above. Fresh water is then pumped through a horizontal diffuser that is immersed to the upper level of the LCZ. The diffuser is subsequently raised to the surface in a continuous motion. When the NCZ has vertical sides, the raising velocity V, and fresh water flow rate F, are related by $V = 2F/A$ where A is the cross sectional area of the pond at the depth of the diffuser. Upon completion of the NCZ the diffuser is raised at twice the above velocity to form the UCZ. This method is quite flexible and is mainly dependant on the capacity of the pumps used. It has also been shown that this procedure is effective when it is performed intermittently instead of continuously.

While the redistribution method requires that most of the brine be concentrated at first, then partially rediluted in the upper region of the solar pond, it is easy to control and cheap to implement. Once the NCZ is established, the pond will begin to collect energy. As the first pond comes up to temperature (at least 68°C) it can be used on an intermediate basis to check-out the turbine-generator system. These check-out efforts will also be of value in training the pond and turbine-generator operating personnel.

4.4.10.2 Pond Operation

Two parallel pumps are provided to remove hot brine from the solar ponds. The two pumps acting in parallel, pump hot brine from the storage layer of the ponds where valving will direct the flow to the ORC sub-system. Should circumstances require it, a single pond can support the load, for a short time and without jeopardy, as long as the total monthly average rate of energy withdrawal remains within limits. Operation of the turbine is accomplished by taking the hot brine to the heat exchanger, and routing it back to the bottom of the pond.

4.4.10.3 Pond Maintenance

Once the gradient region of solar pond is established, maintenance of the pond consists of:

- maintaining the overall salinity difference between the two convective layers (surface and storage)
- correcting portions of the gradient, if internal convective layers have formed in this region
- maintaining the clarity of the brine
- limiting the growth of the surface layer

The response time of the solar pond is very slow; this permits great flexibility in scheduling the required maintenance. Most procedures can be performed continuously or intermittently, depending on operator and brine flow availability, without affecting pond performance.

4.4.10.4 Salinity Control

Salt diffuses from the storage layer to the surface layer on a continuous basis, driven by the salinity difference between these regions. If however, the solar pond gradient has been established properly, no adjustment should be necessary, provided the salinity of the surface and the storage layer is controlled periodically and provided the initial storage layer thickness is at least o.25 m (0.8 ft), in order to minimize daily overheating in the LCZ.

Occasionally, a portion of the NCZ may contain insufficient salt to support the local temperature gradient; if this occurs, a redistribution of brine will be necessary to prevent formation of internal convective layers which would decrease the pond efficiency.

The NCZ condition will be monitored by recording temperature and salinity distribution in this region on a regular basis. The stability of this region can be analyzed using a simple procedure developed by Zangrando*. Although much research is still necessary to completely understand the gradient breakdown process, the general operational rules presented in the above reference should be sufficient to predict operational stability. Should instability occur, the internal convective layers can be easily identified by analysis of the temperature distribution in the gradient region as they will appear as isothermal steps bounded by regions in which the temperature increases with depth.

* F. Zangrando, "Observation and Analysis of a full-Scale Eperimental Salt Gradient Pond", PhD Thesis May 1979. Department of Physics, University of New Mexico, Albuquerque.

Correction of local instabilities is the only maintenance procedure which requires prompt intervention, within a day or two following breakdown of the gradient. However, it appears possible to predict incipient instabilities several weeks prior to actual breakdown; therefore, arrangements for manpower availability should not be a problem.

Adjustment of the gradient can be performed using two similar techniques, both requiring the same type of equipment used for establishment of the gradient.

The first method (Zangrando) consists of injection of low-or high-salinity brine taken from either the surface or the storage layer of the pond, depending on the condition of the remaining gradient. The diffuser is placed at the boundary of the unstable region, and the brine is injected through the diffuser while it is either raised to the surface or lowered beyond the storage layer boundary. The rate of motion of the diffuser is a function of available flow, area of pond, and condition of the existing gradient. This method causes a temporary mixing of the region above or below the moving diffuser (depending on the supply brine used).

The second method (Nielsen) requires external mixing of available brines to provide a solution at the appropriate concentration that is then slowly deposited in the unstable region. Surface and storage layers can be used to supply the appropriate ratios, but temperature may require additional controls. Although requiring control of the external mixing process, this technique does not appreciably change the gradients above and below the unstable region. Selection of the appropriate method is a function of gradient condition.

4.4.10.5 Clarity Control

The thermal efficiency of the solar pond is strongly influenced by the clarity of the brine above the storage layer. Transmission of sunlight through the gradient must be monitored periodically to ensure the best operating conditions.

The pond must be kept free of algae and other organisms that would increase absorption of sunlight in the upper regions. This requires periodic application of an algicide, such as copper sulfate.

Treatment of the brine, two or three times each year, has been sufficient to maintain clarity in most operating ponds in the United States. The treatment normally consists of adding copper sulfate to the pond to a concentration of about ten parts per million. This procedure was used initially in The Ohio State University ponds with good success. However, when algae growth reoccurred and additional copper sulfate was added to control this growth, the copper precipitated to the bottom and was completely ineffective. Eventually it was determined that the copper could be kept in solution by adding a small quantity of hydrochloric acid. The exact value of the pH required was not determined, but pH in the range of 5 to 7 seemed to be enough on the acid side to keep the copper in solution so that it remained effective. Despite its value in allowing the copper to control the algae, the acid may not always be favorable to pond transparency, since it has been observed to accelerate water discoloration due to leaching suspended leaves. As a variation, an organic algecide was tried, but it turned the water milky, apparently as a result of reaction with the sodium chloride in the water.

At present it appears that the most convenient and reliable procedure will be to add copper sulfate with the salt when the pond is filled. In proportions up to 10 or more parts per million the light absorption by the copper sulfate is too small to interfere with pond operation. Diffusion appears to be adequate to maintain sufficient concentration for biological control throughout most of the pond, including around the 0.4 m depth where salinity and temperature may be especially favorable to growth. It is necessary to control the pH, and it may sometimes be necessary to replenish the copper sulfate washed out of the pond by salinity control procedures. This is done simply by distributing a solution of copper sulfate over the surface. If addition within the gradient zone is ever required, this is easily accomplished by pumping out perhaps half a centimeter of depth through a localized diffuser at the desired depth, mixing the material to be added, and returning through the same diffuser. It is known that $MgCl_2$ is less favorable to organic growth than NaCl, and it is not yet determined whether specific chemical control will always be required in solar ponds.

4.4.10.6 Surface Layer Control

The efficiency of the solar pond also depends strongly on the thickness of the surface layer. This is an undesired region since it provides no additional insulation to the storage layer while absorbing most of the infrared portion of the solar spectrum.

Stirring of the surface by wind action, evaporation and rapid cooling in the evening is a complicated process which is not well understood, but research is in progress. An array of wind breakers which divide the surface in small sections has proved very effective in reducing wind-driven convection in operating solar ponds. Silicone or other oils used on water surfaces have been much less successful in preventing evaporation, and no measure exists to prevent rapid cooling.

Based on current experience, it seems possible to maintain the thickness of the surface layer at no more than the design thickness of 0.3 m, using a floating array of wind breakers, as described above. If the local conditions are such that the surface layer tends to grow beyond the design thickness, the gradient will have to be adjusted periodically, as discussed above.

4.4.11 Service Equipment

To install equipment, establish ponds, take measurements, perform adjustments and maintenance, a number of items are required that are not inherently a part of the ponds. Some of these items are listed and discussed here.

- Boat: A small flat-bottomed boat or rubber liferaft with oars is required for access to different areas of the ponds. It should be large enough for two people and yet light enough that one person can take it out of the water or carry it over a dike to another pond.

- Mobile Pump: A trailer mounted pump with a capacity of 2000 L/min (approx. 500 gal/min) is needed for transferring brine or water to maintain the gradient in the pond or to establish a new pond. The pump should be self-supporting for power and easily movable along the tops of dikes. The pump should be self-priming or equiped with a hand priming pump. Lengths of flexible 15 cm (6-in) hose with standard fittings to match the pump are required. Lengths of 6 m (20ft) noncollapsable for suction and 15m (50ft) of discharge hose are recommended.

4.4.12 Monitoring

The prime parameters to be monitored during the operation of the solar ponds are temperature, salinity, pond transparency, and energy output. The amount of information required for routine operation is, of course, much less than it would be for a research pond.

The temperature observations required are conveniently made by means of the permanently installed thermocouples in the pond and buried in the earth under the pond as called out elsewhere in this report. The thermocouples in the pond will give the temperatures in the convective zones as well as an estimate of temperature gradient in the gradient zone, whereas the buried thermocouples will give information about earth temperature and ground-water movement.

Any heat loss to moving ground water will lead to unequal temperatures on opposite side of the pond. The lower convective zone is not necessarily convective at all times, and the thermocouples suggested will provide information about its temperature distribution.

The salinity, changes very slowly and all that will normally be required is an occasional measurement of the salinity at the surface. Less frequently, perhaps annually, salinity at the bottom should be measured. A complete salinity profile is not called for unless there is some operating difficulty requiring a detailed study of pond conditions. A hydrometer gives the salinity to an accuracy sufficient for routine operation. Samples are removed from the levels at which the salinity is to be measured by means of a small pump and piece of tubing. For convenience, small-diameter sampling tuber will be permantly installed.

Since pond transparency has a decisive influence on the performance of a solar pond, transparency measurement is very important. Although in principle it would seem easy enough to determine the fraction of radiation penetrating to a given depth, in practice, it has been troublesome.

The most suitable transparency measuring instrument is the eye. If the pond is clear enough so that objects lying on the bottom can be cleary seen, then the transparency is good.

On a more technical basis, useful information about radiation transmission into the pond can be obtained from a radiation sensor that responds in the wavelength range from about 0.35 to 0.7 nm. This is the range in which clean water is most transparent, and in which dirt and growing organisms are likely to impair transparency.

The radiation sensor chosen should be insensitive to temperature and not too slow in response. A suitable choice is a vacuum photodiode, such as a type 1P29 with S-4 photocathode or a type 926 with S-3 photocathode. (The 926 is rated for a higher maximum temperature) This photodiode is mounted in a watertight box with a diffusing flat window to spread the light evenly over the photocathode and a light-limiting aperture to reduce the intensity down to the normal operating range of the photodiode. The output is high impedance, so that the connecting cable must be free from leakage. Two units are required, one to be mounted just under the surface and one to be submerged more deeply in the pond. The ratio of the two readings gives the transmission, even though the solar radiation may be varying. It is suggested that a reference curve for the sensor be obtained initially by observing the transmission of clean water. Ideally the pond soon after filling will be full of clean water.

4.5 UNIT 500, ELECTRICAL SUB-SYSTEM

4.5.1 Introduction

The electrical design is based upon the electrical power requirements of the various subsystems, minimizing losses and providing the required distribution control. The basis for design and installation of solar CEA system will be in accordance with the U.S. electrical standards, KTI engineering standards, and SESEA electrical requirements. In case of conflict, the most stringent regulation applies. These standards are to be applied fully to all parts of plant electrical design, including packaged units which form part of the plant.

4.5.2 Design Criteria

To attain the desired quality and safety the following codes will be used:

Electric motors	: IEC or arabic equivalent
Electric cables	: " " " "
Switch gear	: " " " "
Grounding and lightning	: " " " "
Explosion proof equipment	: " " " "
Explosion hazards	: API 500

Where electrical energy is a high cost item, adequate trade-offs between investment and operating costs are applied.

To achieve the most economic lighting, the minimum lux in accordance with the local standards will be chosen as the design point.

In addition to the standards and codes, the electrical system will be in accordance with the local regulations and requirements of the following institutions:

- The electric supply company
- The fire fighting department
- The ministry of labor inspection
- National safety laws, etc.

4.5.3 Design and Drawings

The complete electrical system will be designed for a reliable service, highest degree of flexibility, consistent with good practice, safety to personnel and sound economics with a maximum interchangeability of components. Transformer ratings, switchgear interrupting capacities, cable sizes, etc. will be calculated and selected in line with good practice, to minimize parasitic losses.

A system design will be prepared containing the short circuit calculations, relay settings and coordination curves. The system diagram will show and define the complete electrical system including the circuit breaker and switch interrupting capacities, short circuit ratings, relay- and metering devices, transformer ratings, motor loads, etc.

Drawings will consist of complete plans and elevations showing equipment locations, power and control cable lay-out, grounding lay-out, lighting system plans and elevations, communication plans and cable schedule in an orderly numerical sequence, etc. The drawings will also include all wiring and elementary diagrams for all items, such as switchgears, relay cabinets etc. as well as all drawings necessary for the proper interconnection between electrical equipment.

All drawings will be an accurate representation of the electrical system as installed, in such a manner that they may serve the owner as a convenient guide for future operation and maintenance.

4.5.4 Limitation and System Control

The distribution, installation and utilization of electricity will conform to the standards as mentioned under 4.5.2 above.

The distribution system will be designed and installed to provide a maximum of circuit reliability consistent with good economics, efficiency and convenience of operation. All critical loads will be fed from two (2) circuits in parallel.

The electrical system switching will be arranged so as to allow sections of switchgear and feeders to be isolated and deenergized for maintenance, without interrupting service to critical areas.

The low voltage generator distribution system, fed by 380/220V - 60 Hz, will feed all motors and lighting, heating, and instrument power distribution boards.

An emergency source of 380/220V - 60 Hz, will be provided to feed all critical instruments and all lighting fixtures on strategic locations in case of a complete power failure.

To provide a high efficiency system, a scanner unit will be installed initiating economic power distribution to all small electric intermediate consumers.

All electrical consuming equipment such as cables, relays, motors etc. will be designed with very low heat losses, within the limits of installation vs operating costs.

4.5.5 General description of energy supply system

The electrical energy supply has to be available without any interruption. In general, the Rankine cycle turbine is supplying the electrical energy to this system. In emergency cases, a battery-system will supply energy for critical functions for up to 4 hours. When after 4 hours the Rankine cycle turbine has not returned to operation, the diesel motor coupled to the generator will ensure that no unacceptable conditions occur. Referring to figure III-57 the strategy to provide the required energy is shown schematically.

4.5.6 Generator coupled to the Rankine Cycle

The Rankine cycle turbine is coupled to a 3 phase 220/380 Volts, 60 Hz, Pf. 0.75 generator. This generator supplies all the electrical energy required by the system.
The Rankine turbine speed will be controlled within 5% at 3600 rpm independent of the power supplied by the generator.

If the speed exceeds the desired accuracy limits, the control system will shut down the turbine-generator, and switch on battery supply power without interruption.

4.5.7 Generator coupled to the diesel engine

The diesel engine is equipped with a hand clutch coupling to the generator. In a failure case, when the Rankine cycle cannot be repaired within 4 hours, the diesel engine will start and at first, phase-lock the generator output to the battery system's output, before resuming the load.

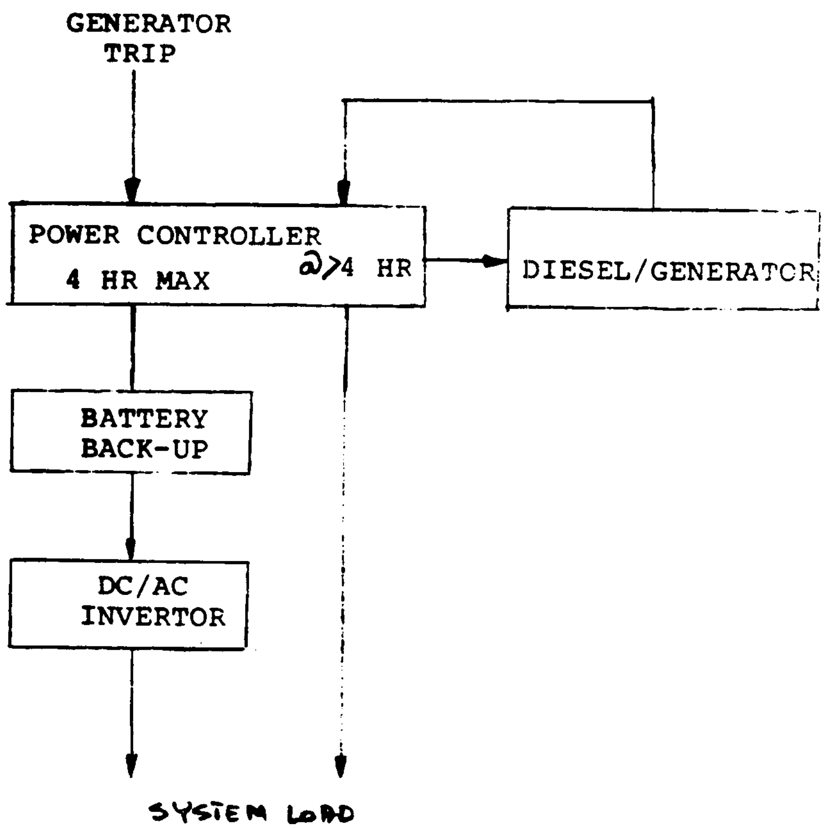
4.5.8 Battery back-up

A battery system is connected to the distribution network via a motor-generator/generator-motor system, 3 phase - 220/380 Volts, 60 Hertz, P.f. 0.75 to 110 V. DC 1000 Ah with a 4 hour total energy system capacity.

In normal circumstances the generator output will keep the batteries in good condition by trickle charging.
Low-maintenance long-lifetime (10 year guaranteed) batteries have to be supplied for this function.

4.5.9 Electrical load characteristics

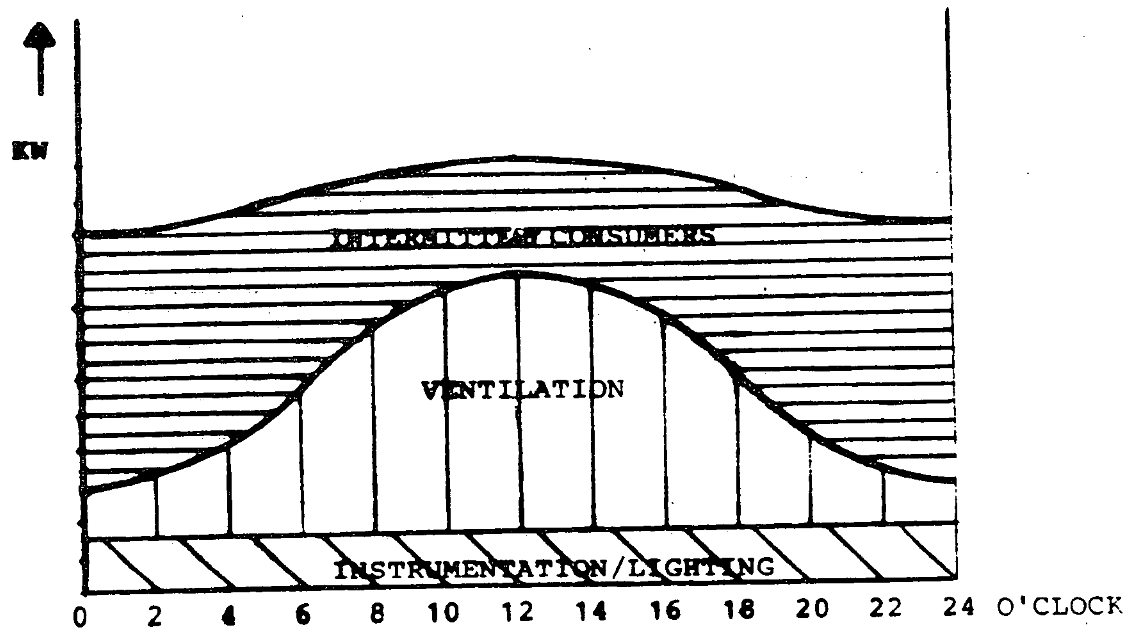
See Figures III-58 A to D.



AUXILIARY POWER STRATEGY

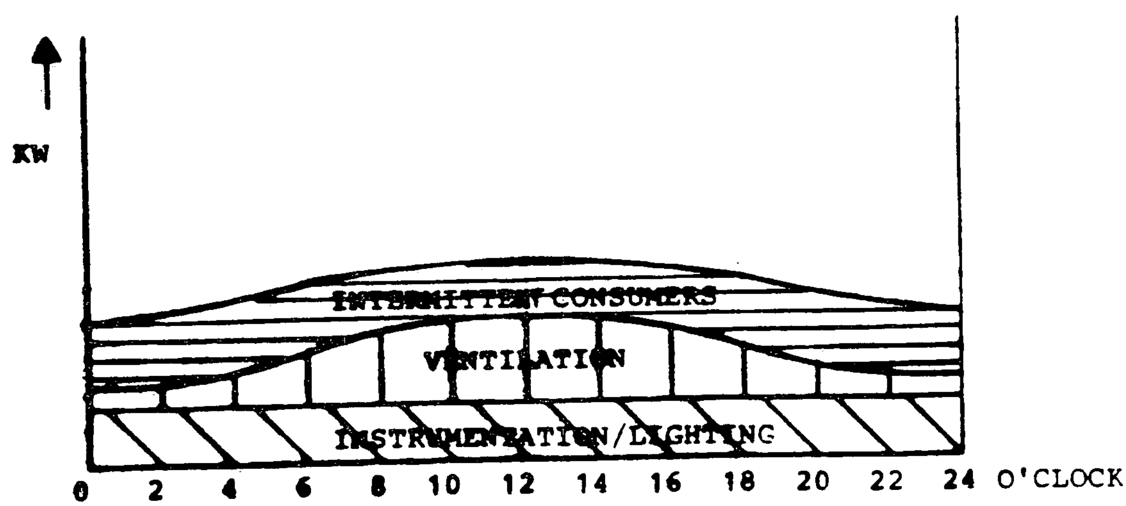
Figure III-57

ANTICIPATED ELECTRICAL DEMAND PROFILES



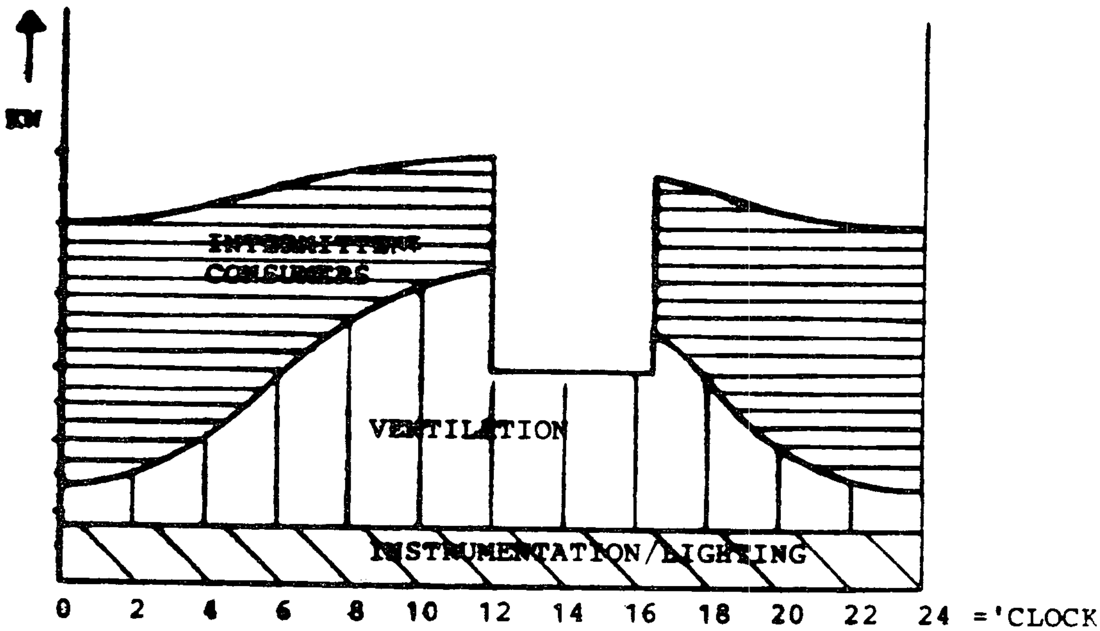
HOT DAY

figure III-58A



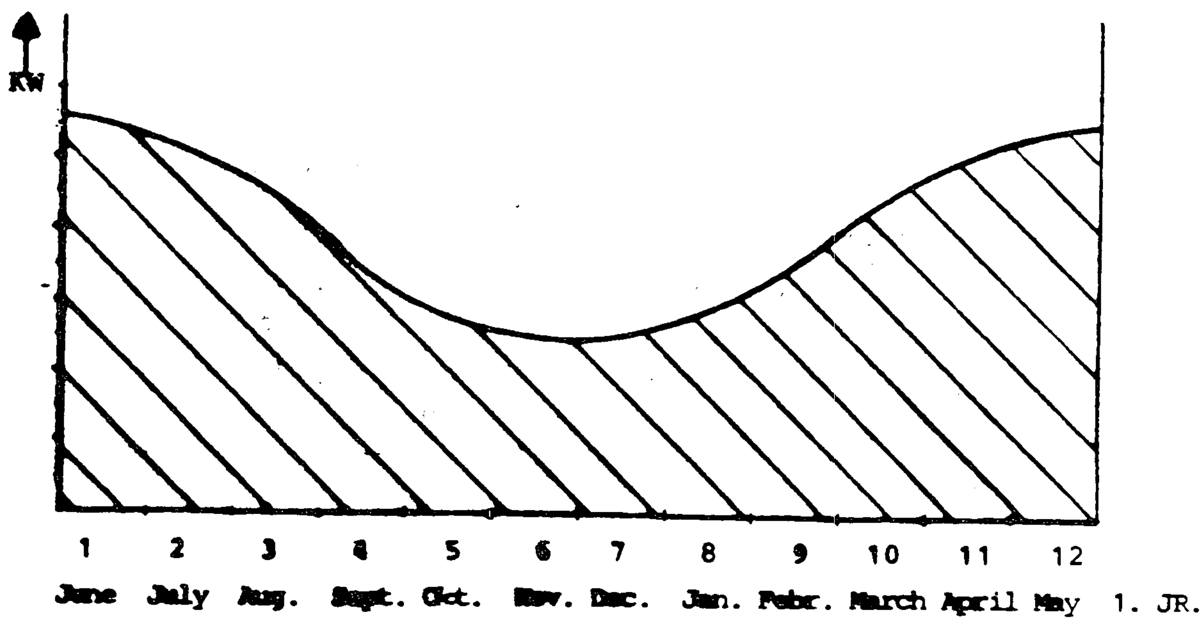
COLD DAY

figure III - 58B



POWER FAILURE AT A HOT DAY MID SUMMER

figure III- 58C



YEARLY CONSUMPTION

figure III - 58D

4.6 UNIT 600, INSTRUMENTATION AND CONTROL SUB-SYSTEM

4.6.1 Introduction

Mindful of the energy saving orientation of the plant, the design of the instrumentation and process control system is based on the following key objectives and criteria:

- Maximum usage of optimized control system for minimum and most economic use of energy.
- Strategy oriented control system performing task oriented functions needing minimum operator intervention.
- Optimum performance of plant while using a simple and reliable control system.
- Provide basic performance data.

4.6.2 Master Control System

This is a master control computer, which integrates the various analog control systems in the following unit operations:

- CEA	- unit 100
- R.O.Water system	- unit 200
- Organic Rankine Cycle	- unit 300
- Solar pond	- unit 400
- Power Distribution	- unit 500

Each operational unit has several control loops and variables to monitor. In addition, an alarm and interlock system enables the operator to have full control view and override of automatic functions in case of emergency. The system design uses existing control technology and is human engineered for rapid operator response and understanding.

The control system hierarchy, shown in figure III-59, consists of four levels representing different degrees of operator intervention.

Level 1, Integrated supervisory control provided by the master plant computer which coordinates automatically all unit analog controllers for the different plant and sub-system operating modes. Routines for water quality control, shade and climate control, ventilation control, pump sequencing, pond salinity and gradient control, freon vaporizer level control, freon vaporizer circulation, turbine-generator output and electrical load control, waterfeed flow control, control of R.O. feed, conductivity control of sweet water etc. etc.

Should level 1 be faulty, Level 2 semi-automatic coordinated control is initiated, requiring operator intervention. Here coordination is provided by the plant operator in the form of manually entered set points and control gains. At the same time, the remaining active independant units continue to be controled automatically.

The next level of control, Level 3, consists of manual control in which each unit operation is controlled by the operator along with coordination of overal plant. Finally, there is a hard wired non-interruptible system (Level 4)of safety interlocks and emergency trips for each of the units and the system as a whole with annuniciator system links to alert the appropriate personnel.

The master control system functions are directed from a central control room. Centered about a process display panel indicating the status of critical components such as solar pond, greenhouse, freon system, power generation, diesel generator, pumps, well water system etc. Also in the central control room are the necessary data acquisition, interpretation and storage equipment. Indicators linked to the sensors allow visual tracking of process flows, temperatures, pressures, analysis (physical) and manual centralized control of all system components will be accessible via this system.

4.6.3 Data Acquisition System

The data acquisition system provides input in real time to the master control system for plant operation and analysis of performance.

This system will sense and record data from the various units. It time shares components and information with the master control system and includes the various interface lines to all sensors, all signal conditioning equipment and required input/output units such as printers, CRT display terminals and disc and tape drives.

The essential elements for the proper coordination and transfer of data throughout the entire plant are the 4-20 mA current loops which hardwire each sensor to the appropriate point(s). The hardwired current loop approach has been taken because of the simplicity, reliability and cost advantages associated with it. Simplicity results from the use of the twisted, shielded pair to both supply power to the sensor and to carry the resulting data in the form of current in the loop. Reliability results from the loop's insensitivity to voltage drops, introduced by changing contact resistances or other sources. Since the data is carried in the form of current, only a physical break in the loop can destroy its information carrying capability.

A priority interrupt system will be implemented that will give ordered access to data to allow manual requests under diagnostic or alarm conditions. Equipment to satisfy these requirements is available with minor hardware changes and software development from vendors such as Hewlett Packard,or Digital Equipment Corporation.

The capability to perform computations, such as daily and hourly performance, graphic output of stored data and graphical integration will be provided as needed. The plant master computer will have storage capability for replay of data to aid in diagnosing of unplanned outages.

4.6.4 Software description

Software in this context means the supporting engineering instrument specification details such as specification sensor type,range, control loop diagrams, panel layout, logic, shutdown sequencing and alarm system diagrams, back-up details etc.

Engineering specifications of control system will be developed during Task 4. A preliminary list of the anticipated engineering documentation is given below.

- Piping and instrument diagram showing comple measurement and control details.
- Logic diagrams indicating the plant safety and interlock system.
- Loop diagrams indicating flow or instrument information.
- Control panel views, wiring diagrams and mechanical details.
- Description of control system inclusive of specification sheets of instruments.
- Instruction manuals for each type of instrument inclusive of maintenance instructions.

4.6.5 Hardware description

The description given below for the salinity gradient profilemeter serves as an example of the individual component descriptions that will be developed in Task 4. This is followed by a description of how the NFT control subsystem can be interfaced with the central computer.

Salinity Gradient Profile meters will be installed for gradient profile measurement and monitoring. The principle of the measurement is based on the conductivity of the brine solution and the temperature of this solution. Preliminary conductivity tests have shown that solar pond concentrations correlate well with pure sodium chloride concentrations. The profile meter consist of a conductivity cell + conductivity meter consisting of:

- copper-constantan thermocouple.
- submersible pump to circulate the brine.
- Gearmotor, winch and control box.

To operate the meter, the pump/conductivity cell/thermocouple will be mounted together on a Plexiglas block as one unit and in operation it is drawn up through the pond profile by a winch at a speed of approximately 20 cm per minute. Four magnets on the rim of the winch drum trigger a proximity detector so as to take a set of readings every 5 cms vertically in the profile of the pond.

The conductivity and temperature are displayed at the central control computer and can be stored on floppy disk for later analysis.

In each solar pond section two profile meters will be installed to analyse the gradient behaviour.

4.6.6 Data Quality Control

Data quality control is an essential element in obtaining satisfactory control system operation. The desired quality can be obtained as follows:

- use of appropriate accuracy sensors
- use of averaging measurement where one measurement may lead to errors e.g. use median analysis
- use established error detection codes to avoid transmission errors in computer systems
- use known standard inputs for system integrity and calibration check
- cross check between interrelated variables for possible diagnostics (for a pump, horsepower vz discharge pressure and flow)
- use display devices which have possibility of arithmetic computation between several variables and automatic hourly/daily reporting

MASTER CONTROL SUBSYSTEM

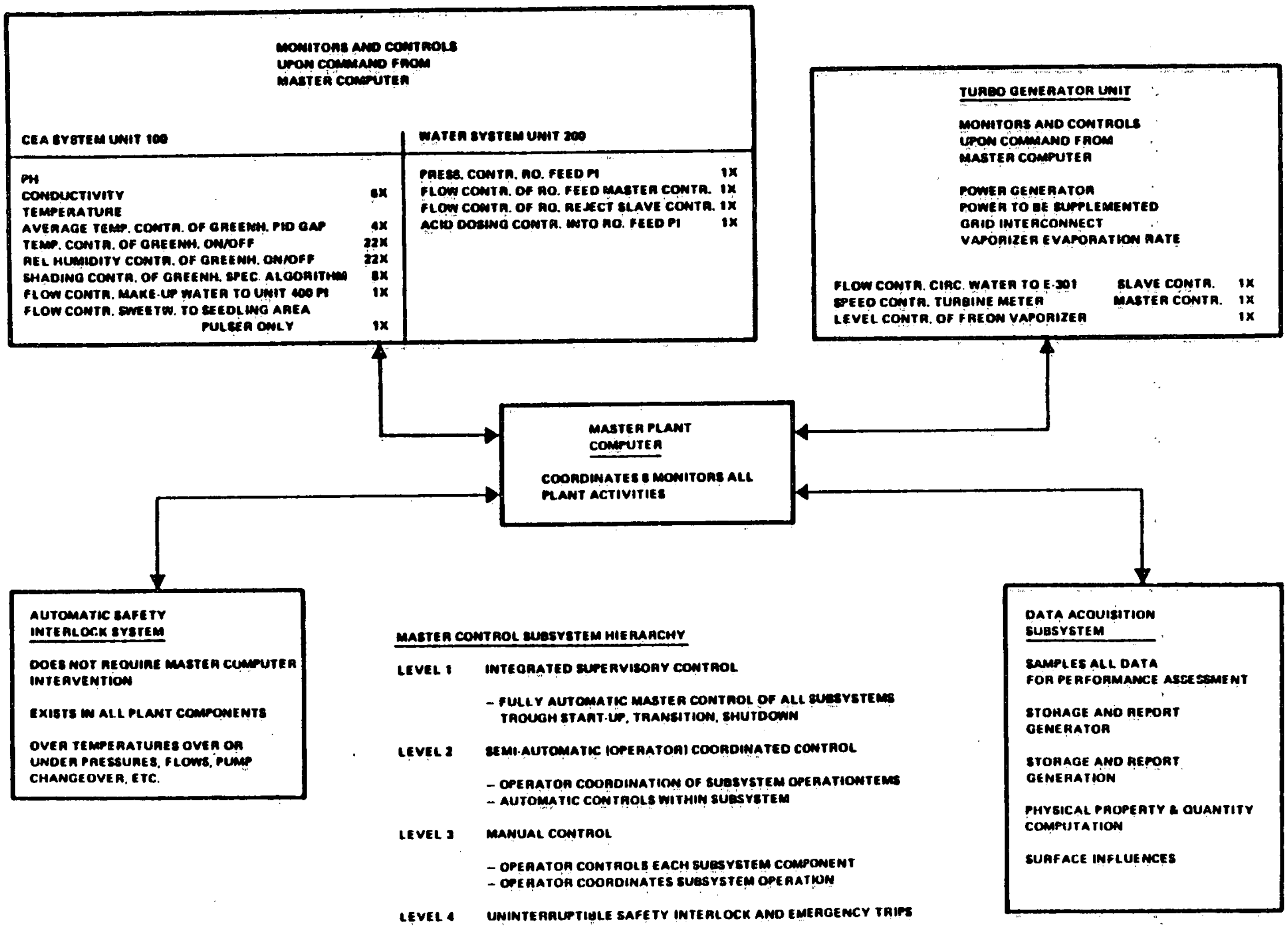


Fig. III-59

5. ENGINEERING FIELD TEST (0.4ha) DEFINITION

5.1 INTRODUCTION

To prove the concept of the system as defined in the former sections, an Engineering Field Test system will be built. Moreover, the Engineering Field Test has to supply more precise design tools for a commercial system than is available at this stage.

Because of the fact that the development of solar ponds is as yet not advanced and reliable design data is difficult to obtain, the information that will be gained from an EFT will be of the utmost importance for the future of the technology.

The variety of techniques, controlled agriculture, water desalination, solar energy collection and conversion present a great opportunity for research and development. The Derab experimental farm in Saudi Arabia has been choosen as the site for this Engineering Field Test. Below, a recommendation for the size of the Engineering Field Test is made based on the criteria and the constraints of the chosen site.

5.2 DEFINITION CRITERIA

For the scale and lay-out of the Engineering Field Test, criteria have been set up based on the requirements of the RFP and the constraints of the Derab site.

5.2.1 All sub-system must be representative for the commercial size.

5.2.2 The size must give minimum costs at a representative scale.

5.2.3 Water constraints must be taken into account.

5.2.4 Aquifer pollution must be prevented in any case.

5.2.5 All components must be available.

5.2.6 All components must have the potential to be scaled up at a commercial size without conceptual changes.

5.2.7 Adequate reseach facilities to be present.

5.2.8 Back-up power will be supplied by grid connection.

5.2.9 Utilization of treated sewage water to be considered.

5.3 DEFINITION

The criteria and constraints mentioned above have lead to a size of 0.4 ha for the Engineering Field Test. This means that SESEA is convinced that the minimum field test size as recommended in the RFP will be sufficient to fulfill all the requirements for scaling up to a commercial size and to prove the concept.

For each sub-system the applicable criteria and constraints have been considered to define the Engineering Field Test:

5.3.1 Unit 100

Divison of the crop system in sections for separate crop growth and management. A part of the greenhouse will be used for a sand culture system. This preliminary set up gives all possibilities for scale-up without conceptual changes.
In principle, the controlled environment is a black box that can be situated in any place. The only variable is the change of climate control which is subject to a specific climate.

5.3.2 Unit 200

This unit will change as a function of well water quality and availability. Due to heavy constraints of well water availability on the Derab site SERI proposes the usage of treated sewage water as feed for the water household. Water samples will be used for task 4 design. The RO principle and pad cooling is easy to be scaled up to evaporative type commercial units.

5.3.3 Unit 300

This sub-system is at a level of 0.4 ha system size the smallest scale available to be representative for a commercial size. This applies specifically to the ORC-turbine, which at this scale-level is the smallest unit which has been constructed and operated (OTEC).

5.3.4 Unit 400

The solar pond sub-system at this scale is fully representative for the commercial size. Most of operational experience for this sub-system is of a far smaller size, and in this case the scale should be considered as a step-up to full commercial dimensions. Especially the wall effects of minimum size units will be excluded in the selected pond size.

5.3.5 Unit 500

This sub-system (electrical) is in itself not critical for scaling aspect. Conceptual change from commercial size is only adapted for cost reason by introducing back-up power from grid in stead of diesel generator.

5.3.6 Unit 600

The instrumentation sub-system is compared to the commercial size system extended in order to accomodate one of the main reasons of the Engineering Field Test, which is to prove the conceptual design of the system, as well as supply and back-up of design information for commercial size systems. To fullfill that requirement, additional recording and datalogging will be applied for a carefull selected number of operational data, which are essential for such purposes.

Where the scope of the Engineering Field Test is essentially the same as for the commercial size system (e.g. no produce storage and/or transportation), SESEA feels that the recommended Engineering Field Test, which will be further outlined in a preliminary basic design in Task IV, responds to the requirements laid down in the R.F.P.

TASK IV REPORT

PRELIMINARY DESIGN OF AN ENGINEERING FIELD TEST

CONTENTS

INTRODUCTION

Task IV of the Solar Controlled Environment Agricultural System Design consists of a preliminary design of an Engineering Field Test, (EFT) located at Derab in Saudi Arabia. See plot plan drawing Nr. DE-51372-01-26-001.

The main purpose of the EFT will be to verify the predicted performance of the commercial unit as analysed in the Task III Report and to provide real experimental data for scale-up and design of a future 5 hectare commercial unit. Full computerised datalogging is provided, which together with the extensive instrumentation, will provide all the data required for practical system and sub-system performance verification.

The size of the system described in this Report is 0.4 hectare. A further size reduction of approximately 10% will be possible for all the sub-systems without losing the possibility of scale-up. This is especially true for the freon expander which at present is at the lower limits of its performance potential.

Furthermore, the systems as described, uses the Derab site well water. Riyadh treated effluent water is under analysis and if suitable, the phase 2 design can be based on the utilization of this water instead of the Derab well water.

The proposed system is a typical scale model of the commercial unit. All sub-systems are checked against the Local Derab conditions.

An artist's impression of the proposed facilities is shown on the attached drawing nr. DE-51372-00-26-010-00-01-01.

1. PRELIMINARY DESIGN, SPECIFICATIONS AND INTERFACES

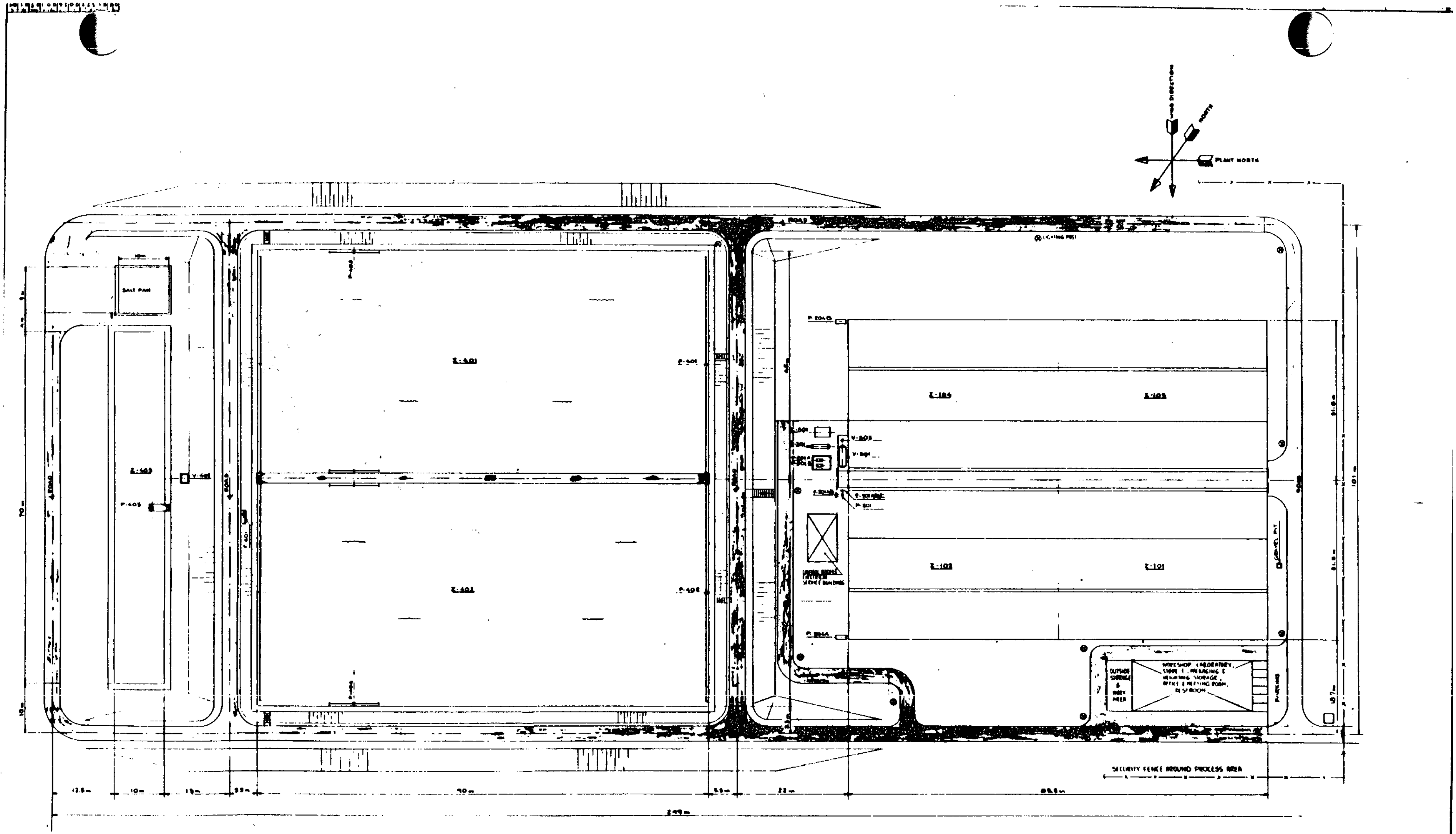
1.1 SYSTEM SPECIFICATIONS AND INTERFACES

The system specifications established by SESEA are formulated to ensure that the system design requirements are met in a focussed and efficient way. Two sets of design specifications have been identified. The first is a general set applicable to the overall system. The second set focusses on the performance of individual subsystems and the specification of their interactions to ensure satisfactory system performance is achieved. These specifications are presented in Figures IV-1 and IV-2 A/B/C. Figure IV-1 presents the overall system specifications giving total consumption/production figures, while Figure IV-2 A/B/C present sub-system specifications in terms of the individual sub-systems inputs and outputs and interfaces.

Figure IV-1
System specifications.

climate	Saudi Arabia, Derab site
insolation	Saudi Arabia, Derab site
land	14000 m^2 gross/4000 m^2 of productive land

Product output (average)		kg/m^2-yr	50
Salt output		kg/m^2-yr	20
Brackish water consumption:		m^3/m^2-yr	
	Solar Pond	9.81	
	Fresh water	1.51	
	Cooling pads	1.76	
	Total	m^3/m^2-yr	13.08
Fresh water consumption:		L/kg crop	30
Thermal energy output (avg.)		Kcal/h-m^2	68.75
Electrical energy consumption (avg. consumption generator + grid)		kW/m^2-yr	42.38
Electrical energy consumption (avg. consumption grid only)		kW/m^2-yr	15.88
Desalination energy requirement		kWh/m^3 of product water	3.0
Crop waste		kg/m^2-yr	150
Estimated life		years	20



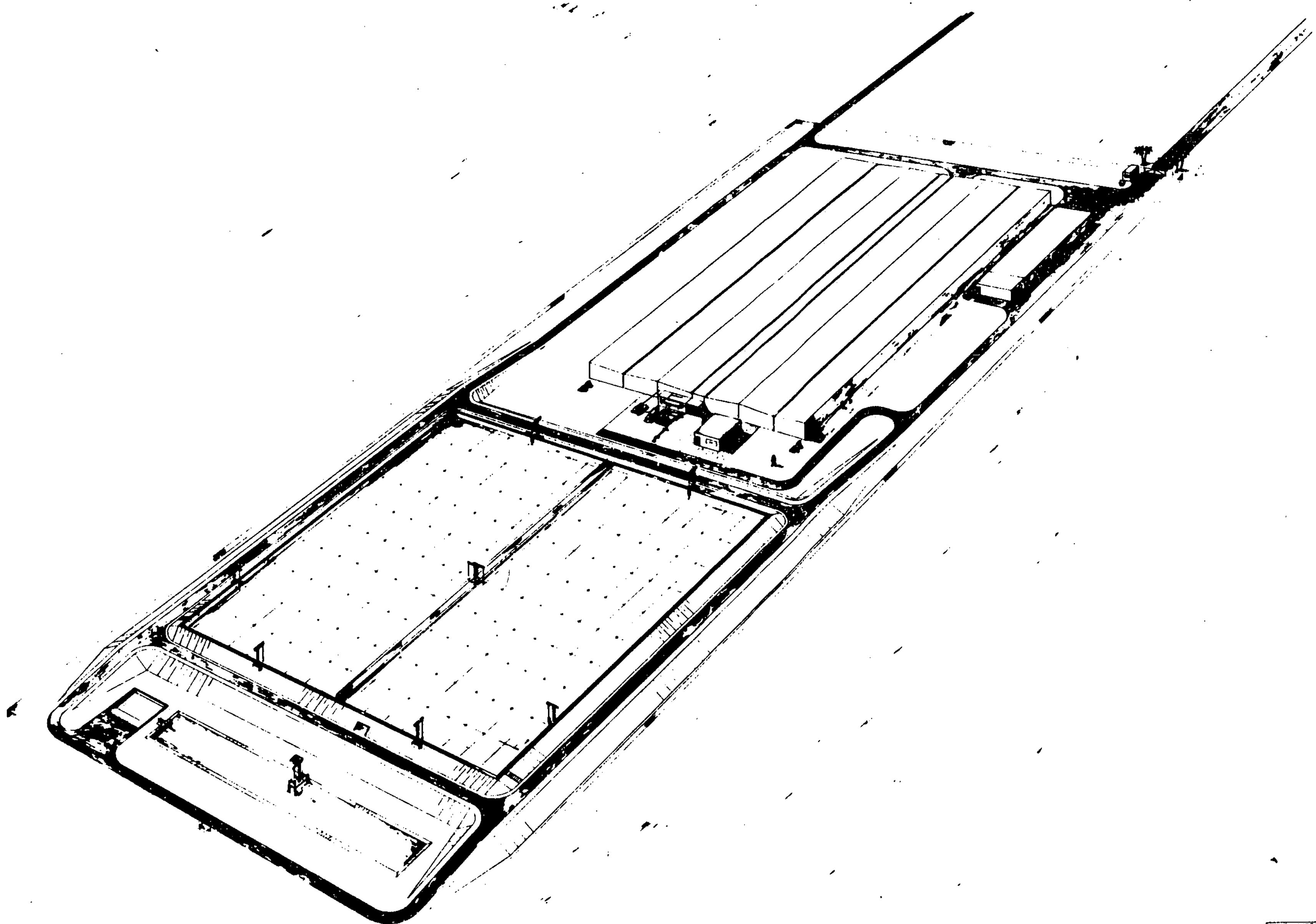
SOLAR CONTROLLED ENVIRONMENT AGRICULTURE SYSTEM PHASE I
MRI CONTRACT NUMBER

SAUDI ENGINEERING SOLAR ENERGY APPLICATIONS

1	REVISED
0	FOR STUDY

PLOTPLAN

SCALE 1 : 250



SOLAR CONTROLLED ENVIRONMENT
AGRICULTURE SYSTEM PHASE I
MRI CONTRACT NUMBER

SAUDI ENGINEERING SOLAR
ENERGY APPLICATIONS

AR... IMPRESSION OF SOLAR ENERGY GREENHOUSE COMPLEX.

REV	DESCRIPTION
0	FOR STUDY

Fig. IV-2A SUBSYSTEM SPECIFICATIONS

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS PERFORMANCE	 INTERFACE
CEA Shelter	Insolation climate heat power	Controlled climate fan power = 8.2 KW_e	Thermal integrity glazing = 5.8 $m^2 \times °C.W^{-1}$ Load to EPGS x Evaporative cooling water consumption: 7045 m^3/year cooling water pump power: 2 KW_e Glazing transmissivity in Photosynthesis band: 79%	Solar pond thermal load Load to EPGS Delivery efficiency for heating system input to NFT growing system

x Electrical Power Generating System

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS PERFORMANCE	 INTERFACE
Solar pond	Insolation water	Thermal energy	- solar Transmissivity - minimum value = .8 Minimum pond delivery temperature 68°C winter Maximum thermal energy load 872 KW_t. Summer evaporation rate 25,110 m^3/yr. Annual average operating temperature 77°C	Flushing and skimmimng system Organic rankine cycle Combined thermal and electrical load

Fig. IV-2B SUBSYSTEM SPECIFICATIONS (Continued)

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS: PERFORMANCE	SPECIFICATIONS: INTERFACE
Evaporation pond	Flushing water from solar	High salinity water	Evaporates 14300 m^3/yr	Solar pond surface washing and salinity control

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS: PERFORMANCE	SPECIFICATIONS: INTERFACE
NFT	Nutrient water	Produce energy	Nutrient consumption rate = 200 kg/m^2/yr growing in area (proprietary) Nutrient pumping power = 1.2 KW_e Water consumption 6000 m^3/year Chemical Consumption: 350 kg/year	Operating cost load to EPGS

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS: PERFORMANCE	SPECIFICATIONS: INTERFACE
Back-up power	Grid connection	Electric power	Backs up the solar pond driven EPGS and delivers to direct - connected consumers	

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS: PERFORMANCE	SPECIFICATIONS: INTERFACE
Organic rankine cycle	Thermal energy	Thermal electricity	Heat rate to evaporator 1.256 GJ/hr Condenser heat rate 1.124 GJ/hr Brine flow rate 79 m^3/hr Brine minimum temp. 64°C Brine pumps 2.5 KW_e	Thermal load to salt pond Load to exhaust from CEA shelter Depth of salt pond thermal

Fig. IV-2C SUBSYSTEM SPECIFICATIONS (Continued)

SUBSYSTEM	INPUTS	OUTPUTS	SPECIFICATIONS: PERFORMANCE	SPECIFICATIONS: INTERFACE
Desalination RO	well water power	irrigation water	65% recovery factor 50 ppm sodium level out for 1800 ppm input Feedwater pump of 1.85 KW_e 35% of water flow (RO reject) to the solar pond	Supply to NFT acts as load to EPGS Well must be sized to provide required flow

SESEA

2 PRELIMINARY DESIGN OF CEA SUB-SYSTEM, UNIT 100

2.1 PROCESS DESCRIPTION OF CEA SHELTER: See Process Flow Diagram DX-51372-00-20-001-03-001 at the end of Section 2

2.1.1 CEA Shelter Description

The CEA Shelter provides the controlled conditions required for the optimum production of crop throughout the year. To achieve this, the following criteria were established:

		DAY	NIGHT
Dry Bulb Temperature °C:	Maximum	29	25
	Mean	23	17
	Minimum	16	14
Relative Humidity % :	Maximum	85	
	Mean	75	
	Minimum	60	
Air Velocity m / sec :	Maximum	1.0	
	Mean	.3	
	Minimum	0 (Night)	
Radiation Level (PAR) W/m^2 :	Maximum	72.7	
	Mean	21.8	
	Minimum	0 (Night)	

Since the collected climatic information from the site indicated that these criteria do not correspond with the existing natural conditions, a CEA-Shelter has been designed which has the primary function of isolating the "Micro" climate inside the Shelter from the environment, while allowing sufficient Solar radiation to enter the Shelter to stimulate plant growth.

The CEA Shelter consists of a structural steel frame which is covered with double acrylic sheets for the roof and side walls. The sheets are 16 mm thick and provide excellent thermal insulation ($U = 2.9\ W/m^2\ °C$) and are also selected for their low transmission of light with frequencies above 1100 nm. A special treatment also eliminates the light with frequencies below 400 nm.

A suspended ceiling of flat fibreglass, premium, 40-mil, provides for additional filtration and diffusion of the light while creating a duct in the top part of the Shelter which is used for return of the ventilation air.

The centre part of the house is a service corridor and forms an airlock to reduce loss of cool air when entering the Shelter.

On the opposite ends of the Shelter an "Air Filter/Louver/Cooling Pad" combination allows control of the air temperature and humidity.

The ventilation air is passed over this combined package by the use of exhaust fans that remove air from the house at a maximum rate of about 0.5 m/sec.

The exhaust fans are installed in the ceiling of the Shelter with a centre to centre distance of 4 m. The air exhausted by the fans from the house is passed through the ceiling duct, providing additional cooling, and is exhausted at the end of the Shelter.

The mixture of return air and outside air is lowered in temperature due to the evaporative cooling effect of water passing over the cooling pads. A by-pass louver allows further control of humidity and temperature.

When the outside temperature is below the temperatures set for the CEA Shelter climate, the ventilating air is heated with the reject heat of the Organic Rankine Cycle and recycled in the Shelter in order to keep the temperature at the required level.

The foundation of the CEA Shelter incorporates also the raw and sweet water storage. This large volume of water will assist in stabilizing the temperatures in the Shelter.

On the outside of the roof an electrically driven shading system is provided. This system will reduce the radiation in the Shelter by 50% and as such, reduce the cooling requirement of the Shelter. The drive motors for the system are of the tubular geared type, suitable for outdoor installation.

The EFT unit will also be equipped with exhaust louvers to allow the condensor cooling air to be exhausted directly to the outside without passing through the duct.

2.1.2. Crop Production System

A 4000 m^2 crop production area is installed inside the controlled area of the CEA sub-system in order to allow for the experimental growing of crops, with the intention to test the satisfactory operation of the overall system and to provide sufficient information to upscale the production area to 5 ha for commercial operation.

The total system provides services for the growing of seedlings, a sand culture system with drip irrigation and a Nutrient Film Technique (NFT) system.

The seedlings are grown from seeds in cubes of peat-moss or "Jiffy-7" cubes. They are placed on tables and irrigated with a mist system. The temperature in this section of the Shelter is seperately controlled. The area is 500 m^2.

The sandculture system will grow plants from seedling size to full size for production over an area of 500 m^2.

The seedlings are planted in a sterile sand medium at distances varying from 0.3m - 0.6m, depending on the type of crop grown. The irrigation water, in which liquid fertilizer is injected, is provided at the base of each plant through a capilliary tube giving a small trickle flow adjusted to the average water consumption of the plant and as such minimizing wastage of water. Once properly adjusted, no water will go to the drain. However during start-up any excess water is captured in a drain tube and is disposed of in a gravel pit. A crop support system, suspended from the roof structure of the Shelter, will be used for certain vine crops.

Two methods of utilizing sand as a growing medium have proven satisfactory. One is the use of plastic-lined beds; the other involves spreading sand over the entire greenhouse floor. For ease of maintenance SESEA selected the Plastic Lined beds. Growing beds will be built as above-ground troughs with wooden sides. 20-Mil vinyl will be used for the liner. The bottom of the trough should have a slight slope of 10 cm per 25 meter, so that it can be drained or leached when necessary. The drain pipe will be placed in the entire length of the bed.

A 5 cm drain pipe is used since in sand culture only excess solution (less than 10 percent of that added) is drained. The drain pipes from all the beds should be connected to a main at one end which collects the waste water from all beds and conducts it away from the greenhouses. Drainage holes are cross-cut, one-third of the distance through the pipe every 0.50 m. The cuts must be against the bottom of the bed so that plant roots are discouraged from entering the pipes. Also, one end of each pipe should be left above the ground so that a Roto-Footer can be used to clean the pipes. The width of the beds may be 0.60 m and the depth 0.30 m. Elevating the edges of the bed above ground level prevents soil from being kicked into the sand beds.

The NFT system comprises of two major equipment sections:

A. Girocrop NFT Central Control Module

This consists of one converter ISO container, 6 metres x 2.5 metres, housing three independent nutrient circulation systems, plus three independent control consoles for monitoring and controlling the pH and conductivity; and for monitoring temperature of the nutrient solution, plus three independent automatic nutrient dosage systems and a bulk acid dispensing system for nitric and phosphoric acids.

Each nutrient circulation system comprises of two pumps (one operating and one standby). The pumps are each capable of delivering approximately 360 litres per minute.

Each of the control consoles comprises of a model 9500 automatic control and monitoring unit complete with dip probes.

The three dosage systems will each share the same three stock tanks two of which have a 1135 litres capacity plus acid tank of 680 litres capacity. Submersible, non-corrosive 500 litres per hour pumps are used.

The acid tank is served by a bulk acid dispensing unit comprising of a hand pump, manifolds and measuring glasses.

The model also includes lighting, ventilation, a hand shower, service flooring and protective clothing.

B. Girocrop NFT Hydrocanal Duct Elevated System

This system comprises of the canals and the associated pipework and equipment necessary to serve a production area of approximately 3000 square metres.

Two of the areas are in the two tray mode suitable for single row crops and the third area is in the four tray mode suitable for bed crops.

The four tray mode also includes top tray covers fabricated from high density EPS sheets which are punched to allow for a variety of plant spacings.

A supply of disposable items for the first year's operations, namely Hydrocanal Duct liner, capillary matting and insulation veneer have been included and the quantities assume 10 crop cycles per annum in the four tray areas, and 4 crop cycles in the two tray areas.

Three GRP nutrient catchment reservoirs each having a nominal capacity of 1,135 litres are also included for positioning below the Central Control Module.

2.1.3 Sizing of the Agricultural Sub-System

The selected size of the sub-system is 4000 m^2. In selecting this size it was important to consider the balance between the achievement of accurate growing results to allow the up-scaling of Engineering Field Test (EFT) to a 5 ha commercial facility and the available area for the EFT.

The requirement to produce different crops and to include both NFT and sand culture calls for a further subdivision of the CEA area resulting in relatively small growing sections:

- 2000 m2 NFT CROP 1 Tomato, Cucumber
- 1000 m2 NFT CROP 2 Lettuce, Strawberry
- 500 m2 SAND CULTURE-MULTIPLE CROPS
- 500 m2 SEEDLING AREA

A larger area is assigned to NFT culture because it promises to be the better system for future CEA development and the data will be better suited for scale-up.
The sand culture area will allow comparative measurement against any other systems of field crop production in Saudi Arabia.

A CEA system of this size will provide sufficient information to forecast production on a commerical basis, if the system were to be operated over a minimum period of two years.

2.1.4 Crop Layout for EFT

For crop type 1 each 1000 m^2 section of the greenhouse will have 100 double rows of 12.5 m long ducts, providing a total length of 12.5 x 100 x 2 = 2500 m.

Tomato plants will be spaced at a distance of 0.75 m providing a total number of 3300 plants.

Cucumber plants will be spaced at a distance of 1.50 m providing a total number of 1650 plants.

For crop type 2 the 1000 m^2 section of the greenhouse will have 150 quadruple rows of 12.5 m long ducts, providng a total length of 12.5 x 150 x 4 = 7500 m.

Lettuce will be spaced at a distance of 0.4 m providing a total number of 18,750 heads.

The alternate crop, strawberries, will be spaced at a distance of 0.50 m providing a total number of 15,000 plants.

2.1.5 General Layout

The Derab site on which the EFT will be constructed, has, due to its location in a valley, little early morning or late evening light. To make the available light period in the CEA Shelter last as long as possible, the CEA Shelter should be arranged in such a way that the minimum of structural shading takes place for lights coming from an Easterly or a Westerly direction. Since the Solar attitude in the South Position of this location is generally above 45°C, the unavoidable mechanical obstructions will be placed mainly on the North side and where this is not practical, on the South side.

The internal layout of the CEA Shelter is designed to allow the individual areas as indicated in 2.1.3. above, to be controlled and operated independently.

The central corridor, which is fully shaded, acts as an airlock and also provides a passage way for servicing. This eliminates the use of the growing section as a passage way and thus facilitates disease and Pest control. The main corridor also provides a space for equipment installation and remote read-outs for each section and its doorways allow entry into the individual CEA growing sections.

The seedling section and the sand culture section, which both use sweet water for irrigation, are located next to each other.

The NFT nutrient tanks and supply system are centrally located in the main corridor floor section and as such, allow a convenient distribution of the nutrient flows.

The size of the CEA growing sections is in the main controlled by the effective length of the ventilation path. This has been established as 25m with a section on each side of the main corridor. The overall length will be about 80m.

2.1.6 CEA Sub-System Process Flow

The CEA Shelter, the main function of which is the control of micro climate, has been shown in detail on the process flow diagram for sub-system unit 100.

A minimum amount of ventilation will allways be required for the condensing cycle of the organic rankine cycle system. This has been established at about 40% of the total ventilation, therefore a minimum airflow of 0.12m/sec. will allways take place in the Shelter.

This airflow is induced by the ventilating fans (C-101-102-103-104 A/K) which are installed in the roof section of the Shelter, equally spaced over the total length of the house. The total number of fans are twenty units for each side. A minimum number of eight fans will be operating on each side, inducing an airflow through the Shelter.

This airflow, is increased in temperature by about 1.5 °C for each passage over the condenser. The airflow which passes over the condenser is returned via the roof duct to the mixing chamber at the end of the house. In the mixing chamber a control louver (X-105-106-107-108 A/B) allows the circulated air to exhaust and fresh air to enter.

The position of the louver is controlled via the tempreature control system and adjusted in such a manner that the balance between the outside air and recirculation air provides the right temperature. If the temperature in the house increases, a greater number of fans will be switched on, this will increase the ventilation rate of the Shelter and as such, remove more solar heat. This process continues until all fans are in operation. If at this time the house temperature continues to increase the evaporative cooling system is started. The louver (X-109-110-111-112 A/B) is closed and air is passed through cooling pad (X-101-102-103-104) over which a cooling water flow passes by means of pump (P-101-102 A/B). The pumps are located on either side of the greenhouse. Two pumps for each section of raw water reservoir. One pump is designed to operate with one as stand-by. The stand-by pumps will alternately supply the solar pond with its required make-up water thus controlling the salinity of the raw water.

In summary, the main control louver mixes the outside air with circulated air, for a suitable mix, to be cooled by the cooling system. The air louver below the cooling pads will bypass certain amounts of air if the humidity of the air in the Shelter reaches 85%. As a result of this bypass, the temperature in the shelter will increase and thus reduce the humidity to an acceptable level. The system is adjusted to control in such a manner that the temperatures as set in the criteria will be maintained.

A shading system is provided if the temperature in the shelter continues to increase because of too much solar radiation. This system reduces solar radiation by 50%. Shading is removed once the temperature reaches a level that it can be controlled without the use of shading.

When the temperature in the Shelter drops, the fans will be switched off commensurate to the requirement for the condensers. The moment that the minimum number of fans are in operation and the temperature continues to drop, the evaporative cooling is switched off. If the temperature continues to drop the main control louver will close and allow recirculation of heated air over the condenser. This operation mode is only expected during short periods of the winter nights, when heating is required.

2.1.7 Agricultural Sub-System Process Flow

The agricultural process requirements are, other than the climate as described above, mainly water and nutrient flow. The irrigation water for the seedling area and the sand culture area is drawn directly from the sweetwater storage tank via pump P-107 and supplied to the respective areas. The solenoid valves interlocked to a timing device allow intermittent irrigation of both areas.

A fertilizer injector is automatically operated on the water pressure to provide liquid fertilizer for the sand culture system.

The NFT solution is prepared with the automatic control system that is preset at the required pH and conductivity levels. The nutrient dosing and acid pumps (P-108-109- 110-111-112-113) inject suitable combinations of nutrient in the reservoir (V-103 A/B) which is filled with sweet water from reservoir V-102 A/B.

The NFT circulating pumps (P-105-106 A/B) draw the nutrient solution from the reservoirs and circulate it through the NFT growing channels from which the remaining nutrient is drained by gravity flow and returned to the reservoir V-103 A/B.

The continuous monitoring system assures suitable nutrient levels at all times.

2.2 CIVIL DESCRIPTION OF CEA SHELTER

2.2.1 Scope

This description covers the design of the concrete structures in the CEA Shelter, consisting of the foundation of the greenhouses and the reservoirs for raw and treated water.

2.2.2 Design Conditions

Design calculations have been made under the following conditions :

1. The main structural beams of the greenhouse are formed of steel sections and for the columns, steel pipes are envisaged. Total load (live + dead) about 1.2 KN/m^2.

2. Allowable soil pressure is 120 KN/m^2 (= 1.2 kgf/cm^2).

3. Live uniform load on flooring on top of storage tanks is 4 KN/m^2.

4. Live concentrated load on floor, on top of treated water storage, is 5 KN/m^2 excluding live uniform load).

2.2.3 Raw Water Storage, V-101 A/B

Structural design calculations indicated that a thickness of 0.15 m of reinforced concrete is required for base, walls and top floor.

Since making form work for the top floor is very difficult, it is recommended to make this floor with precast concrete slabs. Floor elements may be cast and partly matured elsewhere, on a suitable spot on the site, before being lifted into their position by a crane.

If one element is used (seen in cross-section) supported by the three walls, it is very likely that a space develops between the precast top floor and one of the walls due to dimensional deviations of the points of supports and/or the precast floor.

To prevent this and to fix the precast top floor with the remaining structure (cast-in-situ), it is proposed to cover each half of the cross-section with two separated precast floor elements, keeping a space between the two elements on the top of the centre wall. This space can be filled with concrete.

2.2.4 Treated Water Storage, V-102 A/B

Structural design calculations indicated that a thickness of reinforced concrete of 0.20 m is necessary for base and walls and 0.15 m for the top floor.

As described for the raw water reservoir, it is recommended to make the top floor with precast concrete, too.

To prevent obstructions for trucks and trolleys being pushed across the joints of two floor elements, due to different bending of the elements, it is proposed to make a concrete dowel, causing an equal bending at the joint.

2.2.5 Joints

To reduce restraint in longitudinal direction after casting of the slab and the walls of the tanks, it is recommended to make crack inducers.

Spacing should be about 5 m. Expansion joints are to be used to allow for longitudinal expansion of the wall due to thermal heating during the setting and early hardening process of the concrete and to allow for relative movements or displacements due to differential movement of the foundation or applied loads.

It can be assumed that in this case, a spacing of 40 m is satisfactory, giving one expansion joint at the longitudinal centre of the tanks.

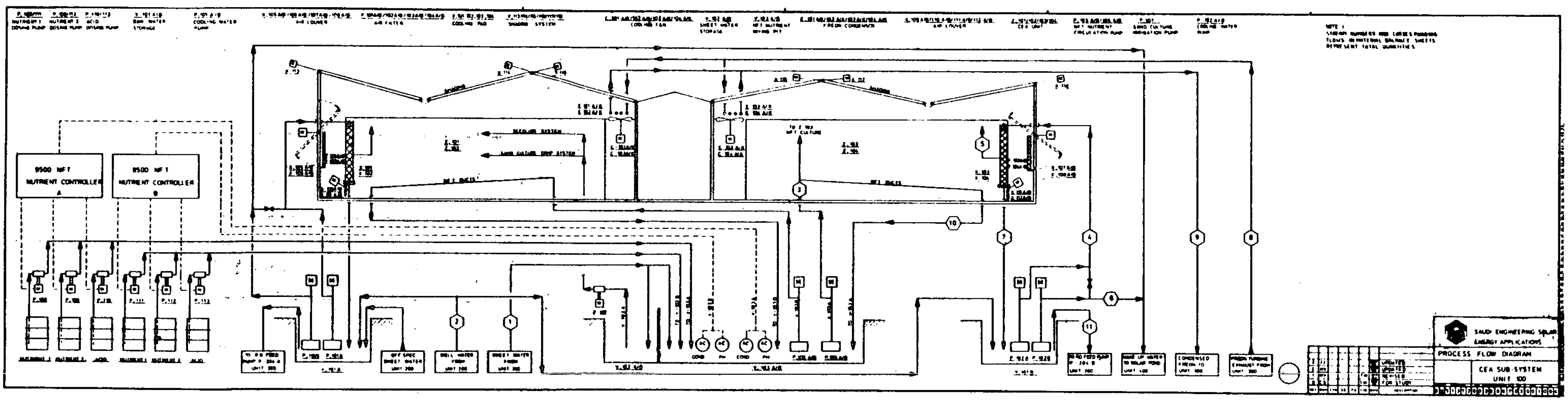
Waterstops in the joints are not necessary, as the inside of the reservoir is covered with a water tight polyethylene sheet.

2.2.6 Footings for Columns

Design calculations indicated that a bearing of 0.74 x 0.74 m^2 is necessary.

To prevent horizontal movement it is recommended to put the bottom of the footing at a depth of 0.4 m.

It may be considered to make the footings with precast concrete. Making the formwork will be very simple in this way.



9500 NFT
NUTRIENT CONTROLLER
A
9500 NFT
NUTRIENT CONTROLLER
B
SAUDI ENGINEERING SOLAR
ENERGY APPLICATIONS
PROCESS FLOW DIAGRAM
CEA SUB-SYSTEM
UNIT 100

Unit 100 PFD

A - 20 - 168 - 2

SESEA

EQUIPMENT_ LIST

JOB NO. : 01-51372
AREA NO.: 100
SHEET : 1 OF 9

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
C-101 A/K	COOLING FAN	10	42" wall fan cap. 15970 Nm^3/h Static press: 3.2 mm WC RPM : 330 Motor: 0,25 kW Model: 56014223A	CS casing Alloy Stl Impeller	ACME	2 common	
C-102 A/K	COOLING FAN	10	"			spares in ware house	
C-103 A/K	COOLING FAN	10	"				
C-104 A/K	COOLING FAN	10	"				

NOTES :

DA - 20 - 168 - 2

EQUIPMENT_ LIST

SESEA

JOB NO. :01-51372
AREA NO.: 100
SHEET :2 OF 9

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
E-101 A/K	FREON CONDENSER	10	Air-cooled finned 1" x 40 tubes 2200 mm length & 1270 mm bundle width one pass. Duty: 6710 kcal/h per unit	C.S. tubes Al fins			1
E-102 A/K	FREON CONDENSER	10	"	"			
E-103 A/K	FREON CONDENSER	10	"	"			
E-104 A/K	FREON CONDENSER	10	"	"			

NOTES :

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EQUIPMENT_LIST

SESEA

JOB NO. :01-51372
AREA NO.: 100

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV
F-101 A/B	AIR FILTER	2	Size: L x H x W = 20 x 1.8 x 0.2 m Type: Inertia Filter	Gal. Stl Sheet	American Air Filter	Assembled on Site	
F-102 A/B	AIR FILTER	2	"	"	"	"	
F-103 A/B	AIR FILTER	2	"	"	"	"	
F-104 A/B	AIR FILTER	2	"	"	"	"	

NOTES :

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EQUIPMENT_LIST

SESEA

JOB NO. : 01-51372
AREA NO.: 100

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
P-101 A/B	COOLING WATER PUMP	1	Cap.: 30 m^3/h NPSH : 10 m S.G.: 1.0 Motor: 1.1 kW TDH : 6 m Type : Vert. subm.				
P-102 A/B	COOLING WATER PUMP	1	Cap.: 30 m^3/h NPSH : 10 m S.G.: 1.0 Motor: 1.1 kW TDH : 6 m Type : Vert. subm.				
P-103						Spare pump numbers	
P-104						"	
P-105 A/B	NFT NUTRIENT CIRCULATION PUMP	2	Cap.: 20 m^3/h NPSH : 10 m S.G.: 1.0 Motor: 0.75kW TDH : 2.5 m Type : Vert. subm.				
P-1 6 A/B	NFT NUTRIENT CIRCULATION PUMP	2	Cap.: 10 m^3/h NPSH : 10 m S.G.: 1.0 Motor: 0.37kW TDH : 2.5 m Type : Vert. subm.				
P-107	SAND CULTURE IRRIGATION PUMP	1	Cap.: 0.2 m^3/h NPSH : 7.8 m S.G.: 1.0 Motor: 0.06kW TDH : 12.7m Type : Pos. Displ.			With warehouse spare	
P-108	NUTRIENT 1 DOSING PUMP	1	Included in 9500 NFT controller package		Soil-less cultiva-tion sys-		
P-109	NUTRIENT 2 DOSING PUMP	1	"		tems Ltd. Haslemere U.K.		

NOTES :

DA_20_168_2

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO : 100
SHEET : 5 OF 9

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
P-110	ACID DOSING PUMP	1	Included in 9500 NFT controller package		Soil-less cultiva-tion sys-tems Ltd Haslemere U.K.		
P-111	NUTRIENT 1 DOSING PUMP	1	"				
P-112	NUTRIENT 2 DOSING PUMP	1	"		"		
P-113	ACID DOSING PUMP	1	"		"		

NOTES :

DA_20_168_2

EQUIPMENT_LIST

JOB NO. :01-51372
AREA NO.: 100
SHEET :6 OF 9

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
V-101 A/B	RAW WATER STORAGE	2	Inside dimensions: H x W x L = 1.0 x 1.5 x 80.5 m	concrete			
V-102 A	SWEET WATER STORAGE	1	Inside dimensions: H x W x L = 1.75 x 3.0 x 34.0 m	concrete		Concrete top provided with manhole	
V-102 B	SWEET WATER STORAGE	1	Inside dimensions: H x W x L = 1.75 x 3.0 x 42.5 m	concrete		"	
V-103 A/B	NFT NUTRIENT MIXING PIT	2	Inside dimensions: H x W x L = 1.75 x 3.0 x 1.8 m	concrete		"	

NOTES :

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EQUIPMENT_LIST

SESEA

JOB NO. :01-51372
AREA NO.:100
SHEET :7 OF 9

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
X-101	COOLING PAD	1	Size : L x H x W = 40 x 1.8 x 0.15 m	treated cellulose	ACME		
X-102	COOLING PAD	1	"	"	"		
X-103	COOLING PAD	1	"	"	"		
X-104	COOLING PAD	1	"	"	"		
X-105 A/B	AIR LOUVER	2	Size: L x H = 20 x 1.5 m Operator: 90 W motor with gear (100 Kgm Torque) Model: VC-200	Double Acrylic Sheet	Rohm Wads-worth	Assembled on site	
X-106 A/B	AIR LOUVER	2	"	"	"	"	
X-107 A/B	AIR LOUVER	2	"	"	"	"	
X-108 A/B	AIR LOUVER	2	"	"	"	"	
X-109 A/B	AIR LOUVER	2	Size: L x H = 20 x 0.6 m Operator: 90 W Model = WPC 2626 MT	Alum.	ACME	Assmbled out of 33 PC of this model	

NOTES :

DA_20_168_2

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 100
SHEET : 8 OF 9

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
X-110 A/B	AIR LOUVER	2	Size: L x H = 20 x 0.6 m Operator: 90 W Model = WPC 2626 MT	Alum.	ACME	Assembled out of 33 PC of this model	
X-111 A/B	AIR LOUVER	2	"	"	"	"	
X-112 A/B	AIR LOUVER	2	"	"	"	"	
X-113	SHADING SYSTEM	1	44 PC of shading assembly 1.8 m wide, 10 m long providing 50% shade, motor operated 2 kW	Alum.	Nutri-culture		
X-114	SHADING SYSTEM	1	"	"	"		
X-115	SHADING SYSTEM	1	"	"	"		
X-116	SHADING SYSTEM	1	"	"	"		
X-117	SHADING SYSTEM	1	"	"	"		
X-118	SHADING SYSTEM	1	"	"	"		

NOTES :

DA_20_168_2

SESEA

EQUIPMENT_LIST

JOB NO. :01-51372
AREA NO.:100
SHEET :9 OF 9

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
Z-101	CEA UNIT	1	H x W x L = 2.4 x 31.65 x 41.6 m with double roof			Sand culture green house	
Z-102	CEA UNIT	1	"			NFT-culture green house	
Z-103	CEA UNIT	1	"			"	
Z-104	CEA UNIT	1	"			"	

NOTES :

3 PRELIMINARY DESIGN OF WATER SUB-SYSTEM, UNIT 200

3.1 PROCESS DESCRIPTION: See Process Flow Diagram DX-51372-00-20-001-01-002, at the end of Section 3.

3.1.1 Well Water

Raw water is pumped out of the well by P-201 and sent to the raw water storage V-101 A/B in unit 100. Pump P-201 is a vertical submerged centrifugal pump with a suction filter and an internal checkvalve. The pump is running approximately 18 hrs. and during the remaining 6 hrs. of daytime, the pump can be stopped to reduce peak consumption of electricity. A spare pump will be provided. For well water supply requirements, see Fig. IV-17 in Section 9.

3.1.2 Raw Water Storage

The storage of raw water in V-101 A/B, is based on the requirement that there will be 7 days' supply of water to satisfy the evaporative loss from the cooling pads. This gives an approximate capacity of 250 m^3 which is divided into two equal sections running the full length of the greenhouse in the form of a concrete trench 80m L x 1.5m W x 1.15m Depth. In the middle section of this trench support footings for the cooling pads are provided. From this storage, the reverse osmosis system and the make-up water to the solar pond are fed. The raw water is periodically treated with sodium hypochlorite in order to control algea growth.

3.1.3 Osmosis unit (RO)

Water is pumped out of the raw water storage by RO-feed pumps P-204 A/B at an average flow rate of 25.5 m^3/h. On the suction line of each pump a set of flexible couplings are provided for connection to the dosing pumps (P-202/203/205) which are to be skid mounted and portable. This is due to the fact that the long distance separating the two feed pumps does not justify installation of a common suction line with a permanently installed dosing system. The portable set of dosing pumps will be connected to the suction line of the RO-feed pump which is in operation. A common spare pump will be provided for P-202/203/205. For the RO-feed pumps, a reciprocal pump type is chosen, which is able to operate at a high efficiency with a negative suction pressure and a high discharge pressure (30 kg/cm^2g). To overcome excessive pulsation in the flow to the permeators, pulsation bottles (V-201 A/B) will be provided on the discharge of each pump (P-204 A&B), reducing the pulsation to 1-2%.

With P-204 A/B, raw water is first sent through a 5 micron cartridge filter F-201 A/B. The spare filter is provided to ensure continuous operation during replacement of a fouled cartridge. After the filters, raw water flows through the first stage (X-201 A/B) and the second stage (X-201 C) permeators of the reversed osmosis unit.

Reject, "high salinity" water (avg. 8.9 m^3/day) from the osmosis unit is flow controlled and sent to the solar ponds for partial make-up. Sweet, "low salinity" water (avg. 16.6 m^3/day) is sent to the sweet water storage in unit 100.

3.1.4 Control of the osmosis unit

Conductivity and pH of raw water are continuously analysed and the pH-analyser automatically controls the dosing of sulphuric acid by stroke adjustment of pump P-202. Rate of dosing pumps P-203 and 205 can be set manually, by stroke adjustment. To protect the osmosis system against overpressure a kick-back control, actuated by a pressure controller, is provided over P-204 A/B. Capacity of pump P-204 can be set manually by stroke adjustment. High temperature or pressure of raw water to the osmosis unit will automatically stop the RO-feed pumps P-204 A/B. Reject water from the RO unit is flow controlled.

Fouling of the cartridge filters is indicated by a differential pressure indicator with alarm. High salinity of the sweet water (due to failure or rupture of permeators) is indicated by a conductivity analyser at the outlet of the permeators. In case of high conductivity, product water will be automatically returned to the raw water storage.

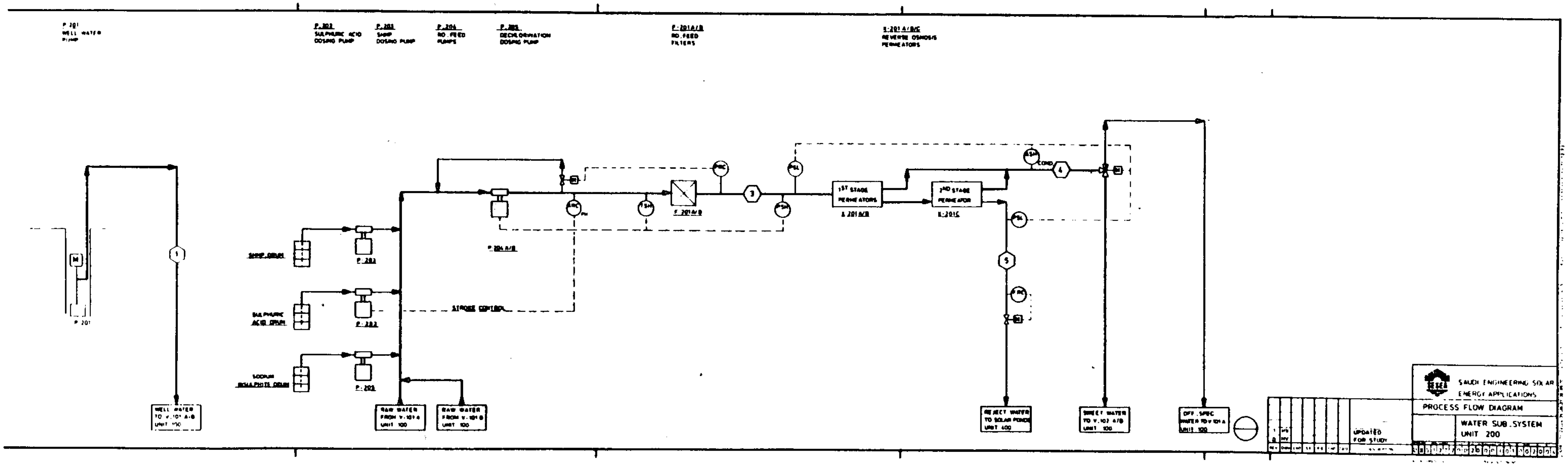
3.1.5 Sweet water storage

The storage of sweet water, in V-102 A/B, is based on the requirement that there will be 20 days' supply based on the normal consumption rate. This gives a storage capacity of approximately 350 m^3 which is provided in the central section of the greenhouses, under the central service corridor, in two sections of concrete trench with V-102 A having 34m L x 3m W x 1.75m Depth and V-102 B having 42.4m L x 3m W x 1.75m Depth. The central part of the trench forms two concrete storage tanks, V-103 A/B, for NFT feed and return fluid. The dimensions of each tank being L x W x D = 1.3m x 3m x 1.75m.

3.2 DESCRIPTION OF REVERSED OSMOSIS PROCESS

Osmosis is a natural phenomenon which takes place when two solutions of different concentration (e.g. pure water and saline water) are separated by a semi-permeable membrane. A semi-permeable membrane is a membrane which is permeable to solvents (pure water) and is impermeable to solutes (dissolved salts). Water will flow through the membrane from a dilute salt solution into a concentrated salt solution, thereby diluting the latter. This flow will continue until the pressure created by the osmotic head equals the osmotic pressure of the salt solution

Osmosis is reversible. If a pressure higher than the osmotic pressure is applied to the concentrated salt solution, the result will be:


P 201
WELL WATER
PUMP
P 202
SULPHURIC ACID
DOSING PUMP
P 203
SHMP
DOSING PUMP
P 204
RO FEED
PUMPS
P 205
DECHLORINATION
DOSING PUMP
F 201 A/B
RO FEED
FILTERS
S 201 A/B/C
REVERSE OSMOSIS
PERMEATORS
1ST STAGE
PERMEATORS
2ND STAGE
PERMEATOR
STROKE CONTROL
WELL WATER
TO V 101 A-B
UNIT 100
RAW WATER
FROM V 101 A
UNIT 100
RAW WATER
FROM V 101 B
UNIT 100
REJECT WATER
TO SOLAR PONDS
UNIT 400
SWEET WATER
TO V 102 A/B
UNIT 100
OFF SPEC
WATER TO V 101 A
UNIT 100
UPDATED
FOR STUDY
SAUDI ENGINEERING SOLAR
ENERGY APPLICATIONS
PROCESS FLOW DIAGRAM
WATER SUB-SYSTEM
UNIT 200

Unit 200 PFD

DA_20_168_2

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 200
SHEET : 1 OF 4

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
F-201 A/B	R.O. FEED FILTER	2	Cap : 2.2 m^3/h of water; filter:5 microns Model: LM 010-316 S/S - $^3/_4$ HP	316 SS	Ama Filter		

NOTES :

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SESEA

EQUIPMENT_LIST

JOB NO. :01-51372
AREA NO.:200

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA		MATERIAL	VENDOR	REMARKS	REV.
P-201	WELL WATER PUMP	1	Cap : 11 m^3/h S.G.: 1.0 TDH : 105 m	NPSH : 9.5 m Motor: 5.0 kW Type : Vert. Subm.	316 SS		With warehouse spare	
P-202	SULPHURIC ACID DOSING PUMP	1	Cap : 100 cc/h S.G.: 1.8 TDH : 0.8 m	NPSH : 4.7 m Motor: 0.25 kW Type : Dosing	316 SS		One common spare in Warehouse	
P-203	SHMP DOSING PUMP	1	Cap : 100 cc/h S.G.: 1.0 TDH : 0.7 m	NPSH : 9.3 m Motor: 0.25 kW Type : Dosing	316 SS			
P-204 A/B	R.O. FEED PUMP	2	Cap : 1.2 m^3/h S.G.: 1.0 TDH : 300 m	NPSH : 9.5 m Motor: 2.2 kW Type : Pos. Displ.	316 SS			
P-205	DECHLORINATION DOSING PUMP	1	Cap : 100 cc/h S.G.: 1.0 TDH :	NPSH : 9.3 m Motor: 0.25 kW Type : Dosing	316 SS		Common spare with P-202/ P-203	

NOTES :

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SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 200
SHEET : 3 OF 4

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
V-201 A/B	PULSATION BOTTLE	2		316 SS		Supplied with P-204 A/B	

NOTES :

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EQUIPMENT_LIST

SESEA

JOB NO. : 01-51372
AREA NO.: 200

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
X-201 A/B/C	REVERSE OSMOSIS PERMEATORS	3	"Du Pont" 4" Dia B-9 Permeator Model no. 0420-024N	Fiber glass epoxy	Du Pont		

NOTES :

- For the pure water to pass through the membrane and thus dilute the concentrated salt solution.
- The direction of flow is reversed and pure water is pressed through the membrane. The membrane retains the dissolved salts, any bacteria, and all particles however fine they may be.

Dissolved salts, retained by the membrane are continuously flushed from the system. The concentrate (reject water) will contain a high level of dissolved salts, while the product (sweet water) will contain a low level.

Reverse Osmosis is a concentrating process. Along the membranes, and in the reject from the modules, the various salts present in the raw water become approximately 3 times more concentrated. Fouling and precipitation must therefore be strictly avoided. In order to prevent this from happening, raw water will be completely analysed. The quality of raw water will be checked continuously during operation by pH and conductivity measurements.

The high Calcium, Bicarbonate, Sulphate and Silica contents of raw water (well water) necessitates pretreatment to avoid any precipitation. Sulphuric acid will be injected (automatically on pH-control) to control the pH and therefore avoid Calcium Carbonate and Silica precipitation. Sodium hexameta phosphate (SHMP) will be injected to avoid Calcium Sulphate precipitation. Biological matter will be partly removed by a fine filter (5 micron cartridge filter).

For the reduction of Chlorine (from Sodium Hypochlorite-dosing in raw water storage), Sodium Bisulphite will be used.
Periodical cleaning of the membranes will be done with a solution of Citric Acid in water.
For detailed performance see subchapter 9.4, Performance Analysis Water Sub-system.

3.3 MATERIALS OF CONSTRUCTION

3.3.1 Piping

The fluid used in the water sub-system is low salinity water (0.2 - 0.6%). Due to the sensitivity of the osmosis unit to iron ions, corrosive resistant materials must be used. For low pressure service (well water lines), glasfibre reinforced plastic is selected. For high pressure service (osmosis unit), SS-316 L is selected, which has excellent resistance to low chloride, Phosphate and Sulphuric Acid concentrations.

3.3.2 Pumps

All pumps will be constructed of SS-316L.

4 PRELIMINARY DESIGN OF ORGANIC RANKINE CYCLE SUB-SYSTEM UNIT 300

4.1 INTRODUCTION

The essential function of the Organic Rankine Cycle as defined in this Section is to convert the energy, accumulated in the Solar Pond, into the energy demand of the key-sub-system (the CEA-Sub-system) in the most effective way. This is achieved by applying the heat pump principle whereby an organic fluid (in this case Freon 114) is pumped and heated in the liquid state to the vaporization temperature, vaporized at constant pressure and temperature, expanded isentropically to condenser pressure, and condensed at essentially constant pressure. About 87 percent of the theoretical enthalpy drop on isentropic expansion is recovered as "work" in the expander. Coupled with mechanical losses in the expander, gear reducer, and generator, the net overall efficiency is about 75 to 85 percent of the theoretical enthalpy drop. The choice of Freon 114 has been justified, in detail, in Task 3 Report.

4.2 PROCESS DESCRIPTION: See Process Flow Diagram DX-51372-00-20-001-02-003 at the end of Section 4.

4.2.1 Vaporization

Freon 114 from freon storage vessel, V-301, at a temperature of 34°C and pressure of 2.96 Kg/cm^2a is pumped by means of freon pumps P-301 A/B to the freon vaporizer E-301, operating at a pressure of 10.3 Kg/cm^2a, this being the saturation pressure of Freon 114 at 84°C. This temperature and pressure corresponds to the highest values which can be achieved by using as heating medium brine from the solar pond, estimated to have a maximum summer temperature of 89°C. Allowing 5°C approach for design, 84°C was taken to be the maximum vaporization temperature. The corresponding brine and freon vaporization temperatures for winter are 68°C and 63°C respectively. The liquid level in the vaporizer is maintained by level control mechanism adjusting the strokes of the positive displacement type freon feed pumps P-301 A/B. The level will be maintained such that there will be sufficient free space available for disengagement of vapour and liquid. The outlet nozzle is also designed with a view to prevent liquid carry-over. The vaporizer and piping are insulated for both personnel protection and heat conservation. The 4" vapor pipe will be kept warm to prevent condensation of freon by allowing the hot brine to first pass through a 6" jacket provided for the vapor pipe.
The vaporizer is provided with high and low level alarms with a high-high level switch interlocked to shut down the expander machine. Pressure and temperature of freon vapour to the expander is continuously monitored.

Brine flow through the vaporizer is controlled by means of a flow controller which modulates a bypass valve on the brine circuit. This flow controller is however, reset by a pressure controller sensing the differential pressure across the main throttling valve to the expander, which in turn, is regulated by the expander speed controller.

The latter, is in fact the master controller of the system because any temperature or pressure changes in the system will be immediately reflected in an increase or decrease of the expander rotar speed.

4.2.2 Freon Expander

Saturated freon vapors at a pressure of 10.1 Kg/cm^2a and 84°C enter the expander and are exhausted as superheated vapors at a pressure of 3 Kg/cm^2a and 53°C. Pressure and temperature of the exhaust freon is continuously monitored. The expansion of the freon drives the rotar at a speed of 23000 RPM which is then reduced in a gear box to 3600 RPM for the A.C. generator. The selected expander from ROTOFLOW CORPORATION is a nominal 100 kW OTEC single stage turbine coupled to a gear box and an A.C. generator with generator output of 28.6 kW. The expander, gear box and generator unit are mounted on a 2m x 1.2m skid.

The expander is provided without lube oil pumps. The ball bearings are open and non pre-lubricated. The lube oil system is a non-pressurized, splash-type system. No contamination of this lubricating oil with the expander process fluid occurs. Expander high speed shaft seal is a labyrinth type, pressurized with the working fluid as a buffer medium.

4.2.3 Freon Condensation

Superheated vapors from the expander exhaust flow to finned tubes of freon condenser, (E-101 A/K, E-102 A/K, E-103 A/K and E-104 A/K) located in the CEA sub-system. The condenser tubes are designed integrally with the cooling fans of the CEA sub-system and consist of 40 x 1" tubes of 2200 mm length and 1270 mm total bundle width. There are 40 condenser bundles each designed for a duty of 6710 Kcal/h. The fan and the tube bundle are located in a horizontal position with a slope to the tubes for gravity drainage into the liquid header. For ease of piping arrangement, 2 x 6" C.S. headers are provided for vapor flow, one on either side of the central corridor. The vapour headers are each provided with a vertically located vent drum to purge out non- condensible vapours. Likewise 2 x 3" liquid headers carry the condensed freon back to the freon storage vessel. A gradient is given to the liquid pipe for natural drainage to the storage vessel. Additionally, the liquid pipe will be kept at condensation temperature by providing the 3" pipe with a 4" concentric pipe jacket through the annulus of which, the solar pond make-up water will flow. Each condenser bundle can be blocked-off from vapour and liquid sides.

Because of the fact that the vapor header is designed with negligable pressure drop, it is not considered necessary to swage the pipe in order to obtain even distribution of flow. In any event freon vapor will flow to the point of lowest pressure, that being the heat sink provided by those condensers which will be loaded less than others.

4.2.4 Freon Storage

Freon storage vessel, V-301 is used for the purpose of receiving condensed freon, as head tank for the freon pumps and as a receiver vessel for fresh freon. The capacity of the vessel is designed on the basis of containing a reasonable inventory as well as a sufficient level in the drum for operation of the pumps plus a minimum vapour space requirement. This results in a total vessel volume of 5 m^3. Liquid freon in the vessel is not vented and sits under its own vapour pressure. Temperature, and pressure in the vessel are continuously monitored and low level will be alarmed.

The vessel is located in an annex of the greenhouse in order to maintain reasonable environmental conditions so as to prevent changes in vessel temperature and hence pressure.

4.2.5 Freon Feed Pumps

The freon feed pumps, P-301 A/B are installed with the view of one operating and one as stand-by. Because of the relatively low flow (6.3 m^3/h) and high head (59 m liq. col.), a positive displacement pump of the diaphragm type is selected in view of its high efficienty. Pulsation dampeners, V-302 A/B installed on the pump discharges reduce pulsations to approx. 2%. Capacity control is achieved by adjustment of stroke, reset by level control of freon in the vaporizer.

Freon losses can be made-up by a hose connection in the suction of the pump. Because of NPSH requirements the pumps are located in a pit outside of the building. The location of he pumps is set by the elevation of the storage vessel, the elevation of which is in turn set by the slope given to the liquid return line from the freon condenser.

4.2.6 Vacuum Pump

The function of the vacuum pump, P-303 is for start-up of the system. The largest portable pump has been selected which will pull a vacuum consistant with total air leakage into the system. The expander can be by-passed and vacuum can be pulled on both sides of the feed pumps. The purpose of putting the system under vacuum is to reduce the amount of non-condensible gases to a minimum before system start-up. Once the freon system is pressurized, periodic purging to atmosphere must be performed to ensure complete removal of all non-condensible gases which would, if allowed to remain, vapour lock the condensers and reduce system efficiency.

4.3 MECHANICAL DESIGN CONDITIONS

The mechanical design conditions of the freon system are determined by the conditions in the vaporizer. The shell side design pressure of the vaporizer will be the highest saturation vapor pressure of freon 114 commensurate with the design temperature.

The highest operating temperature of the brine system is assumed to be 90°C. Allowing 20°C margin for design, the highest temperature will be 110°C. With this temperature on the tube side of the vaporizer, a vapour pressure of 15.5 Kg/cm^2g can be generated. This being saturation pressure and temperature, their values set the design conditions for the whole freon circuit. These design conditions are higher than those which can be generated as a result of abnormal ambient temperatures or temperatures produced by direct rays of the sun.

For mechanical design, full vacuum must also be considered in view of the use of a vacuum pump.

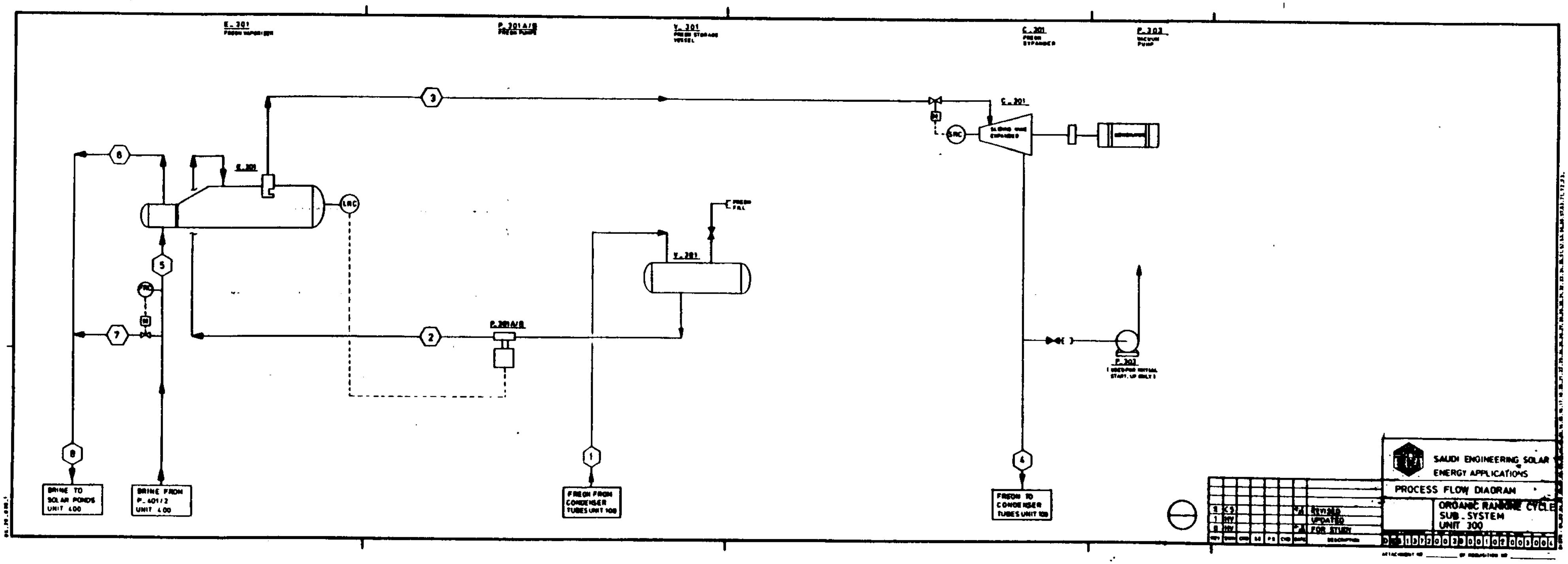
The freon design conditions are therefore:

Pressure	:	15.5 Kg/cm^2g and full vacuum
Temperature	:	110°C
Flange rating:		150 lbs ANSI

4.4 MATERIALS OF CONSTRUCTION

Carbon Steel is used throughout the freon system with Carbon Steel piping and ball valves.

For the tube side of the vaporiser, where brine is circulating, the tube material is titanium. Vaporizer tube sheet is monel and channel is rubber lined.


E.201
P.201A/B
V.201
C.201
P.202
3
6
E.201
LRC
FREON FILL
V.201
5
2
P.201A/B
7
C.201
SRC
P.202
8
1
4
BRINE TO SOLAR PONDS UNIT 400
BRINE FROM P.401/2 UNIT 400
FREON FROM CONDENSER TUBES UNIT 100
FREON TO CONDENSER TUBES UNIT 100
SAUDI ENGINEERING SOLAR ENERGY APPLICATIONS
PROCESS FLOW DIAGRAM
ORGANIC RANKINE CYCLE SUB.SYSTEM UNIT 300
UPDATED
FOR STUDY

Unit 300 PFD

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EQUIPMENT_LIST

JOB NO. :01-51372
AREA NO.:300
SHEET :1 OF 4

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
C-301	FREON EXPANDER	1	Nominal 50 kW OTEC single stage turbine expander with gear box and A.C. generator. Generator output: 24.5 KVA		Roto-flow Corp.		

NOTES :

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EQUIPMENT_ LIST

JOB NO. : 01-51372
AREA NO.: 300
SHEET : 2 OF 4

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
E-301	FREON VAPORIZER	1	Duty : 300.000 Kcal/h: Type: Horz. Kettle Des. Press: Kg/cm^{2}g Shell: 15.5 tubes: 2.5 Des. Temp : °C Shell: 110 tubes: 110	Tubes: Ti Tub/SH: Monel.	Chemtec		
				Channel: lined Shell:CS			

NOTES :

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SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 300
SHEET : 3 OF 4

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
P-301 A/B	FREON PUMP	2	Cap : 6.3 m^3/h S.G.: 1.43 - 1.47 TDH : 56.5 m NPSH : 2 m Motor: 2.5 kW Type : Pos. Displ.	C.S.			
							1
P-303	VACUUM PUMP	1	Cap : 15 Nm^3/h Type: S16 A		Leybold Heraeus	For start-up Purposes only	

NOTES :

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SESEA

EQUIPMENT_ LIST

JOB NO. : 01-51372
AREA NO. : 300

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
V-301	FREON STORAGE VESSEL	1	Cap : 5 m^3 Des. Press : 15.5 Kg/cm^2 g Dia : 1300 mm Des. Temp : 110 °C T.T. : 3700 mm	C.S.			
V-302 A/B	PULSATION BOTTLE	2				Supplied with P-302 A/B	1

NOTES :

5 PRELIMINARY DESIGN OF SOLAR POND SUB-SYSTEM UNIT 400

5.1 PROCESS DESCRIPTION: See Process Flow Diagram DX-51372-00-20-001-02-004 at the end of Section 5.

5.1.1 Pond Description

The purpose of a solar pond is to collect and subsequently store thermal energy from solar radiation.
This is achieved by means of a salt-concentration gradient, increasing from low salinity near the pond surface to high salinity at approx. 1.5 meter below the surface. As a result of this gradient the deeper waters have a greater density than the waters above them. Thermal buoyancy convection is thereby suppressed, impeding upward movement of warmed water which is the principal mechanism of heat loss in an ordinary pond.
The SESEA Solar Pond is built-up of three layers, from top to bottom:

- a thin layer of low salinity water (0.2 - 2.0%), the upper convective zone (UCZ), depth 0.25 m
- a layer of water with in-depth increasing salinity (2-23%), the non-convective zone (NCZ), depth 1.25 m
- a bottom storage layer of water with uniformly high salinity (23%), the lower convective zone (LCZ), depth usually 1.5-2 m.

In the Lower Convective Zone (LCZ), the thermal energy is stored in the form of high temperature brine. Operating static solar ponds have shown temperatures in the LCZ as high as the boiling point of saline water. The solar pond envisaged, will feed hot brine (68 - 89°C) from the LCZ to the Organic Rankine Cycle (ORC) (unit 300) which will power the electric generator. The thermal capacity of the LCZ is sufficiently large to overcome seasonal changes. If due to mechanical failure or extreme weather conditions a shortage of electricity occurs, the required extra power will be automatically taken from the grid. To make-up evaporation of water in the Solar Ponds (approx. 3.05 m^3/m^2-yr), raw, low salinity (0.2%) make-up water will be supplied. With this water, an amount of salt is added to the pond. In addition, salt diffusion occurs vertically (approx. 30 kg/m^2 yr). In order to maintain the desired concentration profile, it is necessary to eleminate the effects of these fluxes. This is achieved by a Brine Concentration Facility further described below under Section 5.2.5.

5.1.2 Pond Sizing

The solar sub-system has been designed subject to the following considerations:

- required energy withdrawal
- minimum water consumption
- state of the art guidelines as described in the scientific literature
- capital and operating costs
- site considerations.

Based on results obtained from the UPM/RI Simulations, a surface area of 8100 m^2 has been incorporated. This figure slightly exceeds the simulation results, because a safety factor must be included for the following reasons:

- Variations in annual radiation values
- Optimistic soil thermal properties assumed in the modeling
- Modeling inaccuracy
- Variations in the ORC thermal load

The total area is equally divided between two symmetric ponds to allow for duplication of experiments and as a safety-control measure in case of leakage.

5.1.3 General lay-out

5.1.3.1 Pond Construction: See plot plan, Drg. nr. DE-51372-01-26 -001.

The solar pond system consists of 2 adjacent ponds each of 45 x 90 m each. Total pond freeboard will be 4 meter.
The solar ponds will be located northernmost in the CEA Facility. The evaporation pond system consists of two evaporation pans of 40 x 20 m and a brine concentration pond of 40 x 50 m. The location of the Evaporation Pond will be north of the solar ponds. Total Freeboard of the evaporation pans and the brine concentration pond will be 0.5 m and 2.0 m respectively.

Both solar ponds will be separated by a concrete wall on which a 1 m wide walk way will be provided to facilitate easy pond maintenance. All edges of the ponds will be constructed for the ease of maintenance. An asphalted road will be constructed around the entire sub-system.

5.1.3.2 Sub-liner (leakage barrier)

In order to physically seal off the solar pond in the unlikely event of leakage, and to detect the slightest leakage, an impermeable liner will be placed underneath each pond at a depth of approximately 0.5 m. The individual liners will be sloped in a way that will direct leakage water through sub drain tiles to a central brine leak sump, located between the solar ponds and the evaporation pond. The sump will be equipped with a ladder and contain pumps and controls.

An electrical grid will be installed to monitor increases in soil conductivity to locate leaks.

For civil details, see sub-section 5.2: Civil Description of Solar Ponds.

5.1.4 Hot brine circulation to Organic Rankine Cycle

Flow to the ORC will be pumped out of the solar pond, Z-401/402 by brine circulation pumps, P-401/402 respectively through two symmetrically arranged manifolds, each approximately 42 m long, located at the south side of each pond. The south side recieves maximum solar radiation and is closest to the ORC.

Pumping rate is 45 m^3/h for each pump. This rate is large enough to ensure sufficient thermal load to the ORC during winter conditions. The brine return manifolds are located at the opposite north side of each pond. Each return manifold will be approximately 42 m in total length. The length and the size of the suction and return manifolds are chosen in such a way that an evenly distributed laminar flow into or out of the pond is safeguarded creating a North to South stream in the Lower Convective Zone. Both suction and return manifolds will be winch-operated for quick positioning at any required depth, (for the supply manifold, this usually coincides with the maximum temperature depth). Due to the low NPSH-available (high vapour pressure of the hot brine) and the relatively low differential pressure, vertical submerged centrifugal pumps are chosen. A full spare pump will also be supplied.

5.1.5 Gradient control

Various fluid processes occur naturally in solar ponds, which require regular attention. Management of these processes depends on the maximum temperature, maximum storage capacity or other desired parameters. Hence a deep Non Convective Zone may be sought, a shallow Lower Convective Zone or any configuration desired, optimum for the application. The management of these natural processes is discussed below:

The major processes are:

- In the presence of strong temperature and concentration gradients, so called "convective cells" appear in the NCZ. Recent work by Meyer et. al. * has furthered the understanding of the heat transport and photographically identified "Thermal Plumes" which support gradient degradation.
  These are detrimental because they accelerate heat loss upwards and cause an erosion of the concentration gradient.

- Evaporation from the pond surface occurs, necessitating make-up flow. Obviously, if evaporation is not made up, the solar pond would eventually run dry.

- The concentration and temperature gradients drive the vertical flux of salts. If left unchecked, a solar pond would slowly revert to a homogeneous state. Diffusion rates cited in the literature average around 20 kg/m^2yr. For this design, a rate of 30 kg/m^2yr is taken.

In general, three major processes must be regularly or periodically encountered: convective cells, thermal plumes, evaporation and salt diffusion. Several techniques may be employed to remedy the various situations as they arise, depending on the desired outcome.

* An Experimental And Theoretical Study of Salt Gradient Pond Interface Behaviour, Meyer, Grimmer and Jones, 1982, Solar Energy Society, Am. Section, Houston.

- Convective cells may be eliminated by any of the following methods:

  . Pumping out to the evaporation pond by maintenance pumps P-403/404

  . Pumping into the LCZ by P-403/404, causing some dilution of that zone

  . Pumping into the maintenance header by P-403/404 and mixing with low salinity make-up water or high salinity brine from brine supply pump, P-405 and reinjecting into the pond. For example, a 14% convection cell may be mixed 1:1 with 24% brine and metered into the 18% layer (overlooking any temperature differences). This procedure requires control of flows and temperatures as well as accurate manifold positioning. The reinjection manifolds may be operated static or dynamic, and can be moved along the complete North-South side of each pond.

- Evaporation losses are made up by adding "wash water" (i.e. reject water from R.O.-unit or water from raw water storage) at the pond surface or by various brine streams as described above.

- Salt diffusion is rectified by the net addition of salts to the pond bottom and the relocation of various layers throughout the pond. Generally this is done by pumping an amount of brine out of the solar pond by P-403/404 and concentrating it by means of partial evaporation in the evaporation pond Z-403 and returning it into the solar pond by means of the brine supply pump P-405.

The procedures briefly describe the techniques employed for maintaining the gradient. Discrete layers may be withdrawn and/or generated across an entire horizontal plane by point-source flow, i.e., the diffusers and manifolds. These procedures are based on data obtained from the vertical temperature profiles and concentration profiles, which are calculated from the temperature and conductivity readings, obtained from analysers X-401/402 A/B.
The gradient control fluids available for the Solar Ponds are "wash water" coming from the R.O.-Unit and CEA-raw water storage, brine from the Solar Ponds and brine from the Evaporation Pond.

Flow rates for the maintenance pumps P-403/404 and brine supply pump P-405 are 5 m^3/h. The rate is large enough to ensure sufficient gradient control flow for a daily maintenance period. Due to the low NPSH-available (high vapour pressure of the hot brine) and the relatively low differential pressure, vertical submerged centrifugal pumps are chosen. A full spare pump will also be supplied.

All manifolds will be provided with a rounded cap on each end, to prevent damaging of the rubber liner in case of rupture of hangers.

5.1.6 Algea Control

An algicide injection point is incorporated on the maintenance header to enable the injection of an algicide into the system by means of a portable dosing pump P - 406. Various chemicals such as HCl or $CuSO_4$ may be introduced to correct pH, clarity or other chemical/biological disturbances.

5.1.7 Filtration & Dust Removal

Because the Solar Pond is a composite of fluids ranging in specific gravity, any foreign objects will be suspended at a particular depth in weight equilibrium. Heavier than brine objects will sink to the bottom and light debris will float, additionally supported by surface tension. This has been observed in existing ponds where leaves might be in the 7% layer, insects in the 14% layer, dust at the surface, etc.

Surface debris may be removed via the surface skimmers. Suspended debris will be removed through the manifolds. Here, the suction and return manifolds will be placed at the desired depth and operated. Any debris will then be removed in the sand filter F-401.

Bottom debris are considered to have little or no effect on the overall operation for the following reasons:

- The specific heat of particulate matter will be nearly equal to brine (alternatively, consider changing the pond depth).
- The bottom reflectance increase will be trivial since what little radiation is reflected off the bottom is largely absorbed on its way up.

Hence, bottom debris need infrequent attention and may be handled with long suction hoses manually operated from a rubber inflatable boat.

5.1.8 Evaporation facility

The evaporation pond is functionally divided into two sections, which are in turn subdivided. One section is the evaporation pan, wherein brine may be evaporated upto a crystalline salt residue.

The second section is the brine concentration pond, wherein brine is concentrated to a high salinity brine (approx. 25%). The evaporation pans may be fed by the brine supply pump P-405 or the maintenance pumps P-403/404. The crystalline salt can be mined mechanically from the concrete floor of the evaporation pan. The brine concentration pond is fed with brine from the maintenance pumps P-403/404 and from the evaporation pans. By manifold feeding at the correct depth, the evaporation pond will behave as a solar pond thereby enabling the return of hot concentrated brine (25%) to the solar ponds. Pump P-405 is designed to return concentrated brine to the solar ponds, to supply concentrated brine to the evaporation pans, to circulate brine over the concentration pans and to maintain a solar pond behaviour in the evaporation pan. The vertical temperature profile and the concentration profile can be obtained by analyser/profile meter X-403.

5.1.9 Leakage detection

There are two methods by which leaks will be detected.

In the first method, flow will be sensed in the subsurface drainage system. Flow detectors will automatically register the flow at the control room. Any leakage of sufficient magnitude will flow to the sump V-401.

In addition to the drainage system, an electrical grid will be installed beneath the pond to identity the location of any leak.

Leakage is further discussed under 5.2.11 below.

5.1.10 Leakage handling

Any leakage will flow through the subdrainage to the sump. Management will automatically be alerted, and will commence determining the gravity of the situation. Once the level of brine in the sump reaches a certain height, a portable sump pump will be used to return the brine to either the solar pond or the evaporation pond depending on the rate of flow.

In the unlikely event that the emptying of a pond becomes necessary, brine storage is available as freeboard in other ponds. In addition, the well may be shut down with all users drawing off the ponds, with evaporation decreasing the volume of brine in hand. During the "run down" process, the sump contents may be pumped to the leaking well in a cyclic fashion, or tanker trucks may be employed as a final remedy if warranted.

5.1.11 Start-up time: Operational/Stable Conditions

Following testing, filling of the solar ponds may commence. During filling, the gradients may be established such that an early temperature rise is achieved. The rate of temperature gain will be governed by the time of the year. A good estimate may be obtained following the detailed study when the entire schedule will be known.

5.1.12 Boiling prevention

Several options are available to prevent any danger of boiling. Firstly, the ORC should be operated to full capacity. Secondly, heat may be dumped by cycling the flow to the evaporation ponds, where considerable brine may be quickly cooled to ambient wet bulb temperature. Thirdly, the collection area may be decreased by floating any adequate radiation interceptor on the ponds. Other techniques may be utilized as well.

5.1.13 Materials

5.1.13.1 Solar Ponds

Material has to be resistant to hot brine (110°C)
Materials used:

Pond bottom	: sand covered with rubber liner
Ponds edges	: concrete covered with rubber liner

The liner will be installed under the manufacturers supervision, Burke Rubber Company of the USA. Only top battens will be employed to fix the liner in place. Upon installation, the liner integrity will be checked with compressed air, visually, and by progressive filling of the ponds.

5.1.13.2 Evaporation pond

Material has to be resistant to hot brine (110°C).

Materials used:

Evaporation pan	: concrete (mechanical resistance required for mining equipment)
Brine concentration pan	: sand covered with rubber liner

5.1.13.3 Leakage barrier

The leakage barrier will consist of clayware pipes above the P.V.C.-subliner (thickness 0.8 mm).

5.1.13.4 Piping

All piping that can transport hot or cold brine will be constructed out of glassfiber reinforced plastic, designed for a temperature of 110°C. For special fittings and instruments the following materials can be used if necessary:

- excellent resistance: Titanium, Nickel, Monel
- good resistance : Marine Bronze, Hastelloy "B" or "C"

5.1.13.5 Pumps

Pumps P-401-405 have to be resistant to hot brine (110°C). Choice of material will be according to the ability of the pump supplier to use any of the above (under section piping) mentioned materials for the construction of the pumps. Pump P-406 material has to be resistant to Copper Sulphate and Hydrochloric Acid. For this, Durimet 20, or Hastelloy "B" are recommended.

5.2 CIVIL DESCRIPTION OF THE SOLAR POND SUB-SYSTEM

There are two possible retaining structures:

5.2.1 Dike Embankment

One is the dike embankment, which has the following advantages and disadvantages:

Advantages:
- easy anchoring of liners.
- no handling of reinforced concrete structures.
- simple, reliable, flexible structure.

Disadvantages:
- larger area (incl. liner).
- more evaporation losses.
- more excavation.
- difficult installation of mechanical equipment.
- water level in pond can hardly be approached from dike.
- sloping, instead of vertical sides results in disturbance of salt and temperature gradients at edges of the pond.

5.2.2 Concrete wall Enbankment

The other retaining structure is the concrete wall, which has the following advantages and disadvantages:

Advantages:
- smaller area, because of vertical sides.
- less excavation.
- water level in pond can easily be approached from top of the wall.
- easier earthwork, back filling instead of raking slopes.
- smaller liner area.
- mechanical equipment may be anchored on top of the wall.
- no disturbance of salt and temperature gradients at edges of the pond.

Disadvantages:
- difficult anchoring of liners.
- handling of reinforced concrete structure.
- rigid structure, hence vertical joints with flexible materials are necessary in concrete.
- structural problems in corners of the pond (perpendicular).

The pond area (2 compartments, each 90 x 45 m) is relatively small. The slopes of the dikes will imply an inadmissable disturbances of the system of zones in the pond. In considering the above advantages and disadvantages, preference is given to the concrete wall on footing.

5.2.3 Structural Design of Retaining Wall

The wall schematically consists of a cantilever fixed at the base, with the main reinforcement vertical and the distribution steel, horizontal.

Owing to the presence of the impervious liner, horizontal water pressure can only be built up from top level of the wall to bottom level of the pond. Uplift of the wall is impossible, because there is no upward pressure of ground water. In the case of leaks developing in the upper liner, the build-up of ground water pressure is prevented by underdrainage.

Configuration of the wall and backfill is such, that axle loads on the road will not cause horizontal soil pressure against the wall, assuming that axle loads spread out under 45°.

It should be noted that it is prohibited to fill the pond with water while retaining wall is not backfilled.

Design calculations have been made under the following loading conditions:

salt water	-	density equivalent to 1200 kg/m^3
reinforced concrete	-	density equivalent to 2400 kg/m^3
soil backfill	-	density equivalent to 1700 kg/m^3
soil pressure (at rest),		K_o = 0.5
soil pressure (passive),		K_p = 3
angle of shearing resistance (sand)		= 30°
friction coefficient between base and subsoil		= 0.6

In designing the wall and the base, two cases are to be considered:

- Soil pressure against the back of the wall, when the pond is empty.
- Water pressure against the wall, when the pond is full (with allowance for passive reaction from backfill).

Concrete structural analysis showed that in the most charged section of the wall (connection with base) a thickness of 0.3 m is required. For this pond size,it will not be economical to reduce the wall thickness along the height. Therefore, for the whole height and for the base, a thickness of 0.3 m is used.

For the given dimensions, the stability per meter length of the wall have been roughly investigated.

The following points have been checked:
- safety factor against overturning = 2.5
- safety factor against horizontal sliding = 1.67
- safety factor against yielding subsoil base = 2.85

The safety factors are satisfactory and only small deformations may be caused.

Case 2 is not decisive for stability. The force due to the water pressure is 96 KN. The ultimate passive resistance is 278 KN. Characteristic stress-strain relationship of sand shows that the required horizontal strain to reach this passive reaction is almost zero.

5.2.4 Structural Design of Partition Wall

The function of the partition wall is:

- damming up the water: water can be present on one side to the full height and empty on the opposite side
- bearing mechanical equipment (pumps, pipes, etc.)
- offering a passage-way
- giving support to the synthetic liners

Design calculations have been made for the same parameters of salt water, reinforced concrete and soil as in the case of the retaining wall.

To design the wall and the base, the case must be considered that the water pressure is acting only on one side, the opposite compartment of the pond being empty.

Concrete structural analysis showed that in the most charged section of the wall (connection with base) a thickness of 0.5 m is required. For this pond size it will not be economical to reduce the wall thickness along the height. Therefore, for the whole height and for the base a thickness of 0.5 m is used.

For the given dimensions (see drawing) the stability per m length of the wall have been roughly investigated.

The following points have been checked:

- safety factor against overturning = 3.5
- safety factor against horizontal sliding = 1.51
- ratio of soil bearing pressure to ultimate bearing capacity of subsoil base = 3.9

The safety factors are satisfactory and only small deformations may occur.

5.2.5 Thermal Behaviour

It is generally known that concrete has high resistance to elevated temperatures. It is incombustible and effectively resistant to temperatures of up to 600°C. The compressive strength of concrete is found to undergo little or no changes up to 300°C. Above 300°C, the strength of the concrete gradually declines. At temperatures above 500 - 550°C a proces of disintegration of the concrete sets in, resulting in considerable decrease in strength.

The splitting tensile strength and the modulus of elasticity of concrete at high temperatures behave in much the same way as the compressive strength: they decrease at high temperatures just as the compressive strength does.

Just as in many other materials, temperature changes in concrete cause deformations: a temperature rise causes expansion, a fall in temperature causes contraction of the concrete. Temperature changes may occur slowly e.g., in consequence of the difference in air temperature between day and night or between summer and winter, or especially in the case of the solar pond the change in water temperature after filling the pond with water and developing the salt-and temperature gradients.

The deformations, and the associated stresses, caused by these changes can be effectively resisted by concrete structures, provided that they are correctly designed and detailed.

For a proper understanding of the effect of such changes in temperature it is necessary to have a clear conception of the thermal behaviour of concrete.

The coefficient of thermal conductivity of a material indicates the rate of heat conduction through that material. For concrete this value of approximately 1 W/m °C.

Obviously, the dimension of the material in the direction of heat flow also plays a part in determining the amount of heat that is conducted. A criterion for this is provided by the thermal resistance $\frac{R}{d}$, where "d" denotes the dimension concerned.

However, the above statements are valid only for <u>steady-state</u> heat conduction, i.e., for constant temperature conditions, whereas in reality the temperature is liable to vary. For <u>unsteady-state</u> heat conduction, the thermal behaviour will have to be characterized by other parameters.

The rate at which temperature variations penetrate into a material can be indicated by means of the thermal equalization coefficient "a" of the material. For concrete, this coefficient is approximately 1×10^{-6} m^2/s. In connection with this aspect of the thermal behaviour of structures, the dimension"d" obviously here also plays a part.

A measure for this is provided by the thermal inertia coefficient $E = \frac{d^2}{a}$.

The time taken for a finite temperature change to penetrate through a wall with thickness "d" is given with the formula: $t = 0.5 \times E$. For example: if $d = 0.3$ m then:

$$t = 0.5 * \frac{0.3 * 0.3}{10^{-6}} = 20000 \text{ sec} = 12.5 \text{ h}$$

The concrete retaining walls of the solar pond may be exposed to one-sided thermal heating.

1. by the varying of air temperature when the pond is empty;
2. by the varying of water temperature when the pond is full.

Temperature variations, related to penetration time, define the steady or the unsteady state of heat flow through the concrete. Biannual variations, such as mean temperature of air and water in the pond, are clearly cases of a steady state heat flow, causing a uniform temperature distribution (with small gradient) through the thickness. However, the daily air temperature variations are cases of an unsteady state heat flow causing a non-uniform temperature distribution through the thickness. If the temperature distribution is non-uniform, it will cause strains (deformations) within the concrete; if these are wholly or partly restrained, i.e., prevented from developing, stresses will be set up, which can be calculated.

During filling or emptying of the pond the concrete wall will undergo one-sided cooling or heating; this can be controlled by employing the correct filling procedure, so that the wall is not subjected to a thermal shock.

5.2.5.1 Thermal Loading of Retaining Wall

Conditions are defined for the selection of design cases where thermal exposure may cause bending of the wall in the vertical and horizontal planes.
Reference is made to the following temperature data:
- mean temperature in lower convective zone in summer is 89°C
- mean temperature in lower convective zone in winter is 68°C
- absolute maximum temperature in lower convective zone is 110°C
- mean maximum air temperature in summer is 43°C
- mean minimum air temperature in summer is 25°C
- mean air temperature in summer is 34°C
- absolute maximum air temperature in summer is 47°C
- absolute minimum air temperature in summer is 20°C
- mean maximum air temperature in winter is 22°C
- mean minimum air temperature in winter is 6°C
- mean air temperature in winter is 14°C
- absolute minimum air temperature in winter is -2°C
- absolute maximum air temperature in winter is 30°C

Thermal loadcases in summer (see figure IV-3) are:

S1 : normal situation when pond is full
S2 : extreme situation when pond is full
S3 : extreme situation if pond could be abruptly emptied
S4 : normal situation when pond is empty
S5 : extreme situation when pond is empty

Thermal loadcases in winter (see figure IV-4) are:

W1 : normal situation when pond is full
W2 : extreme situation when pond is empty
W3 : normal situation when pond is empty
W4 : extreme situation when pond is empty
W5 : normal situation when pond is empty.

To prevent a temperature gradient occurring in case S3, operating instructions should be made available for correct emptying (and filling) procedure of the pond.

On the condition that measures are taken to prevent occurrence of case S3, the decisive load cases are W2 and W4, having the highest temperature gradients.

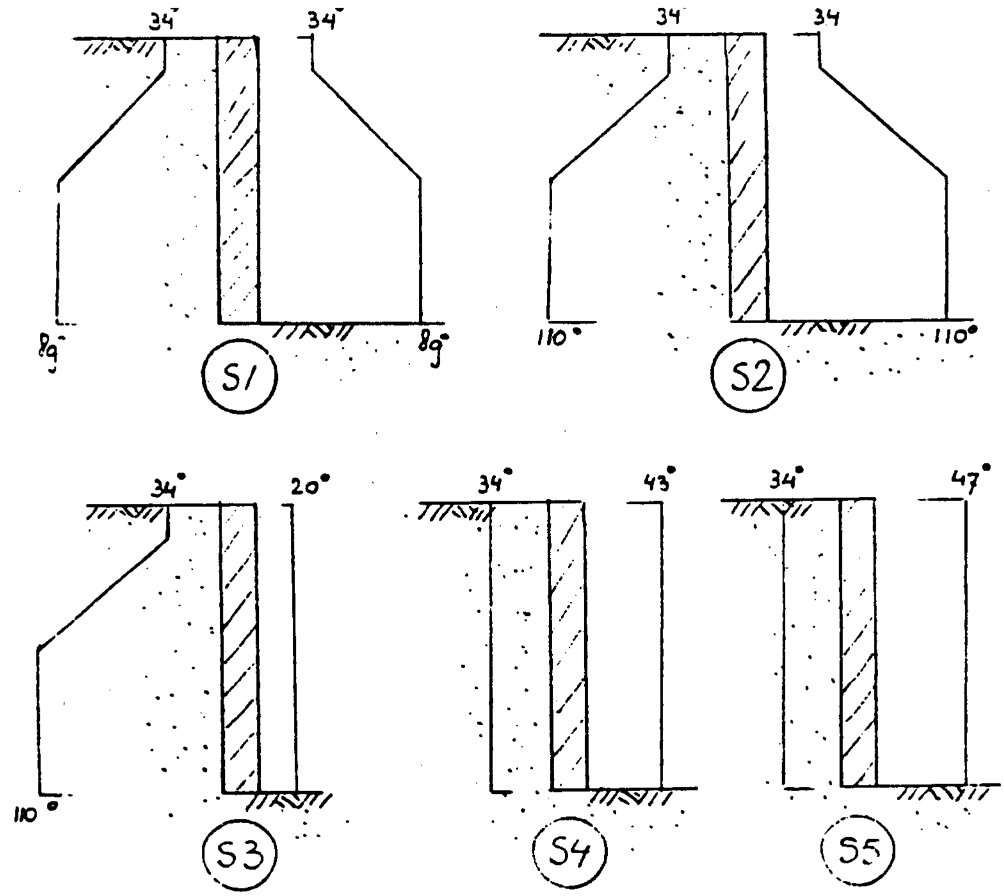


Fig. IV-3 THERMAL LOAD CASES RETAINING WALL IN SUMMER (temperature in °C)

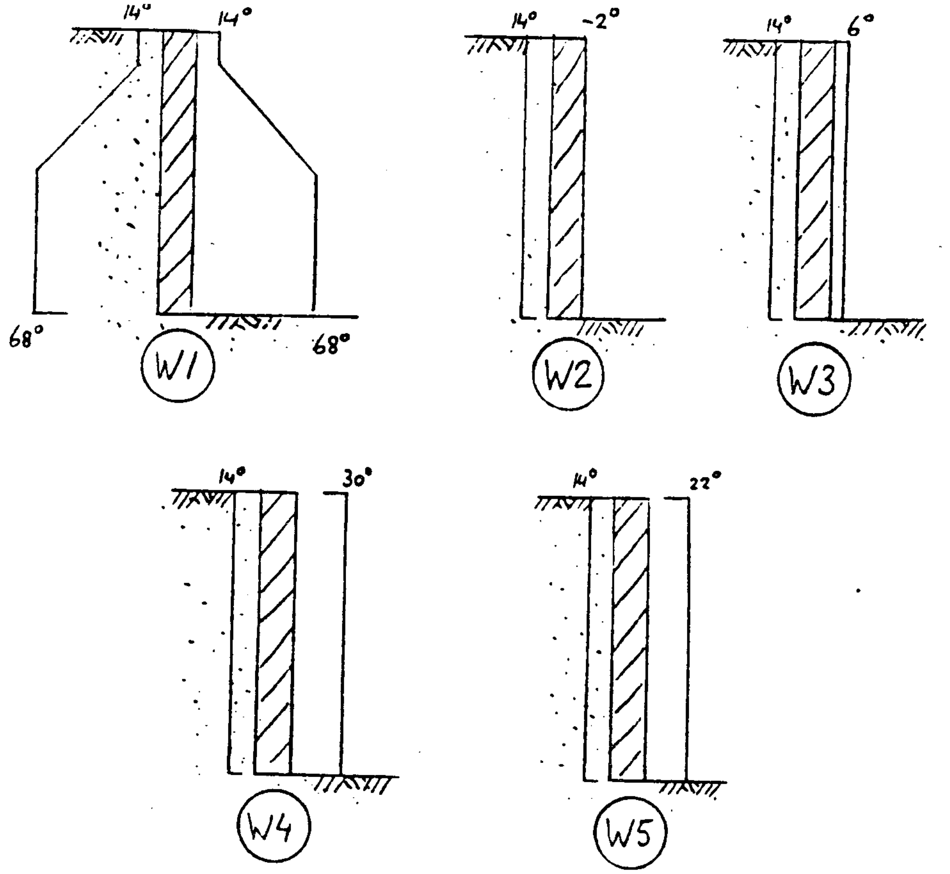


Fig. IV-4 THERMAL LOAD CASES RETAINING WALL IN WINTER (temperature in °C)

5.2.5.2 Thermal Loading of Partition Wall

Conditions are defined for the selection of design cases where thermal exposure may cause bending of the wall in the vertical and horizontal planes.
Reference is made to the same temperature data, mentioned for the retaining wall.

Thermal loadcases in summer (see figure IV-5) are:

S1 : normal situation where pond is full
S2 : extreme situation when pond is full
S3 : extreme situation when one compartment could be abruptly emptied
S4 : normal situation when one compartment is empty

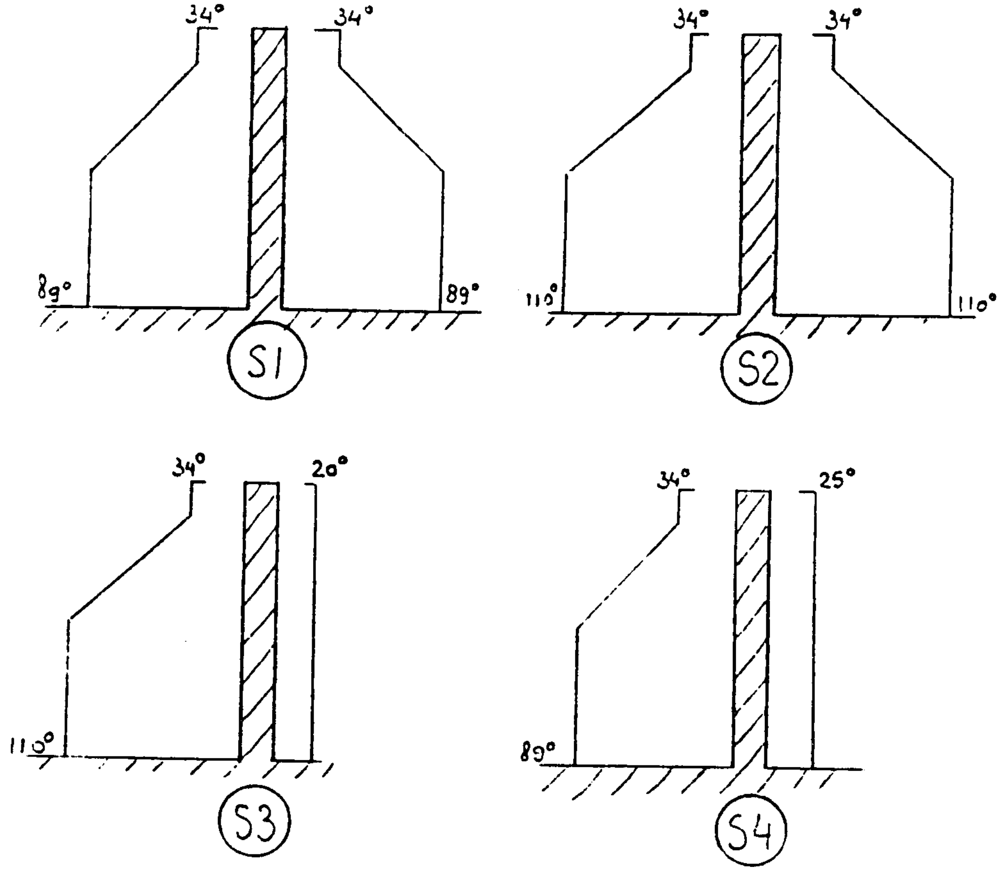


Fig. IV-5 THERMAL LOAD CASES PARTITION WALL IN SUMMER (temperature in °C)

Thermal loadcases in winter (see figure IV-6) are:

W1 : normal situation when pond is full
W2 : extreme situation when one compartment could be abruptly emptied
W3 : normal situation when one compartment is empty

The following points are used in selecting a lower temperature gradient than that found in case S3, at the lower convective zone:

- Emptying of one compartment of the pond will not occur abruptly but will take place over many days. The initial temperature in the other, full compartment will decrease due to heat loss through the partition wall
- As the mean temperature in summer in the lower convective zone is expected to be 89°C, coincidence of the absolute maximum temperature of 110°C with one empty compartment is unlikely.
- As the mean daily minimum air temperature in summer is 25°C, coincidence of the absolute minimum air temperature of 18°C with one empty compartment, is unlikely.
- Combination of the absolute maximum temperature of 110°C in the lower convective zone with the absolute minimum air temperature, while one compartment is empty, is highly unlikely.

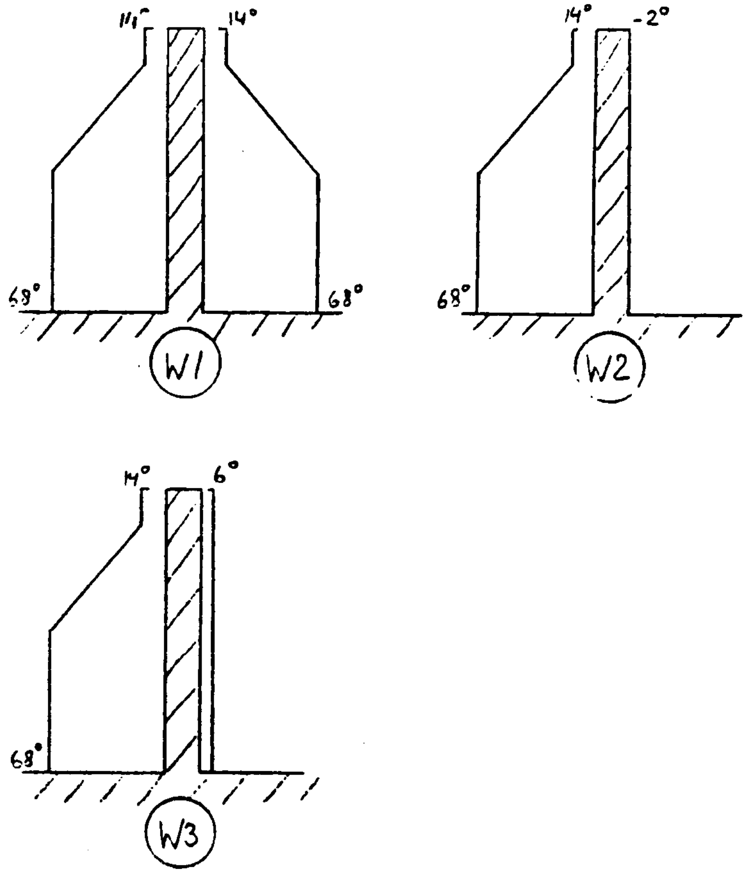


Fig. IV-6 THERMAL LOAD CASES PARTITION WALL IN WINTER (temperature in °C)

Two limiting combinations may be considered now:

1. Absolute extreme difference $T = 110°C - 18°C = 92°C$
2. Mean difference $T = 89°C - 25°C = 64°C$

The mean of these cases $T = 78°C$
The mean temperature of 78°C may be reduced to 68°C for the effect of slow removal of the contents of one compartment.

Transfer of heat through the wall is influenced by the capacity of the surface to absorb from and reject heat to the surrounding air. Since heat is dissipated from the face of the wall to the surrounding air there will be a temperature difference between the air and the adjacent surface. The temperature gradient across the wall is therefore less than the difference in temperature between the air and water. Internally, when the pond is full, the wall surface and the liquid will be at the same temperature.

The temperature gradient T is calculated from:

$$T = (T_o - T_i)RF$$

where T_o and T_i are the external and internal air/water temperatures and RF is a reduction factor which may be taken as

$$RF \text{ (air both faces)} = R_c \times U$$

and:

$$RF \text{ (air/water)} = 1/2 \times (1 + (R_c \times U))$$

where R_c = thickness (m) x thermal resistivity (the thermal resistivity is taken as 1.05 m°C/W for most normal weight concrete) and U = heat transfer coefficient which varies from about 2.6 $W/m^2°C$ for 200 mm thickness to 1.6 $W/m^2°C$ for 400 mm thickness of normal weight concrete. Hence for 0.4 m thickness (say U = 1.6)

$$RF \text{ (air/water)} = 1/2 \times (1 + (0.4 \times 1.05 \times 1.6)) = 0.84$$

Hence the temperarure gradient through the wall at the lower convective zone:

$$T = 0.84 \times 68 = 57°C.$$

At this stage it is not possible to determine whether normal reinforcing is capable to withstand this temperature gradient or not. Further investigations are necessary to show if concrete must be pre-stressed.

5.2.6 Control of Cracking

5.2.6.1 Plastic Shrinkage Cracking

This type of cracking may occur on the surface of wall and slab while the concrete is still plastic. Investigations by various authorities have shown that the principal cause of plastic cracking is a rapid evaporation of moisture from the surface of the concrete.

When the rate of evaporation exceeds the rate at which water rises to the surface plastic cracking is very likely to result.

The rate at which the water in the mixed concrete reaches the surface, and the total quantity involved, depends on may factors; the following are known to play an important part in this phenomenon:

- Grading, moisture content, absorption, and type of aggregate used.
- Total quantity of water in the mix.
- Cement content.
- Thickness of the concrete slab.
- Characteristics of any admixtures used.
- Degree of compaction obtained and therefore the density of the compacted concrete.

The rate of evaporation from the surface will also depend on a number of factors which are:

- relative humidity;
- temperature of the concrete;
- temperature of the air;
- wind velocity;
- degree of exposure of the surface of the slab to the sun and the wind.

Keeping concrete from drying out is the most suitable measure to reduce plastic cracking.

Curing consists of substantially reducing the rate of evaporation of moisture from the surface of the slab for the first 72-96hr after completion of compaction and finishing.

There are two basic methods of curing: by the use of a curing membrane, and polyethylene sheets.

Curing membranes are produced by numerous firms, each claiming special qualities for their own particular product. The type selected should be resin-based and non-toxic. These compounds can be applied by brush or by spray.

The use of polyethylene sheets, well lapped and held down around the edges by scaffold boards so that wind cannot blow underneath them, is very effective.

The wall will have formwork on both faces, so that the area of concrete exposed to the external air is relatively small.

Timber formwork has a much lower thermal conductivity value than steel, consequently the temperature rise in a wall cast between timber forms will be appreciably higher than a similar wall cast under the same conditions between steel forms. The amount of heat lost through steel formwork may be 20 times that lost through 20 mm-thick plywood or formwork.

The actual rise in temperature will depend also on the thickness of the section. In a wall, say, 450-600 mm thick, the peak temperature in the centre of the wall may reach 65-70°C, perhaps within 20h of casting.

5.2.6.2 Thermal contraction cracking

During the setting and early hardening process of concrete, considerable heat is evolved by the chemical reaction between the water and the cement, which results in a rise in temperature of the concrete. The actual rise, the peak temperature, and the time taken to reach the peak and then to cool down, will depend on a large number of factors of which the following are the most important:

- The ambient air temperature.
- The temperature of the concrete at the time of placing.
- The type of formwork used (whether timber, plastic or steel), and the time formwork is kept in position.
- The ratio of the exposed surface area of the concrete, i.e. the area not protected by formwork, to the volume of concrete.
- The thickness of the section cast.
- The type of cement used and the cement content of the mix.
- The method of curing.

Unless the section (wall or base) is completely unrestrained (a state of affairs never met in practice) thermal stress will be developed, particularly as the concrete cools down and contracts. The greater the restraint, the higher the tensile stress.

The tensile stresses may exceed the strength of the concrete in tension and cracking will then occur.

The higher the initial temperature of the concrete the more quickly will the reaction proceed which in turn generates heat more rapidly, resulting in a 'snowball' effect. As an example of this, concrete placed at, say, 10°C may reach a temperature of 30°C in, say, 24 h; if the same mix of concrete were placed under exactly the same external conditions but with an initial temperature of, say, 20°C, the maximum temperature reached may be 55°C after about 20 h. The rapid temperature rise in the hydrating mass of concrete will be increased with increase in cement content.

Also the higher the heat of hydration of the cement used, the higher the maximum temperature reached in the concrete, other conditions being equal.

5.2.6.3 Measures to reduce thermal cracking

To reduce the incidence of thermal cracking, the following measures must be taken:

5.2.6.3.1 To limit the rate of temperature rise and the peak temperature reached, the temperature of the green concrete must be kept as low as possible. It must not be allowed to exceed 30°C up to the point of spreading.

The temperature of the fresh concrete must be kept as low as possible by:
- protecting the aggregates from solar radiation and by sprinkling with water (sand is excepted here)
- cooling of the water used for mixing (maximum water temperature 30°C)
- coating of sunlight-reflecting material on the outside of the mixing compound housing
- cement content not exceeding 350 kg/m^3
- using sulphate resisting Portland cement, which will generally develop less heat in a given period than ordinary Portland cement
- using a retarder in the mix
- careful curing (see plastic cracking)

5.2.6.3.2 To reduce restraint or resistance to contraction of the foot slab which supports the retaining wall, the bays are not to be tied to the adjacent bays. This can be achieved by forming contraction joints (crack inducers). It is recommended that the reinforcement is not carried accross the joint.

Although this type of movement joint provides complete discontinuity in the concrete, there is, initially, no gap between the concrete on both sides of the joint. A gap may develop due to contraction of the concrete.

The object of a crack inducer is to form a stress-relief joint in such a way that concreting is not held up, and this enables long lengths of floor to be concreted in one continuous operation.

As the wall is designed as a cantilever fixed at the base with the main reinforcement vertical, the panels, when they are cast, may be restrained along their bottom edge where they are bonded to the kicker; in addition they will also be restrained at one or both ends if they are bonded to adjacent panels.

Between adjacent panels, vertical joints are recommended, detailed as contraction or stress-relief joints.

By using crack inducers at appropriate centres, long lengths of wall can be concreted in one continuous operation. Distribution steel can be completely discontinuous at these joints.

As the concrete cools down and contracts, a crack should form in the groove provided, thus relieving thermal stress in the panel as a whole, and cracks should not occur at intermediate positions within the panel.

There is no demand for watertightness of the contraction joint, because the "wet" side of the retaining wall is covered by a liner and there is no direct contact with the brine in the pond. So, a waterstop (usually providing a barrier to the passage of liquid through a joint) is not necessary in this case.

The spacing of successive contraction joints can be calculated precisely, but in this stage it can be estimated at 5 m.

5.2.7 Expansion

Expansion joints are to be used to allow for longitudinal expansion of the wall due to the hot brine in the pond, also to allow for relative movements or displacements due to differential foundation movement or applied loads.

This joint has complete discontinuity in both concrete and the steel reinforcements provided to accommodate either expansion or contraction of the structure.

The joint accommodates an initial gap between the adjoining concrete sections of the joint, which then opens or closes to take up the subsequent expansion or contraction movement.

As a rough indication the shrinkage strain will be of the order of 30×10^{-5}. The coefficient of thermal expansion (and contraction) of concrete is of the order of 10^{-5}. This means that a temperature rise of 30°C eliminates the shortening due to shrinkage.

Assume that the maximum temperature in the pond is 110°C, the temperature of the fresh concrete is 25°C and the temperature peak due to the hardening process is 45°C. This means that an expansion remains due to a temperature difference of (110-30-45) = 35°C.

For the spacing between the expansion joints one third of the total length may be taken, i.e.: $\frac{90}{3} = 30$ m, with a joint width of 2 cm.

A joint filler should be used to provide a base for the liner and to prevent the ingress of stones etc. which may prevent the joint from closing.

It is recommended to use a synthetic rubber, e.g. Hypalon, obtainable in liquid and sheet form. It exhibits outstanding resistance to sunlight, weathering, bacterial attack, a wide range of chemicals and heat.

5.2.8 Corrosion

In the pond potental chemical activity is increased because of the high temperature of the concentrated salt in solution. However, a great advantage is that the "wet" side of the concrete is covered by the synthetic liner, so that contact with brine is prevented.

The liner is therefore acting as a means of corrosion protection.

Special attention must also be paid to increased chemical attack (under normal environmental conditions) due to the high temperature.

An important point is that chemicals in the dry state will hardly attack concrete. As measures will be taken to ensure that the soil in the vicinity of the pond will stay dry, the durability of the concrete structure will be enhanced.

The tolerable level of sulphate concentration in relatively dry, well drained soils is about four times the acceptable limit when the sulphates are in solution in ground water.

The use of sulphate resisting Portland cement is therefore recommended.

The reinforcing steel is protected by the cement matrix in the surrounding concrete, and emphasis must be placed on obtaining a dense impermeable concrete cover to the steel.

Steel embedded in Portland cement concrete is subjected to an intensely alkaline environment which is created by the hydration of the cement. The pH of the cement matrix is in the range 11.5-12.5. Research has shown that within this pH range, iron is passivated and as long as this is maintained, corrosion is inhibited.

Because of the above-mentioned reasons a minimum of 50 mm cover to all steel reinforcement is recommended.

It must be noted that all the measures mentioned so far to control cracking (see 5.2.6) provide protection against corrosion. Reinforcement should terminate 50 mm from the face of the joints (compaction joints and expansion joints).

5.2.9 Construction Joints

Joints of this type may occur between successive poured wall panels or between successive lifts of a wall panel.

As the main reinforcement in the walls is vertical, horizontal joints must be avoided as much as possible.

It is recommended to cast a wall panel at one time and to introduce vertical construction joints at the vertical contraction joints. Herewith, a maximum spacing of the successive contraction joints (which will be indicated on the Engineering Drawings) must be observed.

Depending on the guaranteed quantity of deliverable concrete for one batch by the concrete mixing plant, the contractor should agree a certain spacing of the construction joints with the engineer.

In case that the guaranteed quantity of concrete cannot be supplied a horizontal construction joint will become necessary.

A thorough preparation of the surfaces of horizontal and vertical construction joints is essential and the surface of the joint first cast should be treated as soon as possible after concreting. This means within about 12 hours after completion of casting. The surface layer should be removed to expose the coarse aggregate.

Provided the concrete has not hardened, this can be achieved by brushing the surface with a wire brush or by applying an air and water spray but if it cannot be done in one of these ways, it will be necessary to remove the surface layer by a mechanical process such as the use of a scaling hammer. Powerful hammers should not be used as they can fracture the aggregate particles or dislodge them.

Before the next batch of concrete is placed against the joint all loose matter on the surface must be removed and the concrete surface slightly wetted to help the new concrete to adhere.

It is recommended that, in addition to the above, the first layer of concrete placed over a depth of approximately 250mm should be made slightly richer by reducing the amount of coarse aggregate in the mix. This has the effect of increasing the workability and compensating for any loss of water from the new concrete by absorption through the old: it also allows for some of the mortar in the concrete to adhering to the reinforcement cage above the lift being placed as it is deposited from the top of the formwork.

The concrete in the walls should be placed evenly over the surface to be covered and should not be moved horizontally by means of the vibrators. Success in forming the joint will also depend on providing full compaction against the formwork and the original concrete. Adequate compactive effort is essential if areas of honeycombing are to be avoided: this is vitally important around all joints.

5.2.10 Backfill

The earth fill at the back of the retaining wall has several functions:

- resisting outward motion and overturning of the retaining wall by passive soil resistance
- forming a subgrade for the maintenance-road along the pond
- forming an insulating medium to reduce heat loss through the wall

The magnitude of the stresses acting against the wall will depend largely upon the degree of compaction given to the backfill. If the sand is dumped against the wall without compaction, the horizontal stresses may be almost as small as the active stresses. If light compaction is used, such as simply running a bulldozer over the several layers of the backfill, the horizontal stresses will likely equal the at-rest stress. With heavy compaction, stresses approaching the passive stresses might be developed. The usual practrice is to design foundation walls for the at-rest stress; i.e., for a horizontal stress of approximately one-half the vertical stress. As the wall is designed on this basis, heavy compaction on the backfill must be avoided.

It is recommended, that only the two top layers (total thickness 50 cm) are compacted to a least 95% Proctor compaction density, to get a stable subgrade for the road.

Measures must be taken to prevent rainwater penetrating into the soil at the back of the retaining wall, as this soil must remain dry.

Rainfall data at the site:

- a daily max. 10 mm
- monthly max. 50 mm
- yearly max. 100 mm

Referring to these figures, it can be assumed, that water quantities are too small to penetrate deeper than, say, 0.5 m into the ground. The greater part of the water will evaporate at once. The other part can be stored in the top layer until it is evaporated too.

The slope of the backfill should be designed with an adequate safety factor against sliding, generally along a curved failure surface.
Rough stability analysis showed that a slope of 1:2 is adequate. In the design phase, precise slope stability analysis will be necessary.

To prevent wind erosion and dusting, the top of the slope should be covered with a light layer of gravel or crushed rock.

5.2.11 Liner and Leak Detection System

Referring to the report on soil investigation the subsoil on the site consists of the following two layers:

layer 1: extends from the existing ground elevation to an average depth of 3.5 m. It consists of the light brown, fine to medium sand with trace of silt.

layer 2: extends from an average depth of 3.5 m to the end of the probed depth (6 m) and consists of cream and yellow coloured, intensely fractured weathered limestone.

To prevent brine leak to the deep soil (with aquifer at 60 m to 90 m) a native or artificial impermeable layer is required. The existing sand and limestone are highly permeable, the latter mainly due to fissures.

As indicated in the task 3 revised report, a synthetic liner is proposed: BURKE HYPALON, TYPE 45, Industrial Grade, thickness 0.9 mm, a synthetic thermoplastic rubber, reinforced with polyester.

A second synthetic liner is now proposed to serve as an extra leak barrier, as part of the leak detection system.

The second liner will be placed beneath the main liner. The design requirements of the lower liner can be much less than that of the upper liner:

- if a leak develops in the upper liner, the lower liner's task is to turn off the greater part of the downward water movement to a horizontal movement, in other words the resistance to flow downward (passing the lower liner) must be higher than to flow in horizontal direction (passing the sand between the two liners); from this point of view it is not necessary that the lower liner is totally impervious; the lower liner need only function until the upper liner is repaired

- for the lower liner, less temperature resistance is required because a temperature gradient is built up from pond bottom to surrounding soil (sand).

- there is no demand for resistance to U.V.-radiation, for the liner will be embedded.

- the minimum distance between the two liners should be 0.5 m.

Investigations have been made for the material selection of the lower liner. Criterion is that the price of the material should not exceed the price of the upper liner ($ 6.46/m^2, see task 3 revised report).The following choices may be disregarded:

- grouting (cement or chemicals)
- concrete
- asphalt

Information from Bitumarin B.V., Zaltbommel, The Netherlands, shows that an asphalt or bituminous material will be more expensive than $ 6.46/m^2.

The following possibilities remain
- HYPALON 45, thickness 0.9 mm (price ± $ 6.46)
- HYPALON 45, thickness 0.74 mm (price ± $ 6.46)
- P.V.C., thickness 0.8 mm (price ± $ 3.44/m^2)
- P.V.C., thickness 0.5 mm (price ± $ 2.15/m^2)

Characteristics of P.V.C. are:
- relatively low costs per m^2
- light weight as single ply
- good chemical resistance
- poor weathering, cannot be exposed
- low puncture resistance
- becoming soft at 70°C
- good deformation at 130°C
- decomposition at 170°C

It can be assumed that a P.V.C.-liner with a thickness of 0.8 mm will satisfy the design requirements.

Drain pipes are not effective in sand (good permeability) and are normally used in impervious soils (e.g. clay). The reason is that in a highly permeable medium the flow resistance for entrance into the drain pipe is higher than that for penetrating the medium itself.

By placing the drain pipes on top of the lower liner, in the case of leakage, a water head is built on the liner, so that water enters the drain pipes. When giving the lower liner plus drain pipes a slope (about 1:100), the water will flow to the main collector drains.

For the purpose of localizing leakage, the whole area below the pond should be divided into two separate drainage areas, each of which is connected to the main collection pit.

In general pipes used for underdrainage are:

- porous concrete;
- perforated dense concrete;
- plain dense concrete pipes with open joints;
- unglazed clayware pipes with plain butt joints;
- clayware pipes, laid with open joints;
- slotted plastic pipes.

Since in this case, the possible leak water is aggressive it is recommended that porous concrete pipes should not be used as the porosity makes them particularly vulnerable to attack.

Price indication of clayware pipes: Dfl. 0.70/m.
Information from a PVC drain pipe dealer indicated that prices are almost equal.

To facilitate admission of ground water to the drainage system and to help prevent silting of the points of entry, it is recommended that a filter should be placed around the pipes. The filter should be of granular material, i.e. medium gravel.

A disadvantage of clay ware pipes is that placing requires skilled labour. This is in contrast with plastic pipes. However, plastic will be deformed due to the high temperatures. For this reason clay ware pipes are recommended.

Leak detection will be accomplished by measuring soil electrical conductivity on a regular basis. An X-Y electricl grid will be installed between the two liners. A multi-processor will measure current at all points of intersection. Under no-leak or dry conditions, an open circuit will exist and negligible current will be detected. Under leakage conditions, the soil resistivity will decrease dramatically in the leak area causing a current to pass. Hence the location of any leak(s) can be located with accuracy. This leakage detection technique has been installed on several recently-constructed Solar Ponds.

5.2.12 Earth works

The pond will be constructed according to the "cut and fill method" to reduce excavation costs. A depression of 0.5 m below the existing level of the site can be scooped and the earth removed is utilized to construct the backfill of the walls around the pond.

All loose materials, debris, etc. are to be removed from areas and excavations where filling is to take place before filling and compacting is begun. Before any reduced level or trench is filled to the level indicated in the drawings, the exposed surface is to be compacted to a minimum depth of 25 cm and to at least 95% Proctor compaction density.

All fill material is to be free of organic substances and other undesirable matter, e.g. stones exceeding 15 cm.

Fill materials are to be placed and distributed in uniform layers not exceeding 25 cm in thickness.

Compaction is to be performed with approved equipment such as vibrating rollers or rubber-tired rollers. After placement and even distribution of the fill material, it must be compacted to at least 95% Proctor compaction density. Before laying a new level of fill, compaction tests are to be made.

Water should not be used because the soil beneath the solar pond must remain dry in order to minimise heat loss.

5.3 BRINE CONCENTRATION FACILITY (BCF)

The Brine Concentration Facility serves the following basic functions:

- Receive brine from the Solar Ponds as part of the concentration profile requirements.

- Generate concentrated brine at a maximum temperature for feeding the Solar Ponds LCZ.

- Provide for a means of removing salt or brine for disposal.

- Provide storage volume in the unlikely event leakage occurs.

- Operate under a wide range of flow rates.

- Fulfill the experimental requirements of the EFT as required for the future design of the Commercial Facility.

The BCF is composed of five interconnected sections. These are, one brine concentration pond and four evaporation pans.

In order to size the overall area required, the desired volume to be evaporated must be known. This volume in turn depends on the brine management technique. Three concepts are considered, and the method actually used may be a combination of these:

1. Withdrawal from the UCZ
2. Withdrawal from the NCZ
3. Falling Pond

Although method 1 consumes much water, it is the one which has been proven successful at existing Solar Ponds. Methods 2 and 3 are feasible but as yet untried particularly on the large scale required here.

Hence, SESEA has designed a BCF which will operate on the basis of withdrawal from the UCZ, under a wide range of flow rates.

5.3.1 Calculation of Required Evaporation Area

The following parameters have been used in calculating the area required:

- Brine Concentration Pond evaporation rate of $3.09\ m^3/m^2$-yr.
- Evaporation Pan, evaporation rate of $4.10\ m^3/m^2$-yr equal to experimentally observed Pan Evaporation rates in Derab.
- UCZ salinity of 2%.
- Vertical salt flux of $30\ kg/m^2$-yr.

* Salt to UCZ = Diffused + wash water

$$= (8100\ m^2)\left\{\frac{30\ kg}{m^2\text{-yr}}\right\} + \left\{\frac{3.09\ m^3}{m^2\text{-yr}}\right\}(8100\ m^2)\left\{\frac{.002\ T}{m^3}\right\}$$

$$= 243 + 50 = 293\ T/yr$$

* Brine from UCZ to evaporation ponds.

$$\frac{293\ T}{yr} \cdot \frac{100}{2} = 14650\ m^3/yr$$

* Brine from evaporation ponds to LCZ @ 25% approx.

$$\frac{243\ T}{yr} \times \frac{100}{25} \times \frac{m^3}{1.15\ T} = 845\ m^3/yr$$

* Annual evaporation requirement

$$(14650 - 845)m^3/yr = 13805\ m^3/yr$$

* Area

Pan : $2000\ m^2 \times \frac{4.1\ m^3}{m^2\text{-yr}} = 8200\ m^3/yr$ (Derab Data)

Pond: $2000\ m^2 \times \frac{3.05\ m^3}{m^2\text{-yr}} = 6100\ m^3/yr$ (Correlation Factor of 75%).

Total Area = $4000\ m^2$
Total Evaporation = $14300\ m^3/yr$.

Hence, the theoretical evaporation requirement is met with a total area of $4000\ m^2$.

As mentioned above, these flows may be anticipated if current, traditional brine management is utilized. Employing a falling pond technique, or withdrawal from convective cells in the NCZ, may reduce the area requirement by as much as 80%.

5.3.2 Size and Construction

For the Brine Concentration Pond, the following design requirements may be stated:

- Surface area of 2000 sq.m.
- Freeboard of 2m.
- Operationally, a solar pond, with concentration and temperature gradients.
- Feed and withdrawal variable.
- Water tight.

The same design principles for the solar pond liner and drainage system are applied here, consisting of:

- upper liner: BURKE HYPALON, TYPE 45, Industrial Grade, thickness 0.9 mm
- lower liner: P.C.V., thickness 0.5 mm
- compacted sand layer between two liners (minimum total thickness 50 cm), with drain pipes (clay ware) to main collector
- compacted sand layer beneath lower liner, minimum thickness 25 cm.

For the embankment a slope of 1:2 is recommended, giving the slope enough stability and a good configuration for placing the upper liner. The edges of the liner are to be secured in an earth pit, an anchor trench 40 cm from the crest should be provided.

The P.V.C. liner should not be exposed to weather and should be totally embedded. Additionally, measures must be taken to prevent water leakage through the anchorage of the columns to the slab. To make a walkway to and from the edge of the pond, the columns and the edge can be spanned by two steel beams equipped with steel grating and railing. Structural steel should be galvanized.

For the Evaporation Pans, the following design requirements may be stated:

- Surface area of 2000 sq.m.
- Freeboard of 0.5 m.
- Feed and withdrawal variable.
- Water tight.
- High accessibility and easy maintenance.
- Must support light industrial equipment.

The design calls for four pans adjacent to the brine concentration pond. The pans are sloped towards the pond and have gates through which brine may pass to the pond. The pans will be machine accessible and independantly operable.

Watertightness can be achieved by a polyethylene liner beneath the concrete slab. The subgrade is to be compacted to a minimnum depth of 50 cm and to at least 95% Proctor compaction density.

The recommended thickness of the concrete slab is 15 cm. Precise definition on the basis of a calculation is impossible. It is mainly based on considered judgement.

Minimum reinforcement of 0.15% of the total section will be provided consisting of wire fabrics and placed 700 mm from the top of the slab.

After casting and during the settling and hardening of the concrete, some shortening (shrinkage) will occur. Because the floor slab is restrained on the undersurface, tensile stress will develop. The greater the restraint, the higher the stress. If tensile stresses exceed the strength of the concrete, cracking will occur.

The friction developed on the sub-surface of the slab can be reduced by a double layer of polyethylene sheets which are themselves laid on the compacted subgrade.

Another measure to reduce restraint and to control cracking is that adjacent floor bays are not tied together. This can be achieved by forming crack inducers. It is recommended that the reinforcement is not carried across the joint, thus forming a contraction joint.

The object of a crack inducer is to form a stress-relief joint in such a way that concreting is not held up, and this enables large areas of floor to be concreted in one continous operation.

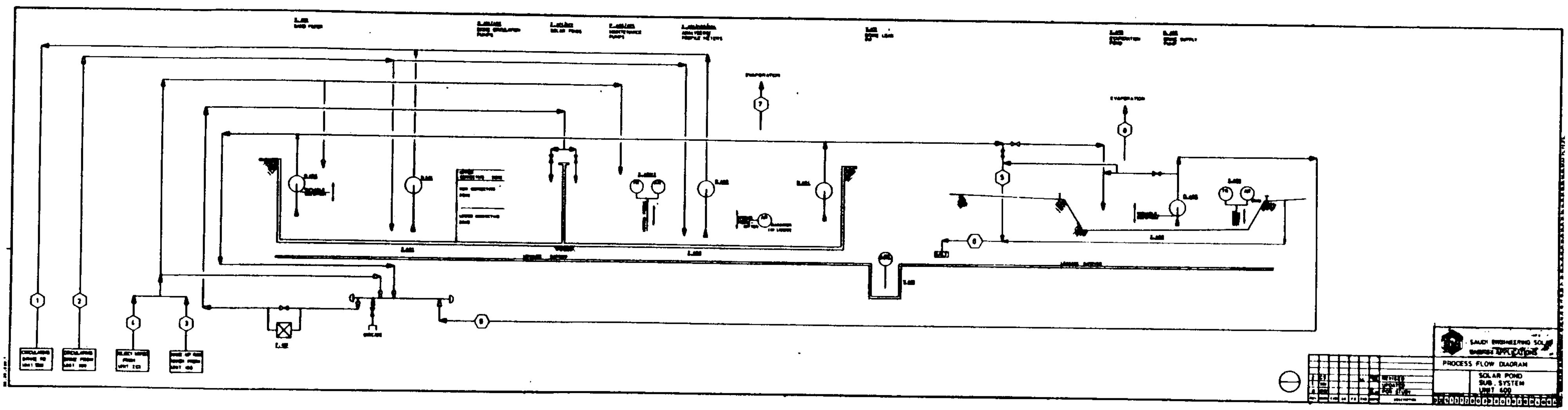
The crack inducer can consist of a groove, formed through the bottom half of the slab with a piece of hardboard (thickness 5 mm), thus forming a plane of weakness.

As a rough indication the shrinkage strain will be of the order of 30×10^{-5}. The coefficient of thermal expansion (and contraction) of concrete is of the order of 10^{-5}. This means that a temperature rise of 30°C eliminates the shortening due to shrinkage.

The maximum recorded temperature on the site is 47°C. This indicates that no expansion joints are necessary as long as casting takes place when temperature is higher than (47-30) = 17°C.

5.3.3 BCF Operation & Highlights

The basic flow pattern is from the Solar Pond UCZ to the Evaporation Pans. Here the low salinity brine is evaporated down to a higher concentration brine and passed to the Brine Concentration Pond for return to the Solar Pond LCZ.


EVAPORATION
EVAPORATION
PROCESS FLOW DIAGRAM
SOLAR POND
SUB. SYSTEM
UNIT 400

UNIT 400 PFD

DA-20-168-2

SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 400
SHEET : 1 OF 5

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
F-401	SAND FILTER	1	Capacity: 0 - 10 m^3/h Size : 400 mm Dia. x 800 mm High Max. ΔP: 1.0 Kg/cm^2	C.S./ Rubber lined		Non-automatic cleaning	

NOTES :

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SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 400
SHEET : 2 OF 5

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV
P-401	BRINE CIRCULATION PUMP	1	Cap.: 45 m³/h NPSH : 3.0 m S.G.: 1.18 Motor: 2.5 Kw TDH : 5.5 m Type : Vert. Subm.	Plastic or Titanium		One common spare in warehouse	
P-402	BRINE CIRCULATION PUMP	1	Cap.: 45 m³/h NPSH : 3.0 m S.G.: 1.18 Motor: 2.5 Kw TDH : 5.5 m Type : Vert. Subm.	Plastic or Titanium			
P-403	MAINTENANCE PUMP	1	Cap.: 5 m³/h NPSH : 3.0 m S.G.: 1.18 Motor: 0.55 Kw TDH : 13.0 m Type : Vert. Subm.	Plastic or Titanium			
P-404	MAINTENANCE PUMP	1	Cap.: 5 m³/h NPSH : 3.0 m S.G.: 1.18 Motor: 0.55 Kw TDH : 13.0 m Type : Vert. Subm.	Plastic or Titanium		One common spare in warehouse	
P-405	BRINE SUPPLY PUMP	1	Cap.: 5 m³/h NPSH : 3.75 m S.G.: 1.2 Motor: 0.55 Kw TDH : 11.5 m Type : Vert. Subm.	Plastic or Titanium			
P-406	$CuSO_4$/HCl-DOSING PUMP	1	Cap.: 20 l/h NPSH : 7.6 m S.G.: 1.1 Motor: 0.25 Kw TDH : 17 m Type : Dosing	Hastelloy "C" or equal		Portable pump	

NOTES :

DA-20-168-2

SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 400
SHEET : 3 OF 5

ITEM NO.	DESCRIPTION	NO.OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
V-401	BRINE LEAK PIT	1	Size: L x W x H = 1.5 x 1.5 x 3.0 m	Lined concrete	-		

NOTES :

DA_20_168

SESEA

EQUIPMENT_LIST

JOB NO. : 01-51372
AREA NO.: 400
SHEET : 4 OF 5

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
X-401 A/B	ANALYSER/PROFILE METER	2	Automatic temperature/conductivity measurement device, consisting of: winch + motor, thermocouple and conductivity cell. Motor 60 W.			2 Analysers per pond	
X-402 A/B	ANALYSER/PROFILE METER	2	Automatic temperature/conductivity measurement device, consisting of: winch + motor, thermocouple and conductivity cell. Motor 60 W.			2 Analysers per pond	
X-403	ANALYSER/PROFILE METER	1	Automatic temperature/conductivity measurement device, consisting of: winch + motor, thermocouple and conductivity cell. Motor 30 W.			1 Analyser in evap. pond	

NOTES :

DA_20_168_2

EQUIPMENT_LIST

JOB NO. : 01_51372
AREA NO.: 400
SHEET : 5 OF 5

ITEM NO.	DESCRIPTION	NO. OFF	PERFORMANCE DATA	MATERIAL	VENDOR	REMARKS	REV.
Z-401	SOLAR POND	1	Size : L x W = 45 x 90 m Depth: 4 m	Concrete lined	-		
Z-402	SOLAR POND	1	Size : L x W = 45 x 90 m Depth: 4 m	Concrete lined	-		
Z-403	EVAPORATION POND	1	2x Evaporation pans: Size: L x W x D = 20 x 50 x 0.5m Brine evaporation pond Size: L x W x D = 40 x 50 x 2m	Pond: Concrete lined Pans: Conc	-	Pan depth varies between 10 to 50 cm.	

NOTES :

6 PRELIMINARY DESIGN OF ELECTRICAL SUB-SYSTEM, UNIT 500

6.1. INTRODUCTION

The lay-out of the electrical sub-system is based upon the requirements of the other sub-systems. The basis for the electrical design and installation of the solar controlled environmental agriculture system will be in accordance with the U.S. electrial and engineering standards and with SESEA electrical requirements. In case of conflict the most stringent regulation will apply. These standards are to be applied fully to all parts of electrial design, including packaged units which will form part of the plant.

6.2 DESCRIPTION

6.2.1 Design Criteria

To achieve the best standards of quality and safety, the following codes, SUB-articles and articles, will be used:

IEC Regulations NFPA 70:

art	110	Requirements for electrical installations
	200	Use and Identification of grounded conductors
	215	feeders
	240	overcurrent protection
	250	grounding
	300	wiring methods
	310	conductors for general wiring
	318	cable trays
	326	medium voltage cable
	323	armoured cable
	340	power and control tray cable
	346 thru 352	conduit and raceways
	373	cabinets and cutout boxes
	380	switches
	384	switchboards and panelboards
	430	motors, motor circuits and controllers
	440	airconditioning and refrigerating equipment
	445	generators
	480	storage batteries
	547	agriculture buildings
	645	data processing systems
	668	electrolytic cells
	675	electrically driven or controlled irrigation machines
	680	swimming pools, fountains and similair installations

IEC regulations no.

66	Fuses not exceeding 1000 Volt
144	Degrees of protection of enclosures for low voltage switchgear and control gear
158-1	low voltage control gear for industrial use

In addition to the standards and codes, the electrical system will be in accordance with the local regulations and requirements of the following institutes:

- Electrical power supply company
- The fire fighting department
- The ministry of labour inspectorate
- National safety laws

6.2.2 Design and Drawings

1 The complete electrical system will be designed for a reliable service, highest degree of flexi- bility, consistent with good practice, safety to personnel and sound economics with a maximum in- terchangeability of equipment.

2. Transformer ratings, switchgear interrupting ca- pacities, cable sizes, etc. will be calculated and selected in line with good practice.

3. A system design will be prepared containing the short circuit calculations, relay settings and coordination curves. The system diagram will show and define the complete electrical system including the circuit breaker and switch inter- rupting capacities, short circuit ratings, relay- and metering devices, transformer ratings, motor loads, etc.

4. Drawings will consist of complete plans and ele- vations showing equipment locations, power and control cable lay-out, grounding lay-out, light- ing system plans and elevations, communication- plans and cable schedules in an orderly numerical sequence, etc. The drawings will also include all wiring and elementary diagrams for all items, such as switchgears, relay cabinets etc. and in- clude all drawings necessary for the proper in- terconnection between electrical equipment.

5. All drawings will be an accurate representation of the electrical system as installed, in such a manner that they may serve the owner as a con- venient guide for future operation and mainte- nance.

6. All drawings will contain the complete infor- mation required for the installation.

7. Drawings, symbols etc. will follow the seller's standards and procedures and comply with the standards as mentioned in para 3.

6.2.3 Limitations and system control

1. The distribution, installation and utilisation of the electrical system will conform to the standards mentioned above.

2. The distribution system will be designed and in- stalled to provide a maximum of circuit relia- bility consistent with good economics and ease of operation.

3. The arrangement of the electrical system switching will be such that it will allow sections of switchgear and feeders to be isolated and de-energized for maintenance without interrupted service to critical areas.

4. The distribution circuits will be designed to provide good circuit reliability and safety.
   All critical loads will be fed from two cir- cuits in parallel.

5. The low Voltage generator distribution system, fed by 380/220V - 60 hertz will feed all power consumers.

6. A local supply of sufficient power 380/220V-60Hz is assumed available at plant site and connected to the main panel.

7. To provide a high efficiency system, a scanner unit will be installed that gives economic power distribution to all small intermediate electrical consumers.

8. All electrical consuming equipment such as cab- les, relays, motors etc. will be designed for low loss of heat with considerations for minimum cost.

6.2.4 Electrical Installation

6.2.4.1 Main Power Distribution Board

This MDB is designed for indoor use and is in accordance with tropical specification 1P54. The construction is based on a modular system, build up in sheetsteel and divided in three main parts. One part for equipment, one for the busbars and the third part for installation of cables. The feeder cables and outgoing cables will enter and/or leave at top of the switchgear. All live parts are screened against accidental contact. The busbar system will have a short current capacity of 25 KA during 1 sec minimum.

The MDB contains the incoming 380/220V - 60 Hz feeders from the generator, battery unit and the local grid plus the outgoing feeders to the power consumers. Each motorgroup will contain at least the following items:

3 fuseholders
1 electromagnetic circuit breaker
1 push button "green" ON
1 push button "red" OFF
1 signal lamp green "ON"
1 signal lamp red "OVERLOADED"

and the necessary terminals, nameplates, fuses and cableglands. The materials to be used will be of Klöckner Moeller, B.B.C., Telemechanique supply or equal.

In considering the various conditions, reference is made to typical performance figures. It must be noted, that any attempt to be specific, can only be made with true performance figures for the load in question.
Full and detailed technical information of current consummers under both starting and running conditions must be obtained from the manufacturer of the load.
In considering motor loads, design data should be sought from the motor manufacturer.

6.2.4.2 Wiring Methods

- In general, all electrical and instrument control cables will be installed in multi conductor XLPE (cross linked poly ethylene) insulated and XLPE sheathed cables.

- In general, all power and/or lighting cables will be installed in prefabricated cable trays.

- Cables running from the trays to the motors or panels, placed on concrete slabs will be installed in PVC-, or steel galvanised conduits. The conduits will be poured into the concrete and must be of sufficient size to allow easy pulling

- In general, cables will be installed exposed, in cable ducts or racks, supported by clips or saddles. Individual cables may be installed direct on steel, ceiling or in galvanised conduits.

- Cables will not be installed in close proximity to hot piping. A minimum of 300 mm clearance will be observed.

6.2.4.3 Grounding

Ground connections for power consumers will be through a conductor in the cable, which is connected to the ground bus in the MDB at one end and at the grounding point of the power consumer at the utilization end.

Shielded cables will have the shield terminated and grounded at one end only, preferably at panelboard end for instrument and communication cables and at the supply end, for electronic power cables. The ground shield at broken connection points at junction boxes, will have jumper connections.

The neutral secondary winding of all lighting, instrument and control transformers will be grounded at the transformer.

Grounding rods will be 3/4" copperweld. The length of the grounding rod to be driven in the soil will be governed by the requirement that the total resistance to ground of each grounding rod will be less than 5 ohm, in accordance with local practice and standards. The grounding rod will be connected to the main grounding loop and bus in the MDB.

6.2.4.4 Lighting

To avoid generating heat due to lighting, its level in the greenhouse is kept to a minimum. However, power supply for lighting in general, is taken from the main electricity grid.

6.2.4.5 Cabling

For the power distribution the following cabling is required:

- cabling from generator to Main power Distribution Board (MDB)
- cabling from Battery unit to MDB
- cabling from MDB to power consumers
- cabling for control and alarm from actuators to the switchboards.

For cabling, cross linked polyethylene cable is selected, the insulation of which, allows a higher temperature resistance than rubber insulated cables.

The thermal resistance depends upon the following:
- construction of the cable and its materials
- the possibilities of loss of heat at cable surface to the surrounding air.
- the manner of installation of the cable.

The above factors are summarised in a table. These values are average and the cable loadings will have to be reduced by empirical factors. However, by common practice, all selected cable diameters will be at least one size larger than that found from the tables.

6.2.4.6 Advantages of high power factor

A low power factor means that for the same Watt-power, the inverse current is larger, e.g. at cos Phi 0.5 (60°C) the inverse current is twice the value of the Watt-current. Consequently, extra power and voltage losses will occur in generator coils and cables. The heat losses are then equivalent to the reciprocal of the squared value of the power factor. Lowering the power factor, means a lower loading possibility of the grid. Using a high power factor, the grid can be used at its optimum and voltage drops become smaller.

Methods to improve the power factor:

The improvement of the power factor which might be capacitive or inductive can in this case be done by using capacitors or synchronous motors or asynchronous commutating motors. Capacitors will take the forward phasing current from the system. Because of its static construction, it has several advantages to rotating equipment, such as no service requirements, simple method of installation and no special foundations. Due to these advantages, capacitors are often used for this purpose.
The capacitors will be installed in parallel with the consumers to the grid and will take a capacitive phasing current (running forward) which compensates for the inductive phasing current.

By using the capacitors, the inverse current is reduced to a level which equals the Watt-current (or nearly equal).

The reduced load of the cable finishes at the point where the capacitors are connected to the load. Hence it follows that compensation has to be achieved as close as possible to the inductive load.

6.3 DESCRIPTION OF ENERGY SUPPLY STSTEM

6.3.1 General

The electrical energy supply has to be available without any interruption. In general, the Rankine cycle expander-generator system will be supplying the electrical energy. In emergency cases however, battery power will supply the energy required for critical functions for up to 5 kW for 5 hours. If after 4.5 hours the Rankine cycle expander is not in operation, the local grid will provide the required electrical energy in order to ensure continued operation. The electrical load calculations showing supply and demand characteristics are provided on Drg.no. DA-51372-00-12-007-00-001 at the end of Section 6.

6.3.2 Generator coupled to the Rankine cycle

The Rankine cycle expander is coupled to a 3 phase 220/380 Volts 60 hertz generator. At a power factor of 0.88 and an efficiency of 0.865; 28.6 kW can be produced by the system. This generator supplies all the electrical energy demand on a continuous basis. The Rankine expander output will be controlled to 5% at 3600 RPM, independent of the power taken by the generator.

6.3.3 Generator Control

The speed of the generator is controlled by means of adjusting the flow of freon to the expander. As energy demand increases on the output of the generator, the amount of freon gas flowing through the expander will also increase.

The speed of the generator is measured via a magnetic pick-up system and is fed to the speed and load sharing control unit.

The load sharing and control unit amplifies the incoming signal and compares this with the required speed. The control signal is then transmitted in order to adjust the position of the inlet valve to the expander.

In case of failure of the generator, the power supply can be switched over to the local grid.

Synchronization of voltage, frequency and phase of the generator supply to that of the grid supply is necessary if it is required to make provision for export as well as import of electrical power. If only the latter is required, no synchronization equipment will be necessary. However, if a synchronizing control unit is used, then the signal is fed to the load sharing and speed controller for automatic adjustment and eventual parallel operation. Similarly the amount of power exported or imported can be measured and controlled.

The synchronising unit compares the generator voltage supply to that of the grid supply. This is necessary with fluctuating grid voltage. The range is from 1 KVA to 1500 KVA.

Frequency control is achieved by comparing grid frequency with that of the expander-generator and adjusting the speed of the expander rotor by increasing the supply of freon to the expander. In this way, the grid and generator frequencies are equalized and parallel switching can be made.

If the expander revolutions exceed the set accuracy limits, the control system will disengage the generator from the grid.

In special cases, where the generator is connected to equipment such as computers and transmission stations, it may be necessary to operate within very specific performance parameters. In these cases, advice from the factory will be sought and where a specification exists for any particular load or installation, it will be forwarded to the generator manufacturer so that any possible design changes could be incorporated in order to provide a low cost machine.

The sequence of control is as follows:

- The speed is measured via a magnetic pick-up system and fed to the Speed and Load sharing Controller.
- The output signal from this controller will adjust the position of the inlet valve by means of an electric or electro-hydraulic actuator. The actuator adjusts the inlet valve via a piston rod or ring.
- The synchronising unit controls the voltage and frequency with respect to the grid and sends a signal to the load sharing and speed controller.
- The import/export unit which controls the power supply from the generator to the grid or from the grid to the generator can be easily adjusted.

These units will be built into a switchboard or into the Main power Distribution Board.

6.3.4 Battery

To equalize the peak power consumption, a battery system is provided. It is connected to the grid via a rectifier, 380/220 V 60 Hz to 110 V D.C. and a converter, 110 V input and 380/220V 60 Hz output system.

The 110 V DC battery is sufficient for 512 Ampere hours or a capacity of 102 Amps during 5 hours energy demand.

The system is designed in such a way that at maximum power demand the batteries will supply electricity at 5 kW maximum power during 5 hours (i.e. the power demand of three electric motors consuming 1.7 kW each). The change-over from generator supply to battery supply has a build-in time delay of 100 milliseconds. No synchronisation is required and there is no risk of damage to the D.C./A.C. converter. This converter is designed in such a way that motors are to be started one at a time. It is therefore important that a proper start-sequence is ensured. During the night, when energy demand is low, the batteries will be recharged.

Maintenance free, long life batteries will be supplied for this duty.

Battery specifications

The battery set will consist of 64 cells, type Tublar plate traction batteries.
nominal voltage 120 volt D.C.
nominal capacity 490 A.h. for 5 hours.
max. load 5 hours 98 Amps. to 105 Volt lowest voltage limit.
The battery set is mounted on a skid, size approx.
4500 x 600 x 600 mm.

Static converter, including mechanical change-over switch.
connection 105 - 160 Volt D.C.
supply input 10.6 Amps at 105 Volts
output 380/220 Volt 60 Hz 3 ph
power 5 kVA cos Phi 0.8.

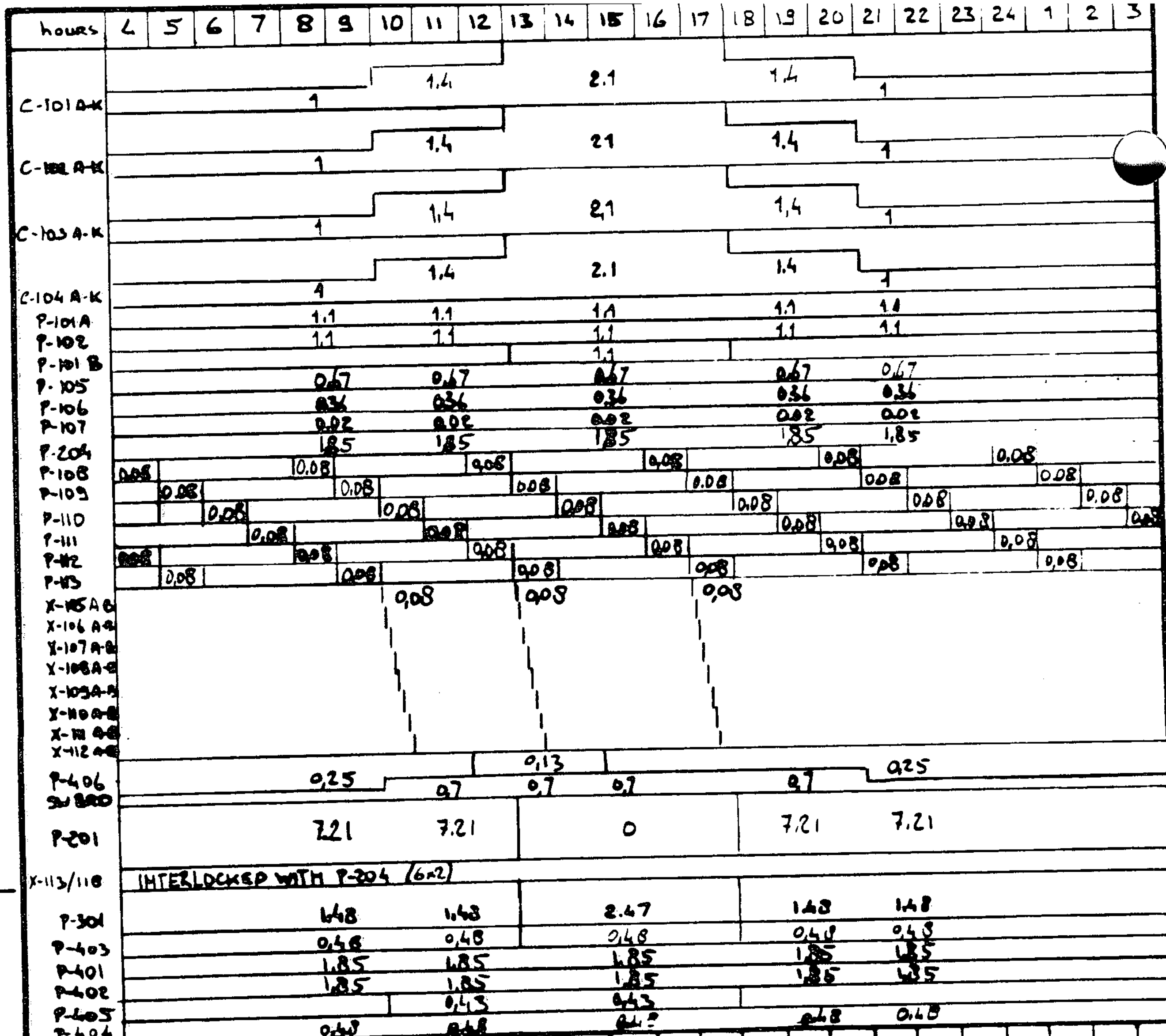
maximum power factor 0.7 inductive to 0,9 capacitive
change-over time min. 100 millisec.
convertor is built in two switchboxes.
Total dimensions 1680 x 700 x 200 mm.
weight approx. 1000 kg.

Efficiencies: batteries 90%
convertor 78%
rectifier 88%

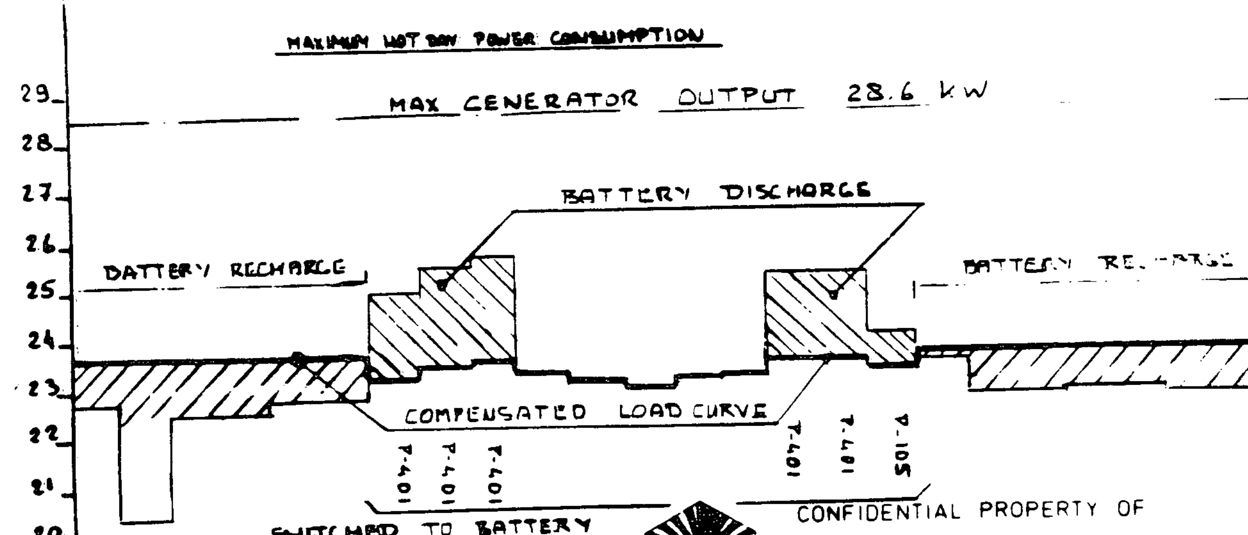
By a charging time of max. 19 hours from 30 to 98 % of the battery capacity, and a discharge time of 5 hours (98 to 30 %), these batteries will have a lifetime of 3 - 4 years. Max. operating temperature 25 °C (conditioned room is required).

6.3.5 Instrument Supply Back-up

For emergency supply of electricity to instruments, control valves and data logging system, a battery unit is provided with a power of 2 kVA for 5 hours. In the event of grid supply failure, battery power will be made available for so long as it will last or until the resumption of grid supply.



hours	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3
TOTALS kW CONS.	22.86	20.66	22.78	22.78	22.86	22.86	24.91	25.26	25.47	23.23	23.07	22.94	23.02	23.1	25.26	25.24	23.91	23.31	22.78	22.78	22.86	22.86	22.78	22.78



ELECTRICAL LOAD CALCULATION

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D	A	5	1	3	7	2	0	0	1	2	0	0	7	0	1	0	0	1	0	0	1		

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7. PRELIMINARY DESIGN OF INSTRUMENTATION SUB-SYSTEM, UNIT 600

7.1 DESCRIPTION

7.1.1 General

Instrumentation is required to enable safe, reliable, consistent and economic operation of the various systems required for the operation of the greenhouse.

Additional equipment is required for optimisation, evaluation and fault finding within the systems.

The main control will be effected from a control room which will house all controlling, data logging, shutdown and alarm, indication and computing equipment.
Transmission to the remote mounted transmitters and actuating devices will be electronic.
All instrument power for actuators will be electrical.

7.1.2 Master Control Sub-system (MCS)

The MCS will integrate microprocessor based analog control systems in each major sub-system of the CEA plant. The objective of the MCS integration and design work is the automatic production and distribution of electricity and product water in a safe and economic manner. The MCS will integrate control of all sub-systems and provide full operator control and override of automatic functions from a central location. Existing control technology is to be incorporated wherever possible and implemented using graphic consoles, human engineered for rapid operator response and understanding. Design conventions, including standard color codes, rationalized control locations, operational procedures, and modifications of different manufacturer's control templates will be used to ensure consistency of operating patterns and appearance.

In general, the design approach is to integrate microprocessor-based analog control systems in each major sub-system with the main power plant computer. Microprocessors, as currently used by the process industry, provide both the flexibility for control system design and interface capability, required for new designs. Hence, the proven performance of a conventional power plant computer serves as the basic process data acquisition and plant monitoring function. The ancillary data acquisition and in particular, sub-system operational requirements are fulfilled by highly versatile and expandable (in both software and hardware) microprocessors. These can be readily obtained from suppliers such as the ANALOG DEVICES MACSYM 10 or HEWLETT PACKARD (9800 Series).

Control System hierarchy is shown in figure III-59 as indicated in Task III Report and consists of four levels representing different degrees of operator intervention. Level I, Integrated Supervisory Control, is provided by the Master Plant Computer which coordinates automatically all sub-systems for different operating modes.

Routines for collector field activation, pump sequencing, transition to and from thermal storage operation, and part load desalination operation are included. Should level I default, Level II, Semi-Automatic Coordinated Control, is initiated requiring operator intervention. Here, coordination is provided by the plant operator while the still active independent sub-system controls enable each sub-system to operate in an automatic mode. The next level of control consists of manual controls in which each sub-system's operation is controlled by the operator along with coordination of the overall plant. Finally, there is a hard-wired non-interruptible system of safety interlocks and emergency trips among the sub-systems with an annunciator system link.

The MCS functions are directed from a central control room. Co-located are process display panels indicating status of critical components such as collectors, pumps, and major valves. Also in the control room are all necessary data acquisition, interpretation, and storage equipment. Digital indicators linked to the data acquisition system and control sensors will allow visual tracking of process flows, temperatures, and pressures of the power generation, water treatment, and product water distribution plants. Manual centralized control of all systems components will be accessible via these panels.

DATA ACQUISITION SUB-SYSTEM

The Data Acquisition Sub-system (DAS) provides input in real time to the Master Control Sub-system (MCS) for plant operation and to the archived data base for diagnostics, analysis of performance, and reporting. The DAS will sense and record data from the solar power sub-system, the water treatment sub-system, product water storage, and the ORC sub-systems. The DAS time-shares components and information with the MCS and includes the various interface buses, all sensors, wiring, and all signal conditioning equipmment and required input/output units such as printers, terminals, and disc and tape drives.

The essential element for the proper coordination and transfer of data throughout the entire plant is the data bus system.

Each microcomputer location will have a data acquisition module to accommodate its set of data channels. Each module will be composed of an analog-to-digital converter, a buffer, an address register, and the supporting de-commutators, gates, and line drivers. Each de-centralized data module will be supplied with an adjustable address switch so that a discrete address may be established for each measurement within the data acquisition system. The central processor computer will sequentially address each decentralized data module with an 11-bit parallel digital address. The addressed module will then sample the parameter of interest, convert it from an analog voltage to digital readout, and transmit the data upon receiving a strobe pulse from the computer.

Power will be provided to the decentralized data modules on the data bus cable. The sequence in which data is acquired will be controlled by tables stored within the computer which may be modified or expanded as future requirements dictate. Using this method, any data channel is accessible to each of the sub-system computers. A priority interrupt system will be implemented that will give ordered priority access to data to allow manual requests under alarm conditions. Equipment to satisfy these requirements is available with minor hardware changes and software development from vendors such as Digital Equipment Corporation and Hewlett Packard.

Capability to perform tabulation of daily and hourly performance, graphic output of stored data, and graphical integration of color charts will be provided as needed. The plant master computer will have storage capability for "replay" of diagnostics of unplanned outages.

The DAS functions in which data are stored for future reference, projections, and diagnostics will be performed by the separate DAS computer and storage equipment. This will allow separate plant control and data acquisition function. Thus, the plant operation will never be interrupted because of DAS failures.

7.1.4 Description of Sub-system Controls

7.1.4.1 CEA Sub-System

The CEA sub-system (Controlled Environmental Agriculture Unit) is the main growing area for the crop. There are four parameters which must be monitored and controlled these are:

1. Temperature
2. Humidity
3. Radiation

To ensure a healthy crop these variables must be maintained at their optimum levels.

The most important factor for the CEA Sub-system is the temperature. This is maintained by circulating air through the greenhouse in order to reduce the temperature. Outside air is drawn into the greenhouse via the cooling pads, passing through the greenhouse and into the suction of the circulating air fans. The air leaving the fans passes over the tubes of the freon condenser and along the cavity roof section and is discharged through the control section X-105, 106, 107 and 108. In this mode, the air is cooled by the latent heat of evaporation of the water on the cooling pad.

The temperature control in the greenhouse is regulated by changing the number of cooling fans running, if the temperature exceeds the desired value with all the fans running, an alarm will be initiated to instruct the operator to manually introduce solar shading.

This action will cause a drop in temperature and will allow a reduction in the number of fans in use. One limitation is that enough fans must always be in operation to satisfy the requirements of the freon condenser. This will be monitored automatically and action will be taken to ensure that the freon condenser duty is maintained. Humidity in the greenhouse is maintained at a constant level by modulating the by-pass louvers in the cooling pad. Operation of these louvers will have a direct effect on the temperature control system. Pad by-pass will initiate a system to re-position the fresh/ recirculating air damper and or change the number of cooling fans in operation.

The control system will always keep the number of operating fans to a minimum to conserve energy whilst observing the temperature and condenser duty limitations.

At times when the outside temperature is below the required greenhouse temperature, the fresh/recirculating air damper will be partially closed to allow a high degree of recirculation and hence heat the greenhouse with heat from the freon condenser.

7.1.4.2 Solar Pond Sub-system

The solar pond is the prime source of energy for the entire system. Automatic controls on the pond are few, but there will however be many important monitoring facilities installed for the efficient utilization of the energy stored in the pond.

The most important information for adequate management of the pond is the temperature gradient, the density gradient and the clarity. For the density gradient, conductivity is measured and the density calculated from this figure. The temperature and conductivity profiles are measured simultaneously to allow meaningful calculations to be performed on the data received. The method of measurement is as follows.

The temperature and conductivity elements are suspended on a line and lowered slowly into the pond. The lowering mechanism has a position transmitter which produces a signal proportional to the depth to which the elements have been lowered. As the elements are lowered, the depth, temperature and conductivity signals are fed into the data logging system at regular intervals as required. The lowering action will be interrupted whilst temperature stability is reached before measurements are made. With this system, an accurate picture of the various layers in the pond can be obtained.

Clarity in the pond is measured in a similar way. The element used is a radiation transducer which is lowered into the pond using the same device as the above and the radiation measured at various depths in the pond. The information on radiation and depth are transmitted to the data logging system for future use. Heat losses through the pond sides are estimated by measuring temperatures both in the pond and at various distances from the pond at various depths from the ground surface. From this data, heat losses from the pond wall may be calculated. Facilities are provided within the data logging system to allow calculations on the above losses.

7.1.4.3 Water Sub-system

Well water enters the sub-system and is analysed for pH and conductivity. The pressure, temperature and flow are also measured.

From the raw water storage, water is fed to the permeators at constant pressure. This is achieved by recirculating some water over the feed pump. Reject water from the permeators is flow-controlled with a conventional flow loop. This configuration enables maximum sweet water production with minimum losses to be realised by correct selection of controller set points.

Sweet water from the permeator is checked for conductivity and is returned to the raw water storage in the case of a high high conductivity reading.

In normal cases the sweet water is flow-metered and sent directly to the sweet water storage.
Other factors which could interrupt production of sweet water are

- low low pressure of reject water
- low low pressure of well water to permeators
- high high pressure of well water to permeators
- high temperature of well water to permeators

Sulphuric acid dosing is controlled automatically via pH measuring system. Mixing is via the return flow to the well water tank from the pressure control valve.

7.1.4.4 Organic Rankine Cycle Sub-system

The function of the Rankine Cycle is to produce electrical energy with which to drive the remainder of the systems.

Other aims of the system are to generate the power as economically as possible and minimise disturbances in the solar pond or the greenhouse due to interactions within the system.

The main factor in the system is the speed of the expander which sets the frequency of the generator A.C. power.

To control this frequency a control valve is installed in the freon feed to the unit. This valve is operated from the speed control system.
To prevent energy waste in the form of a high differential across the valve, the differential pressure is measured and fed back to the brine system to adjust the quantity of brine passing through the freon vaporizer, by modulating the bypass valve of the vaporizer unit.

This method of control will ensure that for all normal conditions the minimum heat will be removed from the brine whilst maintaining a constant generator frequency.

All equipment in the freon line to the expander is designed to produce minimum pressure loss at maximum capacity.

The level of freon in the freon vaporizer is maintained by a conventional level control system which sets the stroke of the freon pumps.

Brine to the freon vaporizer is flow-controlled by a bypass control valve around the tubeside of the exchanger.
Flow to the exchanger is measured and used in the control system to eliminate outside disturbances from the brine/freon system. Total brine flow to and from the vaporizer is measured, together with temperature and temperature difference which may be used for system evaluation, fault analysis, etc.

7.1.5. Flow Meters

Flow meters will be selected with minimum insertion loss. For brine and water flows, electromagnetic flow meters will be used. For freon flows, a venturi tube sized for minimum differential pressure loss with a conventional differential pressure transmitter will be used. These devices should cover all the flow measurement applications. However, if a different element is required, then types like the above with very low insertion losses will be used.

7.1.6 Level Measurement

Level transmitters will be of the differential pressure type with electronic transmission. Local level indication will be by reflex type level gauges. Level switches will be of the external chamber float type with electric switch output.

7.1.7 Pressure Measurement

Pressure transmitters will be of the conventional diaphragm or bellow type as dictated by measurement range. Output will be electronic.

Local pressure indicators will be bourdon tube type or diaphragm as dictated by operating range.

Pressure switches will be direct action bellows types with electric switch output.

7.1.8 Temperature Measurement

Temperature transmission will be by means of thermocouples. Normally the thermocouples will interface directly with the control room equipment. Thermocouple type will be a sleeve protected copper/constantan, due to the low temperature range.

Local temperature indication will be by Bi-metallic temperature indicators.

Temperature switches will be thermocouple input types with electronic switch output. These units will be located in the control room.

7.1.9 Analysis

Analysis instruments will be decided on individual merit. All selected units will have an electronic output which is compatible with the input to the control room equipment.

7.1.10 Transmission

Transmission signals for communication between control room equipment and field equipment will be as follows:

Analogue transmitter	4-20 mADC
Field mounted switch	contact
Control valve	Separate contact to inch open and inch closed
Temperature	mV from thermocouple

7.1.11 Control Valves

Control valves will be electrically actuated. Direct electrical actuators have the benefit that whilst the valve is stationary no power is consumed. Initiation of the actuator will be via two signals one to cause the valve to move towards the open position and the other to move it to the closed position. When both signals are absent the valve will stay put. Power to the valve will be 220 V 60 Hz. Actuators will be fitted with limit switches to prevent damage at the extremes of travel.

Control valve body size and style selection will be decided by the process conditions. Valve types used will be globe, ball and butterfly. Valve sizing will be in accordance with I.S.A. sizing formulae.

7.1.12 Safety Valves

Safety valves will be conventional type sized in accordance with API-RP 520.

7.1.13 Actuators

Actuators for positioning of louver etc. will be electrically operated. Control will be by separate open/close commands as with control valve actuators.

7.2 HARDWARE SPECIFICATION

7.2.1 General

The equipment recommended to fulfill the master control sub-system obligations is a minicomputer-based product manufactured by Analog Devices. The chosen model is Macsym 10.

This model fulfills all the requirements viz:

- data acquisition
- control and alarming
- possible interface with host computer in the future

7.2.2 System architecture

The system architecture recommended here is as given below:

- a central processor unit (CPU)
- system control card
- CRT display unit
- floppy disc unit for use in prom programming
- analog digital input/output controller to interface with the outside
- analog stand-by stations to take over control in case of unlikely occurence of CPU failure

7.2.3 Hardware Details

7.2.3.1 Central Processor Unit (CPU)

Architecture	:	Gen. purpose digital processor with 4 accumulator registers
Word length	:	16 bits
Memory	:	128 K RAM in NMOS
	:	104 K prom.

Extended instruction set	:	Load byte, store byte
Floating pont	:	add, subtract, multiply, divide, fixed and floating point
Execution speed	:	arithmetic/logic instns: 1.2 microsecs memory reference instns: 1.8 microsecs
Technology	:	micro-programmed 4 bit sliced

7.2.3.2 ADIO Controller

Analog to digital conv.	:	12 bit succesive approx.
Range	:	+ 9.990, - 9.995 volts
Non linearity error's	:	$\pm$ 1/2 LSB
Gain temp coeff.	:	$\pm$ 15 ppm °C max.
A/D conversion time	:	25 microsec.

7.2.3.3 Programmable gain amplifier:

Gains	:	1, 2, 4, 8.
Input impedance	:	10^9 ohms

7.2.3.4 Sample/hold amplifier

Aperture time	:	90 ns (max)
Aperture jitter	:	20 ns (max)

7.2.3.5 System control card

Disk buffer
Real time clock
Power monitor
RS232C or 20 MZ current loop

7.2.3.6 CRT Terminal

Screen size	:	12" diagonal
Keyboard	:	full ASCll
Display	:	7 x 10 dot matrix over 24 line by 80 column screen
Colour	:	green on-black
Baud rates	:	switchable

7.2.3.7 Floppy disc drives

Size	:	8" of dual drives
Capacity	:	256, 256 byte per disc.

With ceramic head, and switch
selectable power or bootstrap loading

7.2.3.8 Isolated analog input card AIMo4

No of channels	:	16 differential
Resolution	:	12 bits
Input voltage	:	$\pm$ SMV to $\pm$ 10 V
Gain	:	Programmable
Data acquisition mode	:	Ain

7.2.3.9 Thermocouple input

No of input	:	4
Type of T/C	:	I, K, T, E, R & S
Temp range	:	- 210'C to 1768'C a distinct ranges
Overall accuracy	:	$\pm$ 0.3 ./. F.S.
Data Acquisition Modes	:	Ain, Scan, Collect, or AVG

7.2.3.10 Analog output cards AOC2

No of channels	:	4
Output	:	4-20 mA
Resolution	:	12 bits
Output protection	:	short to ground

7.2.3.11 Solidstate isolated digital I/o interface

No. of channels	:	16 DC input or output
Isolation	:	2500 V max.
DC input range	:	10 - 32 VDC
DC output range	:	60 VDC (a) 3A max

7.2.4 Multitasking

The most advantegous feature of the recommended system is multitasking. This allowes running independent routines simultaneous to control of multiple processes. This feature is essential in this project since one task can gather data on the solar pond, while another will be logging alarms in the turbo expander unit with the third, providing climatic control of the greenhouse. This also permits changing of variables while the system is running so that there will be no need to shut-down in order to accommodate new adjustments or parameters. Tasks can also be set to different priority levels so that critical jobs are handled first, and by using passwords, changing variables can be done with absolute keyboard security.

Furthermore, programmes can be started or stopped independently of each other and the system can even start and stop different programmes on its own, without external operator intervention.

7.2.5 Software

The chosen system has the most advantageous and easy to programme software in "Basic". Enhancements have been added to allow user to perform measurement and control effectively by the use of "Macbasic".

This project involves not only control of process variables, but also the system should perform data logging, computation and even graphic display. The following software examples would clearly demonstrate the ability of the system in different mode of operation.

Example 1	:	Programme for a P + D loop control
Example 2	:	-DO- for Graphic display using analog read-in
Example 3	:	Process demonstration with flow diagram for an (operator user friendly) unit operation
Example 4	:	Application software package 1 for plot of historical data
Example 5	:	Application software package 2 to calculate common statistical information

The examples shown above are a few of the wide choice offered by the machine wherein the only limitation can be the user's imagination. The actual application programme will be detailed in phase II of this project.

8. MISCELLANEOUS, UNIT 700

8.1 GENERAL CIVIL

8.1.1 Roads

The complex of greenhouses and solar pond will be connected with an access to the existing road. Within the site area the roads are called internal roads.

Two types of roads will be provided:
- type A: 6 m width, access road
- type B: 3 m width, internal road

The cross slope in straight lines is 2,5%. One-sided cross slope is used for the roads on the embankments of the solar pond to get the rain water flows away from the pond itself.
From precipitation figures it may be concluded that no storm water drainage system is necessary. The small quantity of rainwater can be discharged to the surrounding areas for recharge and/or evaporation.

The thickness of the sub-base, the bituminous base course plus the wearing coarse shown in the drawing are approximate values only. The exact dimensions can be calculated, taking into account the corresponding axle loads. In this context it is proposed to choose a standard truck with a total weight of 10 tons.

With regard to compactability, special demands will be made on gravel material to be used for the sub-base. Only a well-graded, sand-gravel mixture, or else crushed rock meeting the following conditions may be used as sub-base material:

- Sand Content 0-2 mm:	minimum of 20%
- Gravel Content over 2 mm:	35-80%
- Silt Content under 0.063 mm:	maximum of 08%
- Silt Content under 0.02 mm:	maximum of 03%
- Maximum Grain Size:	70 mm
- Uniformity Coefficient:	minimum of 7

All parts of the sub-base must have at least 102% Proctor density.

The mix of bituminous concrete is to be spread by approved, self-propelled mechanical pavers. These will be capable of laying the mix in the prescribed thickness and will be equipped with spread and strike-off operational systems capable of producing a finished surface of even and uniform texture over the entire paver operating width.

Before the mix is placed, the surface of the sub-base is to be mechanically sprayed with bitumen emulsion amounting to about 0.30 kg/m^2.

If no mechanical paver is available, the mix may be spread by hand. Spreading temperature will be 150-160°C, depending on the binder.

Immediately after spreading, the mix will be thorougly compacted behind each finisher by rollers.

The course already laid must be carefully cleaned prior to placing an overlying layer. For satisfactory bond between layers, a tack coat of cutback bitumen will be applied, amounting to a quantity of approximately 0.2 kg/m^2, if required.

The bituminous base course will consist of a layer of about 9 cm total thickness, corresponding to a weight of 230 kg/m^2.

Aggregate grading will be 0/30 mm and must contain at least 40% crushed material for the combined aggregate, including sand. The percentage of wear for the coarse aggregates as determined by the Los Angeles abrasion test may not exceed 25.

The binder will be petroleum asphalt cement, penetration grade 65/80; the content of asphalt binder is to be approximately 4.7%. The percentage of voids in total mix will be 5%, minimum Marshall stability, 600 kg.

The asphalt top course will consist of one 6 cm-thick layer weighing 20kg/m^2. The combined aggregates must be 100% crushed, well-graded material containing at least 55% multiple-broken aggregates of 2-12 mm in size.

Filler content must amount to at least 10%.
The wear of the coarse aggregates as determined by the Los Angeles abrasion test may not exceed 22%.

Petroleum asphalt cement will serve as binder; penetration grade 65/80, asphalt binder content circa 6.3%.

The bituminous base course will be carefully cleaned prior to application of the top course.

The shoulders may be constructed only after the bituminous concrete and the top courses have been placed.
The shoulder is to be constructed of sub-base material up to a height of 10 cm below the finished height and compacted with smaller compacting equipment. The prescribed shoulder slope is 2.5%.

8.1.2 Civil applicable Codes and Regulations

The latest edition of the following codes and regulations are recommended for civil and structural works. The list below does not claim to be complete.

1. American Society for Testing and Materials

Specification for Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars and Strip	A 123-73
Specification for Welded Steel Wire Fabric for Concrete Reinforcement	A 185-73
Specifications for Welded Deformed Steel Wire Fabric for Concrete Reinforcement	A 497-72
Method of Making and Curing Compressive and Flexural Strength Test Specimens in the Field	C 31-69
Specification for Concrete Aggregates	C 33-74
Method of Test for Compression Strength of Cylindrical Specimens	C 39-72
Specification for Portland Cement	C 150-74
Method of Sampling Fresh Concrete	C 172-71
Specification for Liquid Membrane-Forming Compounds for Curing Concrete	C 309-74
Method of Test for Drying Shrinkage of Concrete Block	C 426-70
Testing Concrete Joint Sealers	1191-64
Specification for Concrete Joint Sealer, Cold-Application Type	1850-67
Testing Concrete Joint Sealers, Cold-Application Type	1851-67
Specification for Deformed Steel Wire for Concrete Reinforcement	A 496-72
Specification for Cold-Drawn Steel Wire for Concrete Reinforcement	A 82-72
Descriptive Nomenclature of Constituents of Natural Mineral Aggregates	C 294
Specification for Sheet Materials for Curing Concrete	C 171
Definitions of Terms Relating to Concrete and Concrete Aggregates	C 125-76
Test for Specific Gravity and Absorption of Coarse Aggregate	C 127-77
Test for Specific Gravity and Absorption of Fine Aggregate	C 128-73
Test for Total Moisture Content of Aggregate by Drying	C 566-67
Test for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete	C 138-77
Method of Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens	C 684-74

2. American Welding Society

Recommended Practices for Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction	AWS D12. 1-61

3. American Concrete Institute

Specification for Structural Concrete for Buildings	ACI 301
Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete	ACI 304
Recommended Practice for Hot Weather Concreting	ACI 305
Recommended Practice for Curing Concrete	ACI 308
Recommended Practice for Consolidation of Concrete	ACI 309
Building Code Requirements for Reinforced Concrete	ACI 318
Recommended Practice for Concrete Formwork	ACI 347
Guide for the Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion Resistant Materials	ACI Committee 515 Report (63-59)

4. American Insitute of Steel Construction

AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings.

5. American Association of State Highway Officials

AASHO Specifications

6. Ministry of Communications, Kingdom of Saudi Arabia

Specifications of Department of Roads.

8.2 PIPING DESIGN DESCRIPTION

The piping design of the CEA system is divided into three parts

- The greenhouse (unit 100)
- Freon and well water system (unit 200 & 300)
- Solar and evaporation pond system (unit 400)

In general, lines are installed to a maximum extent underground or on sleepers. All valves are accessable from grade or platforming.

8.2.1 The greenhouse pipework are installed to a maximum extent underground to minimize interference with the operating and maintanance areas. Air condenser block valves to be operated from grade with chain handwheels.

8.2.2 Freon pumps P-301 A/B are installed in a pit due to suction head requirement and location of the Freon vessel V-301, which is inside the greenhouse.

8.2.3 The solar and evaporation pond pipelines are of glassfibre reinforced material and where possible installed underground. Brine pumps and return headers are vertically movable by means of hoisting beams with counter weights. Maintenance pumps and return headers are vertically movable by means of hoisting beams with counter weights and also movable in horizontal direction over rails. All valves and instruments are accessible from grade.

9. ANALYSIS

9.1 PERFORMANCE ANALYSIS

The performance analysis as carried out in this section will demonstrate the capability of the proposed design to meet the required performance specification under all circumstances. The approach for the Engineering Field Test (EFT) is different from the commercial system, since the EFT is not fully solar powered. The restricted water availability on the Derab site and the uncertainty of solar pond performance although designed with a broad safety margin, have led to an electric grid connection. The grid will deliver electricity for lighting and instrumentation and in the case of shortage of solar pond heat (during winter) will also supply the peak demands of the system.

The reason for the latter will be discussed in paragraph 9.5. First, the overall system performance will be discussed with attention for all interface requirements.
Next, the subsystems are analyzed with respect to their functions in the system.

9.2 SYSTEM ANALYSIS

The system as designed for the engineering field test has been adjusted for the conditions of the Derab site. Since there is enough grid power available, no back-up power system has been provided. The philosophy behind the design is that all items or sub-systems must be able to show their performance during the engineering field test. The results of the engineering field test can be used to optimize a totally solar powered commercial system. Although most of the sub-systems are well known applications and can be designed precisely, some components require design data which must be obtained during the Engineering Field Test. These items are for example the solar pond and the organic Rankine turbine. Prudence demands that the solar pond should be conservatively designed with the implication that water requirements and costs could be heavy.

In fig. IV-7 and IV-8 the summer and winter conditions are shown for the interfaces between the sub-systems.
The total system inputs are the climatic conditions as shown in fig. IV-9 to IV-13. With reference to these figures, the following paragraphs will discuss the capability of each sub-system to meet these specifications.

Fig. IV-7 Interface requirements for summer conditions

Delivery to / from	Unit 100 CEA			Unit 200 Water			Unit 300 ORC			Unit 400 Ponds			Unit 500 Electr.		
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Unit 100 CEA															
Condenser air kg/h	-	-	-	-	-	-	748000	261800	579700	-	-	-	-	-	-
Unit 200 Water															
Pad circ. water m^3/h	60	0	40	-	-	-	-	-	-	-	-	-	-	-	-
Pad evap. water m^3/h	1.5	0	1.3	-	-	-	-	-	-	-	-	-	-	-	-
RO feed m^3/h	-	-	-	1.06	1.06	1.06	-	-	-	-	-	-	-	-	-
RO product m^3/h	-	-	-	0.69	0.69	0.69	-	-	-	-	-	-	-	-	-
Pond evap make-up m^3/h	-	-	-	-	-	-	-	-	-	8.40	4.46	6.18	-	-	-
Unit 300 ORC															
Freon to condenser kg/h	8200	8200	8200	-	-	-	-	-	-	-	-	-	-	-	-
Generator power kW	-	-	-	-	-	-	-	-	-	-	-	-	21.7	21.7	21.7
Unit 400 Ponds															
Hot brine kg/h	-	-	-	-	-	-	102600	102600	102600	-	-	-	-	-	-
Unit 500 Electr.															
Electricity kW	15.0	6.9	9.7	5.8	1.7	4.7	3.8	2.5	3.2	4.4	3.9	4.0	-	-	-

Fig. IV-8 Interface requirements for winter conditions

Delivery to / from	Unit 100 CEA			Unit 200 Water			Unit 300 ORC			Unit 400 Pond			Unit 500 Electr.		
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Unit 100 CEA															
Condenser air kg/h	-	-	-	-	-	-	374000	261800	280500	-	-	-	-	-	-
Unit 200 Water															
Pad circ. water m^3/h	60	0	12.5	-	-	-	-	-	-	-	-	-	-	-	-
Pad evap. water m^3/h	0.5	0	0.04	-	-	-	-	-	-	-	-	-	-	-	-
RO feed m^3/h	-	-	-	1.04	1.04	1.04	-	-	-	-	-	-	-	-	-
RO product m^3/h	-	-	-	0.68	0.68	0.68	-	-	-	-	-	-	-	-	-
Pond evap. make-up m^3/h	-	-	-	-	-	-	-	-	-	3.93	1.83	2.78	-	-	-
Unit 300 ORC															
Freon to condenser kg/h	6820	6820	6820	-	-	-	-	-	-	-	-	-	-	-	-
Generator power	-	-	-	-	-	-	-	-	-	-	-	-	15.9	11.8	13.5
Unit 400 Ponds															
Hot Brine kg/h	-	-	-	-	-	-	103500	103500	103500	-	-	-	-	-	-
Unit 500 Electr.															
Electricity kW	6.3	4.1	4.6	4.7	2.5	2.9	3.8	2.5	2.6	4.2	3.9	4.0	-	-	-

Fig. IV-9

MEAN MAXIMUM AND MINIMUM TEMPERATURE
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN. 1, 1979 THROUGH MAY 31, 1981

MONTH	MEAN MAX. (°C)		MEAN MIN. (°C)	
Jan.	22	(19.9)	8	(7.8)
Feb.	25	(24.1)	10	(10.2)
Mar.	29	(28.2)	14	(14.3)
Apr.	34	(33.3)	18	(19.2)
May	40	(38.5)	22	(23.9)
Jun.	42	(41.6)	23	(25.7)
July	43	(42.4)	25	(26.7)
Aug.	42	(42.4	22	(26.4)
Sept.	41	(39.9)	19	(23.7)
Oct.	35	(34.4)	14	(18.6)
Nov.	30	(27.7)	10	(13.5)
Dec.	22	(21.3)	6	(9.1)
Yearly	34	(32.8)	16	(18.3)

NOTES:

1. Between brackets are data from the University of Petroleum and Minerals (UPM).
   Report, Table 2, PN-32-013-01-1, dated Sept. 1981.

2. The influence of the Derab micro climate versus the Riyadh climate may be noted in lower winter temperatures and higher summer temperatures.

Fig. IV-10

ABSOLUTE MAXIMUM AND MINIMUM TEMPERATURE
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN 1, 1981 THROUGH MAY 31, 1981

MONTH	ABS. MAX. (°C)	ABS. MIN. (°C)
Jan.	32	-1
Feb.	38	-1
March	39	-1
Apr.	42	10
May	44	16
June	46	18
July	47	20
Aug.	46	18
Sept.	43	14
Oct.	40	10
Nov.	34	0
Dec.	30	-2
Yearly	47	-2

Fig. IV-11

CALCULATED WET BULB TEMPERATURES

DERAB FARM SITE

	1979			1980		
	D.B.T. °C	R.H. %	W.B.T. °C	D.B.T. °C	R.H. %	W.B.T. °C
JAN.	28	40	19	30.5	25	17.5
FEB.	37	12	18	32	22	18
MAR.	37	10	17	33	10	17.5
APR.	40	9	17.5	42	10	19.5
MAY.	44	8	19	43	10	20
JUN.	45.5	8	20	44.5	10	20.5
JUL.	45.5	8	20	46.5	10	21
AUG.	43.5	8	19	45.5	10	21
SEP.	43	8	19	42	10	19.5
OCT.	39.5	9	17.5	39.5	11	18.5
NOV.	34	15	17	34	16	17
DEC.	29.5	19	16	29	13	13.5

D.B.T.= Measured Absolute Maximum Atmospheric Temperature
R.H. = Average Minimum Relative Humidity
W.B.T.= Calculated Wet Bulb Temperature

Fig. IV-12

AVERAGE DAILY RADIATION IN W/m^2

YEAR	1978	1976	1975	1974	1973	MEAN	PAR
Jan.	174	145	146	128	181	162	68
Feb.	208	178	175	158	197	199	83
March	271	192	216	155	226	227	95
April	260	242	186	235	223	238	100
May	346	262	223	231	233	264	111
June	334	287	238	235	263	287	121
July	323	279	251	248	247	285	120
Aug.	328	282	234	243	222	272	114
Sept.	307	247	206	246	215	257	108
Oct.	261	208	223	206	213	226	95
Nov.	249	190	171	181	194	184	77
Dec.	191	194	105	117	N/A	161	67
Source	MAW	MAW	MAW	MAW	MAW	UPM	

MAW Ministry of Agriculture and Water - data measured at 24°34' N.LAT, 46°43' E. long.

UPM University of Petroleum and Minerals - average calculated from daily values recorded 1965-1978.

Fig. IV-13

Precipitation

Precipitation recorded on the actual site during the period Jan. 1, 1979 through May 31, 1981.

Daily Max.	10 mm
Daily Min.	Zero
Monthly Max.	50 mm
Monthly Min.	Zero
Yearly Max.	100 mm

Barometric pressure

Based on the available data from the site, the following barometric pressure data can be used:

Max. Barometric Pressure: 956.6 Millibars
Min. Barometric Pressure: 920.5 Millibars

Yearly Avg. Barometric Pressure: 939.5 Millibars

Wind speed

Based on the available data of the site, the following wind speed can be used:

Max. Wind Speed	10 Km/Hr
Min. Wind Speed	4 Km/Hr

9.3 PERFORMANCE ANALYSIS UNIT 100, CEA SUB-SYSTEM

The performance analysis of the CEA system is mainly based on the performance of the CEA Shelter since the NFT and sandculture systems have historically proven performance as long as the climatic onditions are in the accepted range.
The crop production targets as predicted are well within the range of regular CEA units with NFT and sand culture systems.

CROP type	EFT production target ton/ha/day	Proven performance of growing system ton/ha/day
Cucumber	1.9*	2.8
Tomato	0.9*	1.2
Lettuce	1.5	1.5
Okra	0.3	0.4
Strawberry	0.25	0.3

*Yields for variety suitable for Saudi Arabian Markets are lower than yields with North American types.

9.3.1 CEA Shelter Climate

The climate control consists of ventilation and temperature control with a combined humidity control. Finally, a shading system will reduce the high Solar radiation to acceptable level.

The calculated wet bulb temperatures as listed in fig. IV-11 indicate clearly that the air entering the Shelter over the evaporative cooling pad can be sufficiently reduced in temperature to reach the required temperature range, (29°C - 14°C) without exceeding 90% relative humidity.

Since recirculating air may be at all times mixed with the outside air, any desired temperature in the required range can be obtained. The heating of the Shelter during the extreme low winter temperatures is achieved with the reject heat of the organic rankine cycle. Under maximum conditions this will be 256 kw. This heating capacity is more than sufficient to maintain a temperature difference of 20°C between the outside and the inside of the house which is sufficient to reach the minimum CEA temperature at minimum site temperature. Recorded absolute mean, maximum and minimum temperatures of the site are listed in fig. IV-10.

The air velocity in the house will be 0.12 m/sec. minimum, based on a minimum air flow through the Shelter of 25% of the total ventilation capacity (10640 m3/min).
Based on the above, the maximum air velocity in the house will be 0.48 m/sec if unobstructed by plants. With an assumed maximum obstruction of 50% the air velocity will not exceed 1 m/sec.

The radiation levels required for the crop were established at 72.7 W/m^2 maximum and 21.8 W/m^2 minimum, for the PAR levels. The double acrylic roof combined with the fibreglass suspended ceiling will transmit a calculated amount of 68% in the PAR region, data given in Fig. IV-14. Based on the PAR levels recorded in the region (see fig. IV-12) it is clear that sufficient light will be available and that the shading system will prevent excessive light.

Fig. IV-14

	PAR	68%	SHADING (50%)
JAN.	68	46.2	34.0
FEB.	83	56.4	41.5
MAR.	95	64.6	47.5
APRIL	100	68	50.0
MAY	111	75.4	55.5
JUNE	121	82.3	60.5
JULY	120	81.6	60
AUG.	114	77.5	57
SEPT.	108	73.4	54
OCT.	95	64.6	47.5
NOV.	77	52.4	38.5
DEC.	67	45.6	33.5

All expressed in W/m^2

In summary it may be stated that all set design criteria can be satisfied.

9.4 PERFORMANCE ANALYSIS OF UNIT 200, WATER SUB-SYSTEM

The water sub-system components that are subject to this analysis due to interface requirements and climatic conditions are:

1) cooling pads
2) solar and evaporation pond
3) reverse osmosis system
4) the well

All these components have a function in the total system but also interact upon each other. In the following paragraphs each of these components is discussed.

Cooling pads

A circulation flow of 60 m^3/h of water delivers sufficient amount to the cooling pads in order to preform the cooling duty for the ventilation air in the greenhouse. Part of this water will be evaporated and the quantity is a function of the cooling duty and the ambient conditions In fig. IV-15 the average daily evaporation figures for the 0.48 ha greenhouse (0.4 ha growing section) are given. The required water is drawn from a well. Without make-up of the circulating water, a high concentration of salts will build up due to the evaporation of water, with the salt remaining in the circulating flow. In an independent greenhouse, a much higher concentration factor will be allowed. In this EFT, the salt concentration factor will not exceed 0.1 since the make-up water for the ponds and the osmosis unit will be supplied from the cooling water storage, thereby reducing the cooling water salt content.

The cooling water storage has been designed for 7 days storage of raw water based on maximum evaporation rate of 1.5 m^3/h. If well water make-up is stopped, the salinity of the circulating water will increase, but since the salinity of the well water is not very high, no scaling problems on the pads are expected.

Solar and evaporation ponds

From the surface of the solar pond and the evaporation pond water will evaporate due to lower humidity of the surrounding air. The evaporation rate itself is a complex function of temperature, humidity, radiation, insolation, wind velocity and salinity of the water. On the Derab site, pan evaporation data have been recorded during the period january 1, 1979 through may 31, 1981 (see fig. IV-16). Evaporation from a solar pond and evaporation pond will certainly be lower due to a lower surface temperature and higher salinity. The real data for these conditions are not available, but in literature an evaporation of 75% of normal pan evaporation has been reported. This value has been used for the EFT design. The solar pond area of 8000 m^2 and the evaporation pond area of 4000 m^2, need an average make-up flow of 107.5 m^3/day. The water needed for the make-up of these evaporation losses will be delivered by the well. A small part of it comes from the reverse osmosis system reject at an average flow of 8.9 m^3/day.

The other part is delivered from the greenhouse cooling water storage which also functions as the blow-down of the circulating cooling water system. In case of failure or shortage of well water, no water will be used for evaporation make-up. At the highest evaporation rate of 17 mm/day only 120 mm of the pond surface will be evaporated in a period of seven days. It can be concluded that pond performance will not suffer if during this period evaporation losses are not made-up. With this reasoning 7 days' water storage, based on total make-up requirements, will not contribute to performance but will unnecessarily increase costs.

Reverse osmosis system

The water consumption of the crops in the greenhouse can be considered constant at 16.5 m^3/day during the year, since the environment in the greenhouse is controlled, only small crop growing variations will occur. This means that the reverse osmosis system can produce the same amount of water throughout the year. The installed capacity has a margin of at least 20% based on the design capacity. The design value of 25.5 m^3/day has been based on the productivity remaining constant for five years. In the first five years of operation, the productivity will be higher (up to 30%) and decrease exponentially to the design value of 25.5 m^3/day. This results in an overcapacity of 20%, which gives the flexibility to stop the operation during the peak periods of electrical demand. A reverse osmosis system can be stopped and restarted, without any precautions or special actions. The same mebrane type has been selected for both stages of the reverse osmosis to simplify spare holdings.

Well Water

The well water requirement for the system is the total of the water requirements of cooling pads, ponds and reverse osmosis systems. Fig. IV-17 gives the daily requirements for each month of the year. The installed well pump capacity is sufficient to deliver the required quantity of water under all circumstances. In case of shortage of water in the well, the make-up flow for the ponds could be reduced for a period of time. In the hot season, the evaporation is about 0.5 meter/month. The reject flow from the R.O. system is 8.9 m^3/day while the minimum waste flow from the cooling pads would be 7 m^3/day to maintain a concentration factor over the pads of 5. This means that the minimum make-up flow to the ponds is 15.9 m^3/day. There is also a possibility on the site to use treated sewage water from Riyadh in case of long term shortage of well water.

Fig. IV-15

Average daily evaporation in cooling pads

Month	Average daily Evaporation m^3/day
Jan	0
Feb	3.4
March	11.0
April	20.3
May	29.7
June	34.4
July	36.0
Aug	35.7
Sept	30.6
Oct	20.7
Nov	9.7
Dec	0

Fig. IV-16

MONTHLY EVAPORATION DATA (PAN)
RECORDED ON THE ACTUAL SITE, DURING
THE PERIOD JAN 1, 1979 THROUGH MAY 31, 1981

MONTH	MEAN (M.M.)
Jan.	150
Feb.	200
March	300
Apr.	370
May	440
June	530
July	640
Aug.	510
Sept.	340
Oct.	290
Nov.	190
Dec.	140
Yearly	4100

Fig. IV-17

Well water needs for, RO, cooling pads and ponds

	RO product m^3/day	Cooling pads m^3/day	Pond evap. m^3/day	Well water m^3/day
Jan.	16.56	0	47.2	63.76
Feb.	16.56	3.4	63.0	82.96
March	16.56	11.0	94.4	121.96
April	16.56	20.3	116.5	153.36
May	16.56	29.7	138.5	184.76
June	16.56	34.4	166.8	217.76
July	16.56	36.0	201.5	254.06
Aug.	16.56	35.7	160.5	212.76
Sept.	16.56	30.6	107.0	154.16
Oct.	16.56	20.7	91.3	128.5
Nov.	16.56	9.7	59.8	86.06
Dec.	16.56	0	44.0	60.56
Average	16.56	19.3	107.5	143.36

9.5 PERFORMANCE ANALYSIS OF UNIT 300, ORGANIC RANKINE CYCLE SUB-SYSTEM

The main items of the Organic Rankine Cycle are

1. Vaporizer
2. Expander
3. Condensers

9.5.1 Vaporizer

This item has been designed to vaporize the amount of freon necessary for the maximum duty of the expander. The maximum duty is the average design duty for summer conditions and not the maximum electrical duty for the system. Peak requirements of electricity will be covered with battery power. The batteries will be charged by the ORC during the periods when the electrical demand is low.

This implies that most of the time the ORC will run at the design load. More details on this item are given in paragraph 9.7.

The freon flow to the vaporizer will be controlled by the electrical load of the system but with a maximum of 8200 kg/hr. In case of a lower electrical load, the freon flow will also be lower. The flow variations are rather low since the minimum flow at winter conditions is 6820 kg/h, or 83% of the design value. Heat extraction from brine, for the evaporation of freon, will be controlled by the flow of brine through the vaporizer. If the freon flow falls below that of design, part of the brine will be by-passed over the vaporizer, resulting in a lower overall temperature difference for the brine.

Since the maximum expander shaft power equals the design duty, large variations in electrical load are not expected and the performance of the vaporizer and expander will remain fairly constant. The minimum design duty is set by the minimum system load requirements during the winter and can easily be handled with the control system. The minimum electrical load conditions in the summer, for example at midnight, are not critical, since the vaporizer and expander will then perform at a higher level in order to load the batteries.

9.5.2 Expander

The machine selected for this plant, is somewhat oversized but is of proven technology. The problem faced with the EFT is that a number of organic fluid expanders already exist but only a few are capable to perform at the low power requirements of the EFT. The expander to be used for this EFT is in principal a 100 kW engine.

The intrinsic losses are absolute, which means that these will be the same if the engine is used at lower loads. But in order to obtain experience with battery-peak cover, the expander will not be used at a shaft power above 30kW, although the potential is much higher. The mechanical losses will be higher at lower loads during the winter period.

But on the other hand the pressure ratio of the freon will also be lower, due to lower brine temperature and vapour pressure of freon.Consequently thermo-mechanical efficiency will be higher due to lower vapour slip losses. The conclusion is that the engine will not be the most ideal for the EFT, due to the low power requirements, but it is of proven technology and will provide the necessary data for the design of a bigger commercial system in the future, for which more engines are available at optimum design point.

9.5.3 Condenser

The condensers are integrated in the CEA, unit 100, but functionally belong to the ORC. The condensers are designed to condense 8200 kg/h of freon 114 at design duty, with a minimum of 6820 kg/h in the winter. Exhaust air from the cooling fans of the greenhouse will be used to condense the freon. In winter, the condensers will act as heater for the circulating greenhouse air and in this function, they are also part of the greenhouse. The greenhouse air temperature will be controlled in such a way that it will not exceed 29 °C with an expected maximum of 27 °C. On this basis, the condensers have been designed to perform the condensing duty with all the fans running. If the air temperature should fall, the number of fans required for the air flow is also lower, with a minimum of 35% at the lowest expected greenhouse air temperature. Since greenhouse air will be used for condensation, large variations in air temperature are not expected and the performance of the condensers will remain fairly constant. With the condensers running at minimum conditions, in the winter, a temperature difference of about 20 °C between the greenhouse inside and the outside can be tolerated without supply of fresh air. However, with fresh air supply, the temperature difference to be maintained will be lower. But with a min of -2°C recorded on the site, heating with the condensers is more than sufficient.

9.6 PERFORMANCE ANALYSIS OF UNIT 400, SOLAR POND SUB-SYSTEM

The solar pond design has been based on several types of calculations. One has been performed by the Reasearch Institute of the University of Petroleum and Minerals and the other has been based on the theory of Nielsen. The UPM model has been used on different heat extraction figures before its application to the EFT design. Extrapolation of the data would result in a 7000 m^2 pond surface area. The model uses higher extraction figures in winter and spring than in summer due to an assumed lower rankine turbine efficiency at low brine-temperatures. But, with recorded efficiences available, it can be stated that heat extraction will be lower in winter than in summer, resulting in a more conformed insolation/extraction pattern. The Nielsen model is a steady-state model which gives a 3000 m^2 surface requirement at summer conditions and a 5000 m^2 surface at winter conditions. Using a rough step calculation on thermal storage capacity of the LCZ, an average 4000 m^2 required surface is found but with the possibility of boiling in the LCZ in the summer.

From literature data, the average recorded efficiency of a solar pond lies between 13 and 18%.

The use of the UPM model results in a 15% efficiency. The problem with all the models is that they are only checked on small research ponds, while the real, bigger ponds, with less sophiticated manpower control, show much lower efficiencies. It is felt that the use of the model data resulting in pond areas of 4000 to 7000 m^2 would not be realistic and for this reason a 15% safety margin is added on the most pessimistic model output. With an 8000 m^2 surface area we are in the middle of recorded efficiencies for large ponds. For the calculation of optimum LCZ depth and NCZ and UCZ thicknesses, several models are used all giving the same results. The design of solar systems without seasonal storage are normally based on summer conditions and on highest performance points. A design based on minimum winter conditions would lead to an abnormally large surface without economical efficiency. For seasonal storage systems it is also common to use the best summer conditions for the calculations.

The solar pond surface, as designed, is also most critical in its performance in the winter period. However, extracting as much energy as is possible out of the solar pond would precipitate a snowball efffect. If the temperature of the pond were to decrease, the Rankine efficiency would also decrease, in order to deliver the same power, more heat is required from the solar pond resulting in a further drop in temperature. If the pond temperature were to drop below 65°C it is advisable to use more gridpower in order to prevent the above mentioned snowball effect. Increasing the pond surface to ensure coverage of the winter conditions would also result in a higher water consumption for evaporation make-up. Taking the above mentioned points into account, it is felt that an 8000 m^2 surface might cover the total heat requirements. In any case, the data resulting from the EFT will make a great contribution to the world's knowledge of solar pond performance and will result in an optimum design for the commercial system.

9.7 PERFORMANCE ANALYSIS OF UNIT 500, ELECTRICAL SUB-SYSTEM

The purpose of the electrical system is the provision of all the electrical energy requirements of the system.
For this duty the system has three components:

1. The ORC turbine/generator rated at max. 28.6 kW
2. The batteries, rated at max. 22 kWh
3. The local grid connection

For the EFT, a principal decision has been made by SERI to connect several non-EFT typical but critical consumers to the grid. The consumers used for this purpose are, the air conditioning, ORC vacuum pump, lighting and instrumentation. This is equivalent to an installed capacity of about 27 kW with a max. hot day consumption of about 15 kW. To make an optimum design with optimum efficiency, the turbine load line has been compensated on max. daily summer conditions with batteries. During daily minimum, the batteries will be loaded with the redundant power from the generator before the turbine/generator will be controlled down to follow the load curve.

Maximum daily consumptions will be equal to monthly consumptions since the cooling of the greenhouse does not directly follow the ambient conditions especially if the ambient temperature exceeds the average temperature. The greenhouse may have slightly higher than average design temperatures, in order to maximize cooling fan consumptions which are the main variables in the load curve. A critical point in the energy delivery system is the brine temperature from the solar pond. As already mentioned, it is important to ensure that this temperature does not fall below 65°C, because at this temperature, turbine efficiency will decrease with a resulting snowball effect. Although the system has been designed with enough safety margin to prevent this from happening, abnormal conditions might occur that will require temporary use of extra grid power.

9.8 PERFORMANCE ANALYSIS OF UNIT 600, INSTRUMENTATION SUB-SYSTEM

All instrumentation for the Data Acquisition System and the Master Control system have been designed for full automatic control and data acquisition for research-type information. The controls and instruments are situated on fixed-places, except for some instruments used for measurement of solar pond conditions. For this purpose, a large number of elements will be needed for fixed mountings which could result in erroneous information. For this reason, some instruments are placed on transportable mountings for measurements at selected places.

9.9 SUPPORT REQUIREMENTS ANALYSIS

9.9.1 Personnel

Because of the research nature of the EFT, the operating personnel should have adequate technical training in order to be able to discharge their duties in the best possible manner and to contribute intelligently to the overall operation. Unskilled labour will also be required for performance of general maintenance duties. The following manpower requirements are envisaged:

Function	Number
Greenhouse supervisor	1
Maintenance technician	1
Skilled labour	3
Unskilled labour	3
Driver	1

9.9.2 Maintenance

The maintenance requirements of the EFT are divided into the following areas:

- CEA Shelter: This requires daily cleaning and inspection of crops to prevent disease and control pests. Periodic cleaning of air and water filters and lubrication of rotating equipment is necessary.

- ORC Sub-System: The turbine-generator unit requires daily attention to ensure satisfactory functioning. Replacement of ball bearings every 1.5 years may be necessary and periodic check on lubricating oil levels is essential.

- Solar Pond: The brine management and maintenance have been dealt with in Section 5. Routine cleaning of pond surface and floor will be necessary to maintain a pond which is clear and free from algae and debris.

- Reverse Osmosis: Poutine check on pumps and permeators is sufficient. Periodic cleaning of the cartridge filters may be necessary depending upon the quantity of suspended solids.

10. TEST PLANS

10.1 GENERAL

The majority of equipment selected, are of proven technology and only require the normal pre-shipment inspection and tests. It is therefore suggested to follow the manufacturer's recommendations with regard to installation and commissioning.

All rotary equipment plus electrical switch gear and instrumentation would have had pre-shipment tests and inspection, and upon installation, standard procedures, currently used in chemical or petrochemical industry should be used to commission them.

The performance test of each piece of equipment is however, dependent upon the sub-system to which it belongs. The performance of each sub-system is in turn dependent upon the conditions and restraints of that system.

10.2 CEA SUB-SYSTEM

The CEA performance can only be measured over a minimum time span of 18 months in order to allow time for the growth cycle to be completed and for assessment of the production levels reached.

10.3 WATER SUB-SYSTEM

The performance of the RO unit can best be assessed over a one month period during which the quantity, as well as the quality of "sweet" product water can be measured. The pumps in this sub-system and in particular the well water pump, can be tested for their design rating over a 24 or 48 hour period.

10.4 ORC SUB-SYSTEM

The ORC turbine selected for this project is a machine of proven technology which has been used for other test plants. Because of this fact, this oversized turbine has been chosen in preferance to machines which would have suited the system capacity requirements more closely.

The performance of the turbine and of the entire ORC sub-system can only be properly assessed when the solar pond is fully funtioning and desired temperature levels have been reached.

10.5 SOLAR POND SUB-SYSTEM

The integrity of the civil work, plus the proper functioning of pumps and instrumentation associated with the solar pond, can be tested soon after installation work is complete. The performance of the solar pond however, is a matter that requires time for proper assessment. For the solar pond to reach stable conditions and achieve consistent temperature and salinity levels requires an adequate time interval (approx. 12-18 months). However, constant data logging and monitoring can be a guide for the research worker to follow the progress being made towards establishing stable conditions in the pond.

TASK V REPORT

PHASE II - DEFINITION STUDY

CONTENTS

In order to operate the concentration pond as a solar pond, the facility of injecting brine from any component of Unit 400, including the pond itself, at any desired depth is provided. Full profile analysis, instrumentation, filtration, chemical injection and other requirements are available.

The following points are further highlighted:

- The BCF is designed to minimize cuts and fills and pumping energy requirements;
- The pans are sloped towards the sluice gates by way of open channels, so that flow to the pond is by gravity;
- A high pressure line is provided to assist operators in the break-up of any crystallized salt;
- The Pond and Pans provide approximately 5000 cu.m. of combined storage;
- The Evaporation Pond serves as a destructive test pond for research. Experiments may be scheduled including gradient destruction without unduly hindering the operation of the two Solar Ponds. Furthermore, the pond may be readily drained to the Solar Ponds for further experiments in start-up.

1. INTRODUCTION

1.1 GENERAL

SESEA presents in this report the results of the work performed in Task 5 of Phase 1 for a Solar Controlled Environment Agriculture System Design in accordance with RFP/RP-761-810 and the SESEA Proposal and parameters of design established in previous task reports.

The objective of this report is to supply MRI with a comprehensive Phase II Management Plan and Cost Analysis which will form the basis of proceeding into Phase II with a high degree of confidence and assurance of success.

Included in this study is a breakdown of the work to be performed under Phase II and a discussion of the same.

The organizational and management practices SESEA will employ in the execution of Phase II will conform to current professional engineering practice.

The Organizational and Management Plan are tailored to complete the work required in a systematic and efficient way.

Included in this report is the SESEA Management Organizational Chart and the detailed work breakdown.

The information and forecasts in this report are the best estimates based on available data. These will become more exact upon determination of the start date of Phase II.

This report is prepared with respect to the Derab Site in Saudi Arabia and may be readily modified to suit the USA site.

1.2 ORGANIZATIONAL AND MANAGEMENT PLAN

Detailed planning has been used to define each critical element required to carry Phase I preliminary design of the Engineering Field Test through into Phase II, where the detailed design, component fabrication, plant erection, mechanical completion, and acceptance will be performed.

In addition, the Operation and Maintenance Plan and Test Plan objectives are defined.

The main activities for Phase II can be characterized by the preparation of the following sub-tasks identified in the Work Breakdown Structure:

- Final Master Schedule
- Master Manufacturing and Construction Plan
- Operation and Maintenance Plans
- Test Plan
- Risk Analysis
- Management Control Plan

The suggested plans are discussed in Section II of the Task V Report. The subdivisions as indicated in the RFP are followed and adapted where required:

- Management Structure
- Management Processes
- Contract Work Breakdown Structure
- Schedules
- Subcontract Change Control Procedures
- Government Owned Property

1.3 COST ANALYSIS

Based on the preliminary design of the Engineering Field Test, as performed in Task IV, a detailed Cost Analysis has been prepared for Phase II activities, including detailed design, procurement, construction, commissioning and start-up. To ensure accurate project costing, the prices are inclusive of taxes, duties etc. and where required, escalation factors are applied, based on past experience, to reflect actual costs. However, the cost figures have been supplied under separate cover and are deleted from this report because of the confidential nature of the information.

2. MANAGEMENT STRUCTURE

2.1 GENERAL

The SESEA proposed organization for the execution of Phase II is tailored to meet the job requirements.
As the work in Phase I has shown, the SESEA proposed technology incorporates certain original design features. The CEA-EFT Facility will therefore require substantial engineering effort in the initial stages of Phase II.

In Phase II, the Detailed Design time is kept as short as possible. Specialized consulting firms such as the R.I./U.P.M. in Saudi Arabia may be invited to undertake certain segments of the work. Concurrently, SESEA will employ its existing staff, the staff of its current subcontractors and other specialists to optimize the design and supervise the construction work in Derab.

The SESEA head-office in Riyadh will be the main center to which all subdivisions will report.
A coordination office for engineering will be in Al-Khobar. In addition, a Derab Site Office will be set up to commence physical work according to the Construction Schedule. The site office will also report to the Riyadh office.

In the field, SESEA will endeavor to employ Saudi Arabian subcontractors, supervised and assisted by SESEA engineers and technicians. Since many of the subtasks in the EFT facility construction are novel and sophisticated they will, in the main, be executed by the SESEA field personnel.

2.2 MANAGEMENT ORGANIZATION

During the execution of Phase II of this project SESEA will apply established project management procedures.

The company is structured in a way that a project management team is established for the project, headed up by the Project Manager who reports directly to company management and maintains communication with client's representative.

The Project Manager is in full authority on behalf of SESEA for the project.

The project team size and discipline is adapted to the requirements of the actual phase of the project.

For the actual performance of the activities use is made of the subdivisions of the company which assign the required qualified and experienced personnel for such task.

A Management Organization Chart is developed. This chart shows the group according to function plus the supporting staff. Listed below are descriptions of the jobs shown:

2.2.1 SESEA Project Manager

- Overall project control and supervision of job execution.
- Interface with SESEA Board of Directors, MRI, project personnel, and other agencies, and reporting on job progress.

2.2.2 Design

- Complete engineering design
- Planning and scheduling activities
- Supervision of any external consultants and/or manufacturers
- Assistance to Project Manager
- Documentation preparation
- In-house consulting

2.2.3 Purchasing

- Local purchasing
- International purchasing
- Assistance to Quality Control
- Assistance to Accounting

2.2.4 Accounting

- Receivables/Payables
- Financial Analysis
- Financial Reporting
- Cost Control

2.2.5 Government Relations

- Registration, work permits, visa
- Civil and police authorities
- Public relations

2.2.6 Quality Control

- Direct reporting to Project Manager
- Main vendor inspection and expediting
- Subvendor inspection and expediting

2.2.7 Site Manager

- Site control and supervision
- Feedback to design team and management
- Support to Project Manager and design
- Supervision of subcontractors
- Job progress scheduling and reporting

2.3. KEY PERSONNEL PROFILE

The key members of the SESEA team must possess a minimum level of acedemic training and professional experience in order to ensure a satisfactory execution of the project.
The following profiles could serve as a guide for identification.

2.3.1 Project Manager

Education: Minimum BSC in Mechanical Engineering
Knowledge of: Electrical and Instrumentation and Civil disciplines
Basic Cost Control

Experience: Minimum 15 years experience, including
2-4 years: Engineering and detail design
2-4 years: Lead engineering in several engineering disciplines
2-4 years: Operation and Start-up
2-4 years: Project Engineering
2-4 years: Management level experience

Preference: Recent experience in Saudi Arabia
Speaking basic Arabic
Experience in similar job
Agriculture experience

2.3.2 Design Engineering Manager

Education: Minimum BSC Mechanical, or Electrical or Engineering
Additional Courses in relevant disciplines

Experience: Minimum 10 years experience, including
- Minimum 5 years experience in the engineering and detail design
- Lead Engineer in several engineering disciplines
- Management Experience

Preference: Speaking basic Arabic
Experience in similar job

2.3.3 Site Manager

Education: Minimum BSc in Mechanical, or Electrical, or Chemical or Civil Engineering

Experience:	Minimum 10 years experience, including	
	2-4 years:	Basic civil construction - Excavation, concrete, etc.
	2-4 years:	Basic mechanical construction - Installation of Equipment, piping, etc.
	2-4 years:	Basic electrical/instrument construction Project cost control/ supervision
Preference:	Speaking basic Arabic Experience in Saudi Arabia Experience in similar jobs	

2.4 SUBCONTRACTORS AND SUPPLIERS

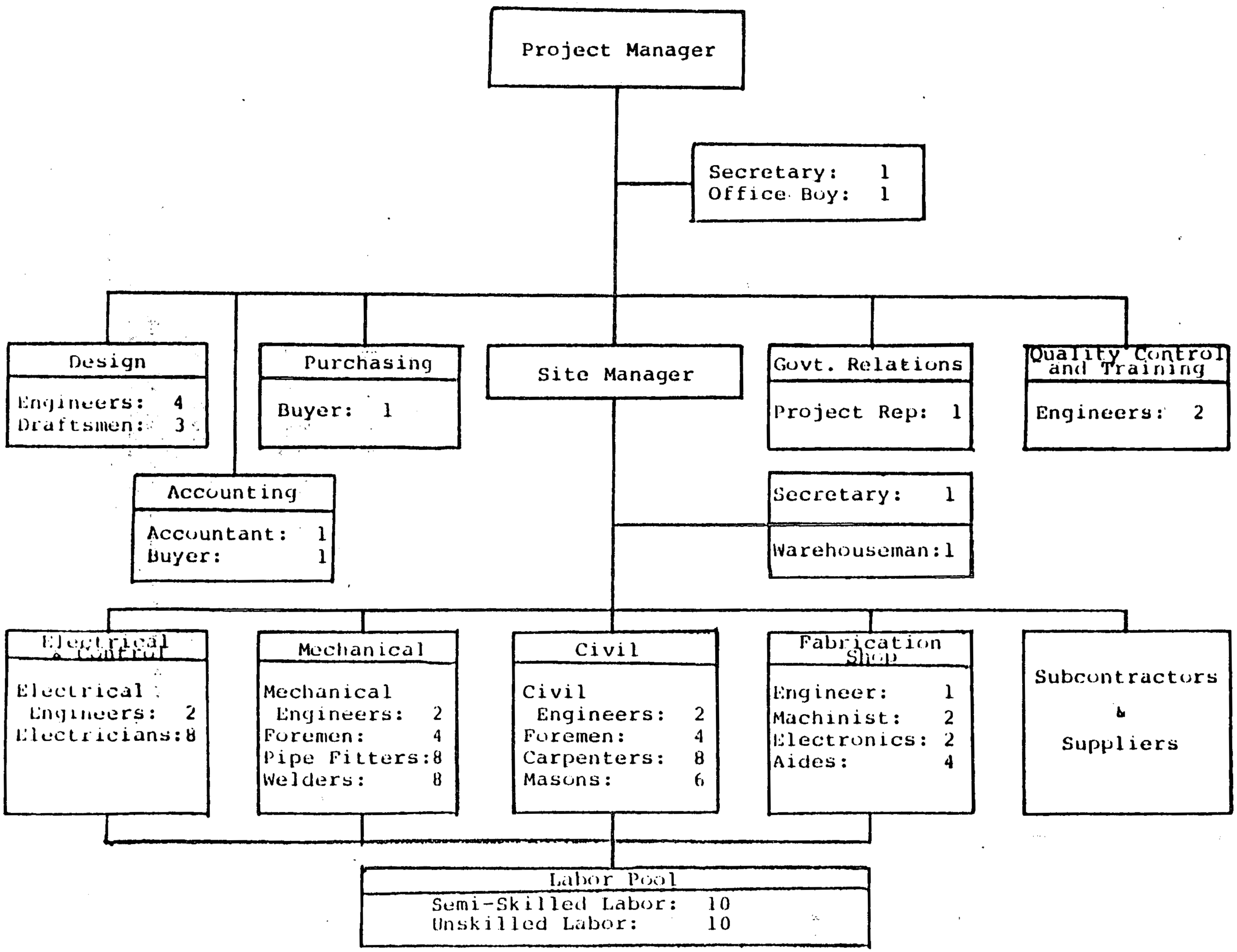
SESEA, in its capacity as major design and application engineers, will select a number of specialized subcontractors and suppliers to design and supply specialized equipment as defined in the specifications produced during the design stage of Phase II.

Suppliers will be selected on the basis of the best overall offer. Evaluation parameters will include but are not limited to, experience, proven performance, delivery, price, technical support and after sales service.

Subcontractors will be evaluated on their capability to perform such specialized work as piping installations, heat exchangers, liner installations, and CEA structure.

Contractors with experience in Saudi Arabia will be selected on the basis of proven performance for the civil works and general plant construction.

FUNCTIONAL ORGANIZATIONAL CHART



3. MANAGEMENT PROCEDURES

3.1 GENERAL DISCUSSION

SESEA possesses and applies a full range of company procedures necessary to execute projects in time and within budget.

An essential part of these procedures pertain to the implementation of management processes, in order to maintain an efficient project realization.

Highlights of these procedures are authorities and responsibilities assigned, clear job instruction, timely reporting, control procedures, records keeping, etc.

At the start of a project, the Project Manager issues the Project (job) Instructions, which contain all the pertinent information required to be known by all personnel working on the project.

Main topics of these instructions are:

- Representation
- Assignments
- Scope of Work
- Specifications (basis of design)
- Design data
- Correspondence, distribution, co-ordination
- Requisitioning and Procurement
- Approvals
- Manuals
- Guarantees and Warranties
- Spare parts
- Deviations from standard procedures.

3.2 MATHEMATICAL/SIMULATION MODEL

For the overall cost analysis of this project, SESEA applies the method prescribed by the RFP.

For the individual components, as well as the sub-systems designs, mathematical analysis is performed to optimize the total design.

3.3 SPECIFICATIONS AND CONTROL

After setting the basic design parameters of the system on an optimized basis (Heat and Material Balances), Equipment specifications are prepared by the engineers of various disciplines. These specifications form the basis of material requisitions, which after vendor selection will be revised to incorporate vendor information and/or recommendations. The completed specification sheets for the basis of the purchase order.

3.4 DESIGN AND PERFORMANCE CONTROL

In accordance with SESEA's standard procedures, regular controls are performed at certain stages of the design. These controls are in the form of review of certain key documents such as Process Flowsheets, Piping and Instrumentation Diagrams, Plot Layout, Equipment Specifications, etc.

All these review meetings are attended by the lead engineer and the job engineer(s) and supervised by project management.

Performance control is exercised by project management via (internal) reporting on a weekly or bi-weekly basis, including such items as, progress reporting, work still outstanding, manhours spent, manhours to completion, manpower requirements, costs incurred on the project, etc. These procedures have in the past resulted in satisfactory project execution.

3.5 QUALITY CONTROL PROCEDURES

Quality control of the project is exercised by SESEA during the execution of all stages of the project by adopting the standard company procedures which can be roughly outlined as follows:

- Design quality control is perfomed by the lead engineer and at review meetings (see above).
- Material quality control is performed by the company's inspectors, at regular intervals, in supplier's workshop.
- Site material quality is controlled by the company's construction supervisor at site.
- Overall project quality control is exercised by project management.

All quality controls result in appropriate reporting to project management.

3.6 TECHNICAL REVIEW METHOD AND SCHEDULE

The technical review methods are described in the sections above.

An overall review schedule is indicated in Section 4.

The detailed review schedules are set in the Project (job) Instructions, based on the detailed planning.

3.7 DOCUMENTATION CONTROL

Essentially all documentation is controlled in accordance with company's procedures by the centralized document control department, which distributes the various documents (either internal or from suppliers) in accordance with detailed distribution schedule which will be issued by project management in the Project (job) Instruction.

The document control also expedites the routing of all technical drawings and documents, which are destined for comment and approval in order to ensure a smooth flow of information.

3.8 SUB-CONTRACT CONTROL

Sub-contracts are controlled by project and discipline engineers for technical aspects during the design stage, and by field engineers and construction supervision during the construction stage.

Sub-contractors have to comply with standard company procedures and report regularly.

A branch of the cost control department dealing with sub-contracts, will ensure that all aspects of the sub-contract are performed in time and report regularly to project management in accordance with standard procedures.

3.9 SUB-CONTRACT-CHANGE CONTROL PROCEDURE

Sub-contract changes are controlled by standard company procedures, which are executed along the following lines:

- In case a change of scope occurs in the sub-contract, a standard form, 'Change Order', is issued in which the scope change is described. This is for an increase as well as a decrease in scope.

- The sub-contractor indicates in this Change Order the cost and time involved and returns the form to the contractor.

- Upon agreement between the contractor and the sub-contractor, an amendment to the Purchase Order is made, based on the agreed Change Order.

- Normally, approval is required from technical and commercial departments involved in the contract, along with final project management approval.

- No changes are allowed to be executed prior to agreement and completion of the Change Order, except for minor changes occurring during construction, where the construction management is allowed to agree upon such changes locally up to a financial limit set by the project manager.

The system as outlined above guarantees that only duly authorized changes are executed, which then form a part of the normal main sub-contract.

4. CONTRACT WORK BREAKDOWN STRUCTURE PHASE II PLAN

4.1 MANAGEMENT AND CONTROL

The following activities are envisaged:

- Management and Control of complete Project
- Status Review Meetings
- Saudi/U.S. Interface Meetings

4.2 FINAL SYSTEMS SELECTION, EFT-FACILITIES

This section includes the preparation of the final design package of the EFT-Facilities, based on the approved preliminary design of Task IV in Phase I. The section is sub-divided into the following activities:

- Process Flow Diagrams
- Heat and Material Balances
- Piping and Instrumentation Diagrams
- Line Designation Tables
- Codes, Regulations and Safety Requirements
- Final Solar Pond Design and Specifications
- Final CEA Design and Specifications
- Final Energy Transfer System Design and Specifications

4.3 DETAIL ENGINEERING AND SPECIFICATIONS

This section includes the detailed engineering and specifications for the components and systems used in the units of the EFT and preparation of installation and construction specifications. The following activities are envisaged:

- Main Equipment Specifications
- Detailed Civil Design
- Detailed Piping Design
- Detailed Electrical Design
- Detailed Instrumentation and Control Design
- Data Acquisition Sub-system Design
- Support Facilities and Utilities

4.4 PROCUREMENT

This section covers all procurement activities required for the realization of the EFT-Facilities and is sub-divided in activities along normal standard procurement practices.

- Requisitions
- Bid, Tabulations and Evaluations
- Purchase Orders
- Inspections
- Expediting
- Transportation

4.5 CONSTRUCTION

This section deals with the construction of the EFT-Facilities, starting from site survey up to test run of the plant. The section is sub-divided into various technology disciplines together with items concerning commissioning, testing, start-up and the preparation of the Plant Books (Operation & Maintenance Manuals).

- Civil Works
- Solar Pond
- CEA Structure
- Buildings
- Equipment Erection
- Piping Installation
- Instrumentation Installation
- Electrical Installation
- Solar Pond Brine Preparation
- Insulation and Painting
- Commissioning and Testing
- Start-up
- Test Run
- Plant Books

4.6 OPERATION & MAINTENANCE AND TEST PLAN OBJECTIVES

4.6.1 Operation & Maintenance Plan Objectives

During Phase II a detailed Operation and Maintenance Plan will be developed on the basis of the specific requirements established by the design engineers and manufacturers. The major objectives of the plan will be such items as:

- Projection of manufacturers warranties
- Minimum down time
- Minimum use of alternate energy source
- Maximum 'in house' repair capability
- Identify optimum spare part stocks
- Optimum productivity from CEA section
- Minimized risks of plant disease
- Optimized pest control.

4.6.2 Test Plan Objectives

The test plan for the EFT will be fully developed during Phase II of the Contract. The major test objectives are:

- To ensure that sub-systems performance specifications are met;
- Analysis of the sub-system performance in sufficient detail to identify any deviations between the actual sub-system performance from the set objectives;
- To identify areas of optimization.

4.7 MAJOR MILESTONE SCHEDULE FOR EFT CONSTRUCTION

ACTIVITY	WEEKS AFTER NOTICE TO PROCEED	
Contract award	0	
Commence Design Engineering	1	
Commence Site Investigation	3	
Secure Visas for Personnel	8	
Complete Well Evaluation	8	x*
Complete Design Engineering	8	
Complete Equipment Specifications	10	
Commence Site Preparations	10	
Order Long Lead Time Items	12	
Secure Salt Supply for Solar Pond	13	x
Commence Civil Work	13	
100% Manning Level	20	
Acceptance of Solar Pond Civil Work	26	x
Completion of Solar Pond Construction	32	x
Testing of ORC Turbine (pre-shipment)	32	x
Completion of all Civil Work	32	x
Start Filling Solar Pond	33	
Commence CEA Structure	36	
Commence Major Equipment Installation	38	
Complete CEA Structure	50	
Completion of Major Equipment Installation	54	
Completion of Support Facilities	58	
Completion of Instrumentation Installation	59	
Commence Commissioning	60	
Commence Start-up	68	
Commence Operational Testing	70	
Complete Operational Testing	75	x
Acceptance	76	x
Demobilization & Clean-up	77	
Commence Phase III (Performance Test and Training)	78	

*Note: X go/no go decision point

4.8 PROJECT CRITICAL ITEM LIST

The key to timely completion of the EFT Facility will be the capability of the project team to identify critical stages in the program.

The following list of equipment has been taken into consideration as being critical for project's schedule.

ITEM	DELIVERY (Weeks)
Solar Pond Liner	18
Salt for Solar Pond	20
Brine Handling Equipment	20
ORC Turbine Generator	20
CEA Structure	22
ORC Evaporator	24
ORC Condenser	26
Specialized Instrumentation	28

5. COST ANALYSIS

5.1 COST MODEL

A cost model was developed using the SERI required technique. Calculations were performed to determine the present value of capital investment, the present value of recurring costs, annualized system costs and levelized farm crop costs.

The present value of capital investment takes into account a given escalation rate for capital costs as well as the cost of capital and the rate of return on capital. Cost figures are not included because of the confidential nature of the information.

5.2 PERFORMANCE

SESEA developed a computer code, SOLAR, to utilize the SERI costing algorithms discussed above. The program calculates the cost incurred for a given agricultural production plant (excluding transportation and distribution costs). The program takes into account the expected annual crop output to determine the levelized farm crop cost (LFCC). In order to calculate the LFCC, a crop production table was generated to determine tons of produce per year per hectare as follows:

Crop type	EFT production target ton/ha/day	Proven performance of growing system ton/ha/day
Cucumber	1.9 *	2.8
Tomato	0.9 *	1.2
Lettuce	1.5	1.5
Okra	0.3	0.4
Eggplant	1.3	1.3

* Yields for variety suitable for Saudi Arabian Markets are lower than yields with North American types.

The performance analysis of the CEA system is mainly based on the performance of the CEA shelter since the NFT and sand culture systems have historically proven performance as long as the climatic conditions are in the accepted range. The crop production targets, as predicted, are well within the range of regular CEA units with NFT and sand culture systems.