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SOLAR AND WIND ENERGY RESOURCE ASSESSMENT FOR THAILAND

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Ministry of Science, Technology and Energy

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U.S. Agency for International Development

Transferring ceremony of the Solar/Wind Measuring and Calibration equipment from USAID to the Meteorological Department, December 16, 1982.

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Ms. Soranee Sangmit
Component Leader

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EXECUTIVE SUMMARY

The Solar/Wind Resource Assessment Component was one of the components in the USAID-Thai Renewable Nonconventional Energy Project, USAID Project No. 493-0304. The objective of the solar and wind resources assessment was to specify how the solar and wind energy potential of Thailand can be reliably determined and subsequently monitored. The Meteorological Department was the agency responsible for this component. The project started in 1981 and will be completed in 1984. After the project has been completed, its activities will be continued by the Meteorological Department on a routine basis.

The assessment of solar and wind energy for Thailand consisted of:

- Establishing a Center for Solar Radiation and Wind Calibration; and
- Evaluation of data.

In order to do the assessment, additional solar radiation and wind measurements were required. For this reason, 6 solar radiation monitoring stations and 10 wind monitoring stations were set up. At these stations, observed solar radiation and wind are transformed into electrical signals and fed into dataloggers for real-time data processing. The processed data were then automatically recorded on magnetic tape cassettes for further analysis.

Evaluation of data was divided into existing data and new data. Evaluation of existing data by King Mongkut's Institute of Technology, Thonburi Campus; and evaluation of new data (1983) by Dr. R.H.B. Exell from the Asian Institute of Technology show that, except at some coastal sites, solar energy has higher value than wind energy. A detailed analysis of existing and new data has been published separately from this report as "Solar and Wind Energy Potential Assessment of Thailand", (Suwantrakul et al., 1984) and "Solar and Wind Energy Data of Thailand 1983", (Exell and Sukawat, 1984).

Besides setting up new measurement, collection and data evaluation processes, the project calibrated the existing solar radiation and wind instruments of many agencies. These efforts form a solid base for further data analysis in the future.

CONCLUSIONS

1. The activities of the solar/wind assessment component were centered at the Meteorological Research Sub-Division, Studies and Research Division, Meteorological Department.

2. The Center for Solar Radiation and Wind Calibration was established at the Calibration Sub-Division, Instrumental Division, Bang Na Meteorological Office.

3. Additional measurements are done at 6 stations for solar radiation, and 10 stations for wind. All additional measurements are automatically recorded by dataloggers.

4. There is a problem with continuity of data recorded by the datalogger due to instrument malfunction.

5. Calibration of solar and wind instruments faced problems because of time limitations, human resources and spare instruments.

6. National standard solar radiation instruments were calibrated at WMO Regional Centers in Australia.

7. Maintenance of solar instruments, wind instruments, and a datalogger is hindered by the problem of unavailable spare parts within Thailand.

8. Analysis of existing data by KMIT and new data by Dr. Exell of AIT was completed and published as separate technical reports.

9. In-country training was mostly completed as it was planned, but overseas training was cancelled due to the delays at DTEC.

10. Foreign and local consultants proved very useful.

RECOMMENDATIONS

1. Additional measurements of solar radiation and wind should be taken (both in space and time) to yield more representative data for further research.

2. The datalogger used in automatic data recording should be modified for more durability. Spare parts should be sufficiently supplied to ensure continuity of recorded data.

3. Qualified researchers and operators should be assigned to carry on project activities, and should be trained to be able to do the job without the assistance of a consultant.

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Chapter 1

Introduction

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INTRODUCTION

The objective of this report is to give general information about the Solar and Wind Energy Assessment Component of the USAID-Thai Renewable Nonconventional Energy Project. This report is not intended to be technical--note, however, some technical detail can be found. In this chapter the historical background, objectives, significance and scope of this study are described.

A. HISTORICAL BACKGROUND

During the past few years the economic development of Thailand has faced a variety of problems, partly because of the rapidly increasing prices and the high demand for petroleum. The government is aware of this situation, and therefore the Project for Alternative Energy Sources was included in the Fifth National Economic and Social Development Plan. The objective of the Project is to increase the self-reliance of the country's energy supply.

The Renewable Nonconventional Energy Project was a cooperative project involving Thailand and the United States of America as a consequence of the United States Vice-President's visit to Thailand in May, 1978.

The project covers various fields of technology and consists of fourteen components, including Biomass Energy, Geothermal Energy, and Solar and Wind Energy Assessment. The National Energy Administration coordinates and supervises the entire Project.

The Meteorological Department of Thailand (MET) is the agency reponsible for the Solar and Wind Energy Assessment component, a three-year project planned to last from 1981 to 1984. After the project is completed, the Meteorological Department will continue its activity on a routine basis.

B. OVERALL OBJECTIVE

The objective of the Solar and Wind Resource Assessment is to specify how the solar and wind energy potential of Thailand can be reliably determined and subsequently monitored. Assessment consists of:

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- Establishing a "Center for Solar Radiation and Wind Calibration" for continual measurement and calibration of radiation and wind instruments including maintenance of the instruments; and

- Evaluation of relevant meteorological data to generate a useful set of numerical values for solar and wind energy which will serve as a frame of reference for calculations of potential energy using the engineering specifications of the various conversion systems.

C. SIGNIFICANCE

As Thailand is a tropical country with high order radiation and moderate wind, solar and wind energy seem to be attractive sources of renewable energy. The assessment of solar and wind energy to be investigated in this project was to provide assistance in evaluating the potential for solar and wind energy. The assessment was considered to be the most important step to be taken before systematic harvesting of both types of energy could be done. The assessment was to provide the foundation for sound technical, economic and social decisions.

D. SCOPE

The study was conducted to determine the atmospheric constraints of solar and wind energy in Thailand. The focus of the study was on defining the special and temporal characteristics of solar and wind energy resources and to provide a means to assess their availability and reliability in both regional and local terms.

Chapter 2

Existing Data Base

EXISTING DATA BASE

Before doing the assessment for solar and wind energy, determination of existing data should be made. This will be very useful for the planning of additional measurements and analysis of data. This chapter reviews the related existing data for assessment of solar and wind energy for Thailand.

A. SOLAR ENERGY

Existing data related to assessment of solar energy are mostly collected by the Meteorological Department (MET) and the National Energy Administration (NEA).

Measurements Made by the Meteorological Department

An excellent network of 66 first-class meteorological stations has existed in Thailand for the past 25 years. Detailed synoptic analysis is carried out at the surface and at various levels in the atmosphere four times per day at the forecast center in Bangkok. Some of these data were used in the study described in Chapter 3. Additional analyses using the following existing data sets are proposed, (Gartang, 1981).

Cloud cover observations

Sixty-six stations (see Annex I, Table I.1) record cloud amounts in eighths (octa's) of sky covered at 0700, 1000, 1300, 1600 and 1900 local standard time (LST). The following data are recorded at each observation:

- Direction of motion of the clouds;
- Amount of low cloud;
- Height of base of low cloud;
- Amount of middle cloud;
- Amount of high cloud; and
- Total amount of sky covered.

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Forty-three of these stations have been in continuous operation for 25 years. The observing locations vary from open rural or coastline locations to urban centers.

These data represent the basis for detailed analysis of:

- Cloud cover distributions in space as a function of time and as a function of meteorological state;

- Distinctions in amount of sky cover by different types of clouds. In particular, a distinction can be made between low, middle and high cloud.

- Estimates of the number of hours of sunshine based upon the cloudiness record. These estimates can be determined for:

  - time of day,

  - time of year (in increments of tens of days to more than months),

  - seasons;

- Estimates of the amount of global radiation available for similar breakdowns as above;

- Frequency distributions of cloudy days by increments of cloudiness. Once again a distinction can be made between cloud types.

- Consecutive hours of cloudiness and consecutive days of cloudiness above or below certain thresholds of cloudiness. Distinction can be made between the types of clouds.

Tabulations and spatial distributions (maps) of cloudiness and quantities derived from the cloud record can be compiled to aid in the assessment of the available solar energy. In particular, the cloud record will provide detailed time and space information on the inter- and intra-diurnal distribution of solar radiation.

Sunshine observations

Twenty-two sunshine recorders (Campbell-Stockes), listed in Table I.2 (see Annex I) have been in operation from 1 year (3 stations) to more than 20 years (15 stations). The observations have been compiled by the hour and fraction of the hour, by the day, and by the month. The stations are representative of urban, rural, mountainous, and coastal locations.

These data represent a basis for detailed analysis of:

- The number of hours of sunshine over the country as a function of time and as a function of meteorological state;
- Frequency distributions of hours of sunshine by increments of one hour;
- Number of consecutive hours of sunshine and number of consecutive days with sunshine above certain thresholds;
- Interdiurnal distributions of sunshine as a function of location, time of year and meteorological state; and
- Estimates of the amount of global radiation available at each location for each time interval. As above, these estimates can be made as a function of location, time of day, time of year, and meteorological state.

Tabulations and spatial distributions (maps) of the number of hours with sunshine and the global radiation derived from the sunshine record are compiled to aid in the assessment of the available solar energy. As for cloudiness, the record of number of hours with sunshine provides detailed time and space information on the inter- and intra-diurnal distribution of solar radiation.

Observations of the number of hours with sunshine are combined with the estimates of this quantity from cloud amounts. Cloud amounts are recorded at all 22 sunshine recorder stations. Thus it is possible to carry out a detailed analysis of the estimates of number of hours with sunshine based upon the cloud record and, from this analysis, improve the estimate of number of hours of sunshine. The improvement of the estimate is likely to be achieved by distinguishing between the types of clouds and cloud amounts rather than by simply using the total sky cover.

Atmospheric visibility

Estimates of horizontal visibility (km) are available at the stations making cloud observations at the same times and for the same period as the cloud observations.

Correlations can be established between horizontal atmospheric visibility and transmissivity of the solar beam through the atmosphere at locations where both visibility and solar radiation measurements exist.

A measure of the turbidity of the atmosphere can therefore be estimated at all of the locations where visibility measurements are made. This determination is particularly important in choosing a location to make direct solar beam measurements and for the installation of a calibration facility. Exell and Saricali (1976) [illegible] that Bangkok exhibits relatively high values of turbidity while, at other locations (Chiang Mai), turbidity has a seasonal variation. Atmospheric visibility measurements should be taken to extend these observations over other parts of Thailand.

Rainfall

Detailed analyses of the rainfall of Thailand already exist (Sternstein, 1962; Dusadee Sukawat, 1979; Crutcher et al., 1969; Meteorological Department, 1961; U.S. Air Force, 1965).

Compact updated summaries of daily and monthly rainfall would represent useful additions to the above description and would aid in:

- Identifying periods and locations where low radiation, particularly low direct solar radiation, can be expected;
- Providing information on the daily cycle and on the persistance of days with rain;
- Providing correlations with cloudiness and hours with sunshine useful in planning potential locatio of solar systems with particular reference to direct beam system; and
- Providing correlations with the distribution in time and space of synoptic scale systems.

Satellite record of cloud cover

Satellite observations of cloud fields over Thailand are available from 1970 to date. Two previous studies, Miller (1971) and Anderson (1974) show cloudiness over SE Asia from satellites. The early observations from ESSA-8 have poor resolution in time and space. From 1979 onwards, polar orbiting and geostationary satellites have provided excellent coverage of Thailand. The satellite cloud observations, particularly the high resolution geostationary pictures, should be used in conjunction with the cloud amounts, hours of sunshine, and calculated values of radiation listed above to verify space and time distributions of these fields.

Solar radiation

One pyranometer measuring global radiation is located at the Meteorological Department Headquarters in Bangkok. A fairly long (about 20 year) record exists for this instrument.

The data should be examined and compared with the results from the Asian Institute of Technology (AIT). However, caution should be exercised in the use of the data until some measure of its validity can be established.

Measurements made by the National Energy Administration (NEA)

Measurements of hours of sunshine and solar radiation have been made by the NEA as part of the hydrological program at a number of stations since 1971. (see Table I.3 in Annex I).

Sunshine observations

Sixteen sunshine recorders (Campbell-Stokes) have been operating in Thailand, concentrated mostly in the north and northeast. Most stations (13) were in operation by 1976 (see Table I.3 in Appendix I). Data is tabulated by the hour, day and month. These data have not yet been incorporated into a solar assessment scheme. They clearly represent a resource which should be combined with the data available from the Meteorological Department and subjected to the same analyses as listed under table I.2 in Annex I).

Solar radiation

Eleven bimetallic (Belfort and Weather Measure) and 10 thermoelectric (Kipp and Zonen) instruments have been deployed by the NEA to measure global radiation.

Most of the bimetallic instruments were in operation by the middle of 1977 (Table I.3 of Annex I). The thermoelectric instruments were all installed between 1979 and January 1980.

The bimetallic instrument is not recommended by the Radiation Commission of the International Association of Meteorology (CSAGI, 1958, p. 417) for any measurements except daily totals of radiation and only then "with the reservation that even if a calibration factor varying from month to month is used, these daily totals must be regarded as having an accuracy of not better than ± 5% to 10%."

The reason for this caution is that the instrument is sensitive to the temperature of the ambient environment as well as to the flux of incident radiation. Temperature correction must therefore be applied. Changes of the calibration of the instrument also occur with changing angle of incidence of the radiation. These changes have been found to be very large for the bimetallic instrument. The calibration is also a function of the incident energy itself.

Because the time constant of the bimetallic instrument is large and unreliable, this instrument is not suitable for measurements involving integration periods shorter than several hours to a day. "The best bimetallic instruments operated with the greatest care are suitable only for daily totals of radiation in which accuracies of ± 10% are adequate" (Coulson, 1975, p. 121).

The thermoelectric instrument is more reliable than the bimetallic device, but this is subject to careful calibration.

These radiation data have been compiled by the NEA and daily totals of global radiation are available for the period of record. At the thermoelectric equipped stations, power failure resulting in failure of the recording system interrupts the record. The data should be compared to the estimates made by AIT and to estimates which can be made from the NEA and MET sunshine recorders.

Other Measurements

Measurements of direct solar radiation have been made by researchers at King Mongkut's Institute of Technology (KMIT) by means of pyrheliometer.

B. WIND ENERGY

Existing data related to the assessment of wind energy are those observed by MET and NEA.

Observations Made by the Meteorological Department (MET)

Surface wind measurements

Surface wind measurements are made at 66 meteorological stations of the Meteorological Department of Thailand (see Table I.4 in Annex I). Most of the stations are indicator cup and vane instruments which are read every 3 hours. The reading instructions follow World Meteorological Organization (WMO) procedures of obtaining a mean value over a period of 2 minutes. All anemometers underwent a calibration check in a wind tunnel prior to deployment. No field checks on performance are made to correct anything but catastrophic failure.

Mean monthly wind direction, wind speeds and the direction and magnitude of the maximum wind have been obtained for 30 years (1951 - 1980) in the Climatological Data of Thailand.

Recording anemometers exist at 7 stations.

Upper air measurements

An excellent network of 12 pilot balloon stations together with 7 rawinsonde stations have existed over Thailand from 9 to 30 years.

Streamline analysis at the synoptic hours (00, 06, 12, 24 Z) is available for more than 20 years for 12 levels from 2,000 ft (0.6 km) to 60,000 ft (18.0 km). The two lowest levels of 2,000 and 5,000 ft are of particular interest to wind energy assessments. Higher levels serve as valuable guides for determining the synoptic weather patterns over Thailand.

Observations Made by the National Energy Administration (NEA)

11 recording and 26 non-recording anemometers are maintained as part of the hydrological network by the NEA. The non-recording anemometers measure 24 hours wind passage or run in kilometers, thus providing a mean 24 hour wind speed. The recording anemometers provide a record which yield integrated mean wind speeds with a time resolution of at least 1 hour. Both anemometers are mounted at a height of 2 m above the surface. Table I.3 in Annex I shows that most (20) of the non-recording anemometers have been in operation for more than 5 years. Most of the recording anemometers, however, have only been functioning for the past 5 years.

Chapter 3

Review of the Literature

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REVIEW OF THE LITERATURE

In this chapter, related studies used for planning the solar and wind energy assessment are presented. Due to differences between solar and wind energy, the literature is presented separately, except for that related to foreign consultation.

A. FOREIGN CONSULTANT PLANNING

In 1981, as the consultant to the project, Garstang proposed a resource assessment plan for solar and wind energy for Thailand. The plan can be summarized as follows:

- Additional measurements of solar radiation and wind speed were recommended, especially short time and space scales;
- A synoptic classification of the weather system over Thailand which controls the available solar and wind energy was proposed; and
- A three-dimensional numerical model was recommended to be used to determine the wind energy potential over the Gulf of Thailand and over the adjacent coastal areas.

This topic will be discussed in Chapter 4 in more detail.

B. PREVIOUS STUDIES IN THAILAND

The review of literature presented in this section was mostly done by Garstang in 1981.

Solar Energy Studies

Atmospheric circulation with its attendant regions of high and low cloudiness and the earth's geometry and its rotation around the sun dictate that the greatest amount of solar energy is found between two broad latitudinal bands - between 15° and 35° north and south (Robinson, 1967). In these regions there is a minimum monthly mean global radiation of 500 cal. cm^{-2} d^{-1}. The next most favorable global region is in the equatorial belt between latitudes 15° N and 15° S. Global radiation is from 300 to 500 cal cm^{-2} d^{-1} throughout the year. Thailand, extending from about 5° to 20° N, lies within both regions, and can be expected to have radiation values equal to those quoted above.

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Studies at the Asian Institute of Technology

R.H.B. Exell and his colleagues at the Asian Institute of Technology (AIT) have done the most extensive work on solar radiation in Thailand. Exell (1982a) analyzed solar radiation data over a 5-year period (1968-72) and daily duration of sunshine data from 18 stations all over the Kingdom. Exell (1982 b) proposed a compact, first-order random model for simulating daily totals of solar radiation by computer. Empirical formulae give satisfactory approximations and could be applicable to the rest of Southeast Asia. Kalwar (1976) made a comprehensive survey of atmospheric radiation and sky temperatures at Chiang Mai, Ubon, Bangkok, and Songkla using empirical methods. Exell and Saricali (1976) made a survey, study, and analysis of solar data to provide information in a suitable form for use in designing and predicting the performance of solar energy equipment. The findings from this work can be summarized as follows:

- Mean values of global radiation are above 470 cal cm^{-2} d^{-1} and are widespread in the summer transition period and early SW monsoon;
- Lowest values of global radiation are below 350 cal cm^{-2} d^{-1} and occur over limited areas with heavy rainfall in the late part of SW monsoon;
- Diffuse radiation is estimated to average 200 cal cm^{-2} d^{-1} with high atmospheric turbidity at Bangkok all the year round. To the north (Chiang Mai) turbidity is low during the SW and NE monsoons, but high in the transition period;
- Daily totals of global solar radiation over the country reach a maximum close to 500 cal cm^{-2} d^{-1} during the NE monsoon and transition period;
- Diurnal values of the mean midday radiation flux range from 70 cal cm^{-2} h^{-1} in the transition period to 50 cal cm^{-2} h^{-1} in the late SW monsoon. There is only a small (3%) decrease in the mean radiation received in the afternoon compared to the morning; and
- The greatest number of consecutive days with low (< 300 cal cm^{-2} d^{-1}) global solar radiation occurs during the SW monsoon.

Measurements of global radiation by means of thermopile pyranometers were available for the above study from only two locations: Bangkok and Chiang Mai. The spatial distributions of global radiation are based upon estimates of the daily duration of sunshine from observations of total cloudiness at 26 stations and upon measurements of the daily duration of sunshine at 18 stations. The estimates of the duration of sunshine and the measurements of the duration of sunshine were used in a regression equation to obtain an estimate of global radiation at 44 stations.

No distinction was made in the cloudiness-to-hours of sunshine conversion between types of cloud cover. An underestimate of the number of hours of sunshine is noted and is probably due to the fact that high thin stratiform cloud transmits a fair amount of the solar radiation.

Errors introduced by estimating global radiation from the number of hours with sunshine are claimed to be no greater than 30 cal cm^{-2} d^{-1} (7%).

Correlations and coefficients are not shown for either estimated sunshine hours from cloudiness and measured sunshine hours or for the calculated global radiation from the sunshine record or from the estimated sunshine record. The fact that direct measurements of global radiation were available from only two locations limited some of these possible comparisons.

The length of record of the observations used varied considerably:

- Global radiation from Bangkok and Chiang Mai: 4 years from 1968 to 1972;
- Sunshine recorder observations for about 13 years from 1955 to 1968; and
- Cloudiness measurements for about 19 years from 1951 to 1970.

Meteorological conditions were not considered in any detail. Eight 1½ month periods were used for convenience in defining standard solar declination values. The analysis of fluctuations in daily totals of global radiation and in consecutive days with radiation above or below certain thresholds is limited because of the lack of data and the generalized climatological approach that is used. The occurrence of clouds virtually reverses the expected annual march of solar radiation over Thailand. Due to this marked control exercised by cloudiness, it is desirable to treat radiation as a function of the atmospheric synoptic scale systems which produce the cloudiness.

Other studies

Thongprasert (1982) made detailed descriptions with tables and diagrams of the high intensity solar flux measurement technique, which can be used as a standard for conversion of temperature. Kirtikhara and Siriprayuh (1980) made a study of relationships between solar radiation and some meteorological data.

Wind Energy Studies

Like solar power, wind energy constantly present in the middle and upper atmosphere may not be available at the surface of the earth. The large planetary circulations such as the trade winds and the westerlies over the open oceans represent the best locations for the utilization of wind energy. Over land, greater variability is introduced by topography

but in the broad belts of the trades and in the mid-latitude westerlies, locations can be found where the wind energy exceeds 500 W m^{-2} (for comparison with the previous section, 1 cal cm^{-2} d^{-1} = 1.163 W m^{-2}, thus a daily value of 350 cal cm^{-2} d^{-1} is $\sim$ 400 W m^{-2}). Over wide areas of oceans and more limited areas over land in the trades and in the westerlies, the wind energy exceeds 200 W m^{-2}.

Thailand is in the heart of the great monsoonal belt of Asia. Surface winds go through a drastic (180°) seasonal reversal. Although the large scale winds may have a fairly constant seasonal direction (SW monsoon, NE monsoon), mean wind speeds are not known to be high (< 5 m s^{-1} over large areas). Mean annual or mean seasonal wind speeds below 5 m s^{-1} may be used to generate power for specialized purposes such as lifting water. Wind speeds above 5 m s^{-1} represent an energy resource which could supply a significant percentage of the energy needs of a country.

Existing knowledge of the general circulation over Thailand (U.S. Air Force, 1965; Crutcher et al., 1969) indicates that over most of Thailand the lower figure quoted above is likely. However, over the coastal regions of the Gulf of Thailand, it is possible that local circulations increase the mean wind speeds to above 5 m s^{-1}.

In the second study, a survey was made of wind energy conversion. Analyses were carried out using measured wind speeds at the same 53 meteorological stations used in the first study. In this study no attempt was made to correct for anemometer height and all zero values of wind speed were omitted. Further, the authors note (in a personal communication) that the height of the anemometers at almost all stations were changed at least once during the 13 year period of record (1966-1978).

Products of the analysis include:

- A map of the annual average wind speeds over Thailand;
- Maps of mean monthly wind speeds;
- Frequency distributions of numbers of hours per year of wind speeds in different classes of wind speed for each of the 53 stations;
- Frequency distributions of kilowatt hours per square meter for different classes of wind speed for each of the 53 stations; and
- Tables of monthly average wind speeds for each year of the wind speed and direction of record and the monthly mean wind speed for the period of record of each station.

The results presented agree with those of the first study showing the highest mean annual wind power potential to lie along the coastlines of Thailand.

Regional and seasonal variations in mean wind speeds are evident from the results presented in this report. Maximum mean monthly wind speeds appear to occur in February when mean values of over 5 m s^{-1} are reported in the southern extremity of Thailand. Minimum mean monthly wind speeds occur generally during the wet season with the month of September appearing to have the lowest wind speeds over most of the country. During September no station records a mean monthly wind speed in excess of 3.71·m s^{-1}.

Studies by the King Mongkut's Institute of Technology

Two studies of wind energy have been made by researchers at KMIT: *Estimated Wind Potential in Thailand* by Pinij Siriprukpong et al., 1981; and *The Analysis of the Wind Situation in Thailand and the Designed Local Wind Turbines* by Boonchai Ngernswas, 1981.

In the first study, Meteorology Department observations every 3 hours at 53 stations over a 13 year period (1966-1978) were used. Wind speeds were normalized to 10 m using two values of the exponent α in the power law: $\alpha = 0.14$ for $h > 10$ m
and $\alpha = 0.4$ for $h < 10$ m
The value of α can then be used in the power law profile:

$$\frac{u(h)}{u_{10}} = \left(\frac{h}{10}\right)^{\alpha}$$

The Betz limit of 0.59 is assumed as a power coefficient and air density is assumed constant. Results are presented in terms of an empirical shading equation and are averaged over the entire year. The findings in tabular and map form are therefore in kW km^{-2}, an unusual and difficult unit to interpret.

Maximum potential power is shown to lie along the coastline of the Gulf of Thailand and on the Indian Ocean coast. The potential wind power density in these locations is, however, shown to be in the order of 50 W m^{-2}. Inland over the central plain and to the north and northeast wind power potential is shown to be low.

Other studies

Exell (1982 c) assessed the availability of wind energy in Thailand using data taken from 48 stations over a 10-year period. Exell et al. (1981) made a survey of wind regime in Thailand for use in assessing the potential for the utilization of wind energy. Hourly wind data from 4 stations were used for analysis of the availability of wind energy in Thailand. Thavapalachandran (1980) studied the availability of wind energy in Thailand for water pumping. Hourly wind velocity data for one year were used to determine the seasonal velocity distribution curves and power duration curves at stations in Chiang Mai, Ubon, Bangkok and Hatyai. Energy that could be extracted from the wind by means of an irrigation wind pump has been calculated.

Chapter 4

Design of the Study

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DESIGN OF THE STUDY

This chapter discusses the design of the study in terms of organizational involvement, relationships and responsibilities for particular measurements. Additional measurements, measurement methods, maintenance and calibration of instruments, data processing, training and consultation with other agencies are also presented.

A. ORGANIZATION

In order to have the project operated with maximum efficiency, two centers of activity were envisioned - the Meteorological Department and the Center of Solar Radiation and Wind Calibration. The activities of these centers are specialized and the project was designed so that they could maintain their distinct identities.

Meteorological Department

The Meteorological Department was expected to play the lead role in directing the Project. During the assessment period, a meteorologist was to play the key role in delineating the solar and wind potential. A small group was to be identified and charged with this task within the framework of the Meteorological Department. A senior level meteorologist was to be designated as a Project Director.

Center for Solar Radiation and Wind Calibration

The necessity for continual calibration of radiation and wind instruments, and the difficulty of routinely carrying out some of the required radiation and wind measurements, dictated centralization of these functions.

Care was taken in the choice of the location of the center. Two considerations were dominant:

- Availability of qualified technical staff and facilities; and
- Representativeness of the site.

The two requirements were met by the Instrument Division of the Meteorological Department.

The center was assigned the responsibilities of:

- Measurement of radiation and wind at the center;
- Calibration of radiation and wind instruments; and
- Maintenance of equipment.

A senior instruments technician capable of managing the center and all of the field measurements was to be appointed as the supervisor of the center.

B. ADDITIONAL MEASUREMENTS

Before discussing the measurement methods used by the project, it is necessary to discuss the measurements used (and rationale) for solar radiation (direct radiation, global radiation, and diffuse radiation) and wind energy.

Solar Radiation

Planning for the use of solar energy requires at least the following measurements:

- Monthly means of the daily totals of direct and diffuse solar radiation;
- Monthly means of the daily march of direct and diffuse solar radiation;
- Statistical data on the frequency distributions of days with totals of direct and global radiation above and below pre-determined levels; and
- Information on the spatial differences in direct and diffuse radiation which may accompany the above temporal changes.

Any measurement program for the use of solar radiation must also address the question of how the solar energy is most likely to be used.

There are four broad approaches to Solar Energy Conversion System (SECS):

- Low grade solar heat;

- High grade solar heat;
- Direct conversion to electricity; and
- Photosynthetic and biological conversion processes.

Devices for the conversion of solar energy to low-grade heat include water heaters, solar stills, cookers, driers, refrigerators and pumps, solar ponds and low temperature steam turbines. Most of these devices use a simple flat plate collector, converting solar energy to heat which is absorbed by a working fluid. Flat plate collectors can convert 80% or more of the solar radiation to heat reaching operating temperatures of 50 to 95°C. The flat plate collector uses both the direct and the diffuse beam radiation.

High grade solar systems focus the direct solar beam upon a collecting surface. High grade circular parabolic mirrors can concentrate the direct beam upon a collector to reach temperatures of 3500°C. Crude parabolic collectors achieve temperatures of 500°C. The focusing collector must "track" the sun and is critically dependent upon the availability of direct solar radiation, performance being seriously impaired by cloudiness.

The direct conversion of solar radiation into electricity may be achieved either by the thermoelectric process or by photovoltaic power generation. Maximum efficiency of these systems is currently about 15%. An efficiency as high as 30% has been predicted. The cost of the solar cell is dropping progressively but is still high enough for the method to be mostly applicable to special purposes such as charging of batteries at remote telecommunication or measurement sites.

Photosynthetic or biological conversion of solar energy achieved by planting fast-growing, woody plants or trees which have a high photosynthetic efficiency will be left to the Biomass assessment.

For Thailand the greatest potential use of solar energy would appear to be in the conversion to low grade heat. Emphasis in the measurement program for this project was therefore to be placed upon this form of solar energy conversion. However, both high grade solar heat and the direct conversion of solar radiation to electricity have possible future applications in Thailand. Basic measurements required for planning the use of these systems were included.

The evaluation of the existing data base and the requirements of the kind of solar radiation energy conversion program which can be envisioned for Thailand required the following measurements:

Direct Radiation

A solar tracking direct beam pyrheliometer was required to make continuous measurements of direct solar radiation at one location.

An instrument with the following characteristics was required:

Sensitivity	5-6 mV/cal cm^{-2} min^{-1}
Impedance	200 (approximately)
Temperature dependence	± 1% over range -30 to +40°C
Linearity of response	Linear up to 4 cal cm^{-2} min
Response time	4 sec maximum

The instrument must be temperature compensated and have a reliable solar tracking mechanism.

The signal should be capable of being transmitted to a remote recorder. The instrument itself must be housed in a weather-proof case capable of exposure in all weather. The instrument must be attached to an electrically driven equatorial mount for solar tracking. The output signal should preferably be recorded upon a strip chart and simultaneously digitized and recorded on magnetic tape. If the latter method is used, the tape must either be compatible with a computer or equipment to convert the recording to computer compatible tape must be acquired. If the digital recording method is adopted, then much of the difficulties which are encountered in using the strip chart recorder will be avoided. Standard procedures can be used to program the output in any desired time interval above 4 sec.

Global radiation

Global radiation must be measured at the same location where direct solar radiation is being measured. The World Meteorological Organization (WMO) (1965) has defined three classes of pyranometers on the basis of overall performance. All of the pyranometers require calibration with respect to a primary radiation standard. None is classified as a standard pyranometer. Table 4.1 gives the classes and their respective characteristics.

Table 4.1 Classification of Pyranometers

	1st Class	2nd Class	3rd Class
Sensitivity (mW cm^{-2})	± 0.1	± 0.5	± 1.0
Stability (% change per year)	± 1	± 2	± 5
Temperature (maximum error due to changes of ambient temperature - %)	± 1	± 2	± 5
Selectivity (maximum error due to departure from assumed spectral response - %)	± 1	± 2	± 5
Linearity (maximum error due to nonlinearity not accounted for - %)	± 1	± 2	± 3
Time constant (maximum)	25 sec	1 min	4 min
Cosine response (deviation from that assumed, taken at sun elevation 10° on clear day - %)	± 3	± 5-7	± 10
Azimuth response (deviation from that assumed, taken on clear day - %)	± 3	± 5-7	± 10

The rating, according to the criteria in Table 4.1 of pyranometers which were available in 1965 is the following:

Diffuse radiation

Diffuse radiation was to be measured at the same location where direct and global radiation were to be measured. The observed values of diffuse radiation can be used in calibration of radiation instruments by comparing them to the observed values of direct and global radiation.

Diffuse radiation is measured by pyranometer with a shadow band. The appropriate method was to be used to correct for the portion of sky screened by the shadow band and for elevation of measurements. However, for convenience, tabular values of the shadow band corrective factor, applicable to average condition of partly cloudy skies, are listed by manufacturer below.

First Class:

Selected thermopile pyranometers

Second Class:

Moll-Gorczynski (Kipp) pyranometer
Eppley pyranometer (also called 180° pyrheliometer)
Volacine thermopile pyranometer
Dirmhirn-Sauberer (star) pyranometer
Yanishevsky thermoelectric pyranometer
Spherical Bellani pyranometer

Third Class:

Robitzsch bimetallic pyranometer

Since 1965 several new types of pyranometers have been developed. Two by the Eppley Laboratories are based upon thermopiles. The precision spectral pyranometer of Eppley meets the criteria for a first class pyranometer, while the Eppley black-and-white pyranometer falls into the second class category.

It was recommended that the Center for Radiation Calibration be equipped with an Eppley Precision Spectral Pyranometer with electrical compensation for the dependence of sensitivity on ambient temperature, optical compensation for deviation of response from the cosine law and provision for the use of broad-band filters. Specifications of the instrument (1973) are shown in Table 4.2.

Table 4.2 Specifications of the Eppley Precision Spectral Pyranometer

Sensitivity	5 mV/cal cm^{-2} min^{-1} (approx.)
Impedance	300
Temperature dependence	± 0.5% from -20 to ± 40°C
Cosine error	± 1% over angles of 0° to 80°
Response time (1/e)	1 sec
Linear response up to	4 cal cm^{-2} min^{-1}

An alternate instrument to the Eppley is the Spectrolab Pyranometer. The output signal of the pyranometer should preferably be recorded by both a strip chart recorder and in digital form as described for the pyrheliometer above.

Wind Energy

An assessment of the wind energy potential of a country requires wind measurements on a range of time and space scales. Long time and large

space scales provide the climatological background and provide a first approximation of what can be expected. Such large scale descriptions are available for Thailand as described in earlier sections. Descriptions of wind speeds on time scales of a month or less and space scales of regions or less are much less certain for Thailand. While the wind measurements at relatively low levels exist, these data have not been systematically analyzed to provide a basis for assessment of the wind energy potential of Thailand.

Planning for the use of wind energy requires:

- Hourly average wind speeds at a representative height at or near 10 m at a sufficient number of locations to describe regional differences and for a sufficient period of time to describe seasonal differences;

- Statistical data on the frequency distributions of days with wind speeds above or below pre-determined mean wind speed levels;

- Statistical data on the diurnal distribution of wind speed at representative locations and times of the year;

- Measurements of wind speeds at selected sites, at least, three levels between 10 m and 50 m. Measurements of temperature and humidity at these sites and levels are desirable; and

- Capability to obtain detailed wind speed distributions in the horizontal (x and y coordinates) and from the surface to 300 m (z coordinate) at selected sites.

As for solar energy, any measurement program for the use of wind energy must also address the question of how the wind energy is most likely to be used.

Wind Energy Conversion Systems, (WECS), can be divided into three classes:

1. Small WECS $P < 100$ KW

2. Intermediate WECS $100 \text{ KW} \leq P < 1 \text{ MW}$

3. Large WECS $P \geq 1$ MW

For Thailand the most immediate use of wind energy would appear to be the use of small WECS for agricultural purposes including integration with solar systems for crop drying and salt production. The potential use of intermediate and large WECS in Thailand should be explored. However, the design of the assessment program emphasized the use of small WECS in Thailand.

Evaluation of the existing data base and the requirements of the kind of wind energy systems to be employed in Thailand indicate the following additional measurements.

Wind speed and direction

A recording anemometer should be used for measuring wind speed and direction. Most of the 12 NEA recording anemometers are located in the north and northeast. Only two are located on the Gulf coast at Ban La Mai and Ban Khlong Muang. The nearest recording anemometer to the region southwest (Samut Songkram) and southeast (Bang Pakong) of Bangkok where windmills are still being used (U.N., 1976).

The small WECS has been most widely used for lifting water. It can also be applied to crop drying and the production of small amounts of electricity for relatively specialized purposes. Integrated solar-wind systems may use small WECS for salt production, desalinization of saline or brackish water, fish farms and other specialized applications. The small WECS is often constrained to a given site and height above the ground. It can utilize relatively low wind speeds and can operate on an intermittent basis without any requirement for the storage of the energy.

The intermediate WECS can be applied to small localized industry and commercial operations such as cooling, air conditioning, electrical production and the pumping of water to impoundments or irrigation systems and desalinization or purification of saline or contaminated water. Intermediate WECS in the range of about 250 KW have been used elsewhere as auxiliary electrical supplies for small and remote communities which are outside any major electrical grid and must depend upon diesel powered generators for their electricity. The intermediate WECS requires relatively good mean annual wind speeds (> 5 m s^{-1}) to be effective and great care must be taken with the siting, in both the horizontal and in the vertical dimensions.

Large WECS are still primarily in the development stage but sufficient testing of prototype machines has now been done to warrant the consideration of these large machines. Economy achieved by the scale of these large machines suggests that electrical energy can be produced at favorable locations, and at a competitive cost.

Recording anemometers capable of accurately determining the total hourly duration of wind velocity are required for the compilation of diurnal, inter-diurnal, monthly, seasonal and annual power potentials.

The NEA recorders are all mounted at 2 m above the surface. Whereas this observation will be useful in showing the general distribution of wind speeds and can be used with caution in estimating the potential for small WECS, there is an urgent need to make continuous wind speed measurements at greater heights and at certain key locations. Four recording anemometers were recommended for this project, three for deployment and one as a standby replacement instrument.

The three recording anemometers were to be placed to provide detail of the wind regimes of the:

- Gulf coastline;
- Central plains; and
- NE plateau

Where possible, at

- Ban Khlong Muang;
- Khon Kaen; and
- Nakhon Sawan.

Each anemometer was to be placed at 10 m above the ground in a well exposed (free from obstructions such as buildings or trees) location.

The recording system was to incorporate a microprocessor which could be pre-programmed to provide a range of wind speed statistics including:

- Mean hourly wind speed based upon an integration of the instantaneous wind;
- Variance of the mean hourly wind speed;
- Standard deviation of the mean hourly wind speed;
- An estimate of gustiness;
- Mean hourly wind power density (W m^{-2}); and
- Daily (24 h) mean wind speed and power density.

The data was to printed in hard copy form and recorded on magnetic tape.

Wind direction was to be recorded every hour as a mean direction and as a standard deviation in degrees for that hour.

Profile measurements

Extrapolation of wind speed measurements from one height to another height depends upon atmospheric stability, the aerodynamic roughness of the surrounding terrain, and upon topography.

In Thailand it may be unlikely that the need to estimate winds above 10 m will exist in any location except those surrounding and over the Gulf of Thailand.

A single location, Songkla, was therefore recommended as a site for profile measurements. A 50 m mast was suggested with wind speeds and temperatures being measured 10, 20 and 50 m. Wind speeds and temperatures were to be recorded using a microprocessor to routinely provide hourly values of:

- Atmospheric stability based upon the Richardson Number;
- Estimates of the exponent, α, the exponent in the power law;
- The mean wind speeds at each level;
- The variance in wind speed at each level;
- The mean layer wind speed between 10 and 50 m and between 20 m and 50 m; and
- Other programmable products such as gustiness and power density.

Wind direction was to be measured at only one level (50 m) and recorded every hour as a mean hourly value together with the standard deviation in degrees.

The data was to be printed in hard copy form and recorded on magnetic tape. It was required to have the capability to transfer the record on the magnetic tape to a computer where more extensive calculations could be carried out.

Mobile tower

Site survey capability is essential for intermediate and large WECS. For small WECS, simpler portable wind measuring systems are adequate. It was recommended that only a simple mobile tower be acquired until such time as the need for more elaborate site surveying and capability was demonstrated.

A simple strip chart recording anemometer mounted on a telescoping mast capable of being extended to 10 m was suggested. The mast was to be trailer mounted and easily deployed in the field. The recording anemometer and chart recorder were to be battery powered for remote use and the recorder housed in a weather-proof shelter.

C. MEASUREMENT METHODS

In this section the methods for measurement of solar radiation and wind are described. Measurements can be divided into measurement at the Center and measurement in the field.

Center for Solar Radiation and Wind Calibration

The Center was to take responsibility for solar radiation and wind measurements of the Project and also for calibration of solar and wind instruments. The Center itself was to make observations for data collection and calibration purposes.

Solar radiation

At the Center, solar radiation measurement was to be made by four kinds of instruments:

- Normal Incidence Pyroheliometer with solar tracker for measuring direct solar radiation;
- Precision Spectrum Pyranometer for global radiation measurement;
- Precision Spectrum Pyranometer with shadow band for diffuse radiation measurement; and
- Angstrom Pyrheliometer (2 sets) which belong to MET. These instruments are used as the National Standard Pyrheliometers for direct radiation measurement.

Wind

For wind measurement, wind speed and direction were to be observed at the Center by an anemometer and a wind vane.

Solar Radiation Measurements

Planning for solar radiation in the field can be divided into two steps: site survey and installation.

Site survey

The objective of a site survey is to find a suitable place for solar radiation measurement as recommended by WMO. The site for solar radiation measurement should free from any obstruction above the plane of the sensing element. It should be located according to the following conditions where:

- Shadows will not be cast on it at any time;
- It is not close to light-colored walls or other objects likely to reflect sunlight onto it;

- It is not exposed to artificial radiation sources; and

- No obstruction over the azimuth range has an elevation exceeding 5° between earliest sunrise and latest sunset. It is also useful, for reference purposes, to note the instrument's altitude above mean sea level and its geographical coordinates.

Installation

When the site has been chosen, the instrument will be installed according to the appropriate method for each kind of instrument. This section deals with how to install a pyranometer, a shadow band for shaded pyranometer and a solar tracker for normal incidence pyrheliometer.

- Pyranometer

  The pyranometer should be attached to the rigid stand or to the tripod. Then the pyranometer should be oriented so that the retaining screw is located approximately south (for the Northern Hemisphere) of the receiving surface. The pyranometer should then be secured lightly with this screw. After the instrument is levelled with the aid of the levelling screws and the circular spint level is mounted on the tripod, the retaining screw should be tightened, taking care that the setting is not disturbed. When properly exposed, the receiving surface is horizontal and the leads emerge on the poleward side of the pyranometer base. The stand used should be sufficiently rigid so that severe shocks to the pyranometer will not occur throughout the periods of exposure.

- Shadow band for shaded pyranometer

  The shadow band stand should first be placed on the specially constructed supporting stand. Then it should be verified so that the N-S orientation is correct and the base is level. The latter should be secured rigidly to the supporting platform with four belts. The two wing nuts damping the side bars carrying the shadow band should be loosened and each bar reset so that the 0° mark of the declination scale engraved on the bar is scale. Both wing nuts should then be tightened.

The pyranometer should be placed on the small adjustable platform and secured. The height of this platform should be set so that the receiver of the radiation sensor is approximately in the center of the shadow band. Then the two bolts securing the horizontal bars of the stand should be loosened and the bars moved until the receiver of the sensor, as viewed through the two small holes drilled in the band, lies in the vertical plane determined by the positions of these holes. In order to obviate skewness in this setting, both bars carry similar relative scales and should be graduated from a common reference mark. Such a provision is made for the latitude and declination settings. The exact height adjustment of the sensor should be checked and the radiation sensor should be properly levelled.

- Solar tracker

The first step in setting up the tracker is the choice of location. The sight should be chosen to ensure that the tracker will be free to rotate 360°. There are four settings that have to be aligned to ensure proper tracking on the sun; North to South, latitude, declination, and the time of day.

Wind Measurements

For wind measurements, WMO has also recommended the method for observation which should be followed to ensure the reliability of the observed data.

Site survey

According to WMO recommendations, the standard exposure of a wind instrument over level, open terrain is ten meters above the ground. Where a standard exposure is unobtainable, the anemometer should be installed at such a height that its indications are reasonably unaffected by local obstructions and represent, as far as possible, what the wind at ten meters would be if there were no obstructions in the vicinity.

Installation

Installation of wind instruments can be divided into installation of wind speed sensor (anemometer) and of wind direction sensor (wind vane).

- Wind speed sensor

  - Check to see that the cup assembly rotates freely (threshold and bearing check);

- Install the sensor in the end of the mounting arm at 10 m. height;

- Tighten the locking set screws, but do not overtighten. Apply a small amount of silicone grease to the set screws to prevent "freezing up" in corrosive environments; and

- Connect the cable assembly to the keyed sensor receptable and tape it to the mounting arm.

- Wind direction sensor

  - Install the sensor in the bushing end of the mounting arm. The screw in the bushing will pass through the bushing and will be tightened into the sensor housing;

  - Loosen the two set screws holding the bushing and orient the sensor so that the counterweight is pointing south. Remove and retain shoulder screw. Check to see that the van assembly rotates freely; and

  - Connect the cable assembly to the keyed sensor receptable and tape it to the mounting arm.

D. MAINTENANCE AND CALIBRATION OF INSTRUMENTS

For continuity of observed data, maintenance of the measuring instruments is required, and for reliability of the observed data, calibration is essential. In this section maintenance and calibration of solar and wind instruments are described.

Center for Maintenance and Calibration

The maintenance and calibration for solar radiation and wind instruments was to be centralized within the Solar Radiation and Wind Calibration Center. The Center was to be equipped with standard instruments and other facilities required for maintenance and calibration of the instruments.

Standard solar radiation instruments

The standard instruments that were to be used for calibration of solar radiation instruments were the normal incidence pyrheliometer, precision spectrum pyranometer with and without shadow band, and Angstrom pyrheliometer as mentioned in the previous section.

Wind tunnel

The wind tunnel at the instruments Division of the Meteorological Department was to be overhauled with attention given to the motor drive and the pilot tube - anemometer.

All anemometers in the field were to have their manufacturer's calibration curves checked by running them in the wind tunnel prior to deployment. The anemometers currently in the field (both those deployed and maintained by the MET and those of the NEA) were to be recalled on a planned schedule for their calibration check in the wind tunnel.

Other facilities

Other facilities that might be required for maintenance and calibration of solar and wind instruments such as a data processing unit, spare parts, etc. were included in the project design.

Solar Radiation Instruments

Solar radiation instruments should always be in good condition, and for this reason, maintenance and calibration of the instruments were included in the project design as follows.

Maintenance and spares

There should be spare equipment to replace the malfunctional instruments in the field, the reason being continuity of observed data.

Calibration

Different kinds of solar radiation instruments require different methods for calibration. This section explains how the calibration for each kind of instrument was to be done.

- Calibration of the pyrheliometer

  In order to calibrate the pyrheliometer a standard is required. Two options are open: comparison with the Eppley Normal Incidence Pyrheliometer at a WMO regional center, or acquisition by the Center of the necessary instrument standard. Once the Center pyrheliometer is calibrated it will become the secondary standard.

- Calibration of the pyranometer

  A second Eppley Precision Spectral Pyranometer was to be acquired and calibrated against a primary standard. The instrument may be calibrated by the manufacturer and kept as a secondary standard for field calibration purposes at the Center only.

  Calibration of the Center pyranometer and recording system was to be carried out once a year. The pyranometer was also to be checked against the calibrated pyrheliometer by shading the pyranometer.

- Calibration of the Kipp and Zonen Thermoelectric pyranometers

  Ten thermoelectric pyranometers have been deployed by NEA. These instruments were to be calibrated by comparisons with the Center's standard pyranometer.

- Calibration of the Belfort and Weather Measure bimetallic pyranometers

  Four of the eleven bimetallic pyranometers were co-located with thermoelectric instruments. The bimetallic instruments at these locations were to be calibrated each month against the thermoelectric instrument and a calibration factor applied to the bimetallic instrument on a month-to-month basis.

Wind Instruments

Maintenance and calibration of wind instruments are necessary for continuity and reliability of the observed data.

Maintenance and Spares

For continuity of data, spare equipment was to be available at the Center.

Calibration

Calibration of wind instruments was to be done at the Center using a wind tunnel as mentioned previously. Two constant-speed, D.C. motors were to be obtained for field checks of the anemometers. The two wind speeds corresponding to the rotation rate of the motors were to represent two points on the calibration curve. All generator-type anemometers were to be checked with the constant speed motors once a year.

At the NEA automatic wind recording stations (Lambrecht type), a comparison was to be made between a calibrated instrument which has recently been put through the tunnel and the field instrument. The comparison should be conducted over a period of at least 5 days.

All calibration and comparison data for all anemometers were to be carefully compiled and recorded. Instruments which have been found to have systematic offsets were to be labelled and correction factors established and applied to existing and future data. Instruments which display random errors or malfunctions were to be repaired or returned to the manufacturer. When fixed, wind tunnel calibration was again required. Data taken by instruments with non-systematic discrepancies were to be removed from the data archives.

Regional Calibration

For accuracy of National Standard Pyrheliometer, calibration of the instrument at a WMO Regional Center is required at least once every 5 years. The nearest WMO regional center maintaining working standard pyrheliometers is Australia.

E. DATA PROCESSING

One critical objective of this project was to generate a useful set of numerical values of solar and wind energy which were to serve as a frame of reference for estimations of potential energy using the engineering specifications of the various conversion systems.

To make reliable estimates of the solar and wind energy potential of Thailand, detail is needed on a time scale shorter than one day and applicable to specific locations. Only in some instances will annual data alone be an adequate measure of the potential of the resource. The emphasis in the analytical methods is therefore on determining reliable estimates of solar and wind energy on short time and space scales. Care was exercised to devise a method whereby these short time and space scales could be extended to the larger domain.

Synoptic Classification

In order to understand how data was to be processed it is necessary to go into some detail about synoptic models as they provide the framework for the data collection process.

The study of solar and wind energy patterns in terms of synoptic models was proposed by Garstang (1981). Annual averages of wind and solar power are not sufficient to describe the resource in the strongly seasonal climate of Thailand. Seasonal variations in atmospheric circulation over Southeast Asia govern both the surface wind speeds and the amount of solar radiation received at the earth's surface.

The solar and wind power potential of Thailand needs to be defined on a seasonal and intra-seasonal time-scale together with any spatial variation in the resource, across the country, which may accompany the time changes.

The purpose of defining the resource in time and space scales which are determined by the atmospheric fields of motion is to:

- Eliminate the smoothing imposed by averaging over the annual cycle;

- Determine the magnitude of the resource in space and time as a function of atmospheric fields of motion;

- Isolate the time and space scales important to the resource to provide guidance on the assessment of the resource. For example, knowledge of the time(s) and the location(s) of the maximum values of the resource will permit efficient measurements to be made and specific applications such as crop drying to be assessed; and

- If certain atmospheric regimes can be identified as optimum energy regimes, then the general kinematic and thermodynamic properties of these regimes may be characterized in terms of a mean state for each regime. The mean state may then be used as input to numerical models capable of providing valuable estimates of the resource which are economically impossible to duplicate with measurements.

Conditions are characterized in terms of synoptic models of the atmospheric systems which control the day-to-day weather of Thailand.

Because of the monsoonal nature of the flow, classification is made in terms of the:

- SW Monsoon, and the

- NE Monsoon.

Each day is designated as a SW or NE Monsoon day according to the streamline fields over Thailand. Daily synoptic streamline charts at 2,000 ft, 5,000 ft, 10,000 ft, 15,000 ft, 18,000 ft and 20,000 ft at 00 GMT (07 TST) and 1200 GMT (1900 TST) are used as the data source.

Ambiguity in southerly (northerly) flow occurring over Thailand during the NE Monsoon (SW Monsoon) is resolved in terms of the depth of the flow.

SW Monsoon Synoptic Model

When the SW Monsoon is established, southwesterly flow extends through much of the lower troposphere (below 20,000 ft). Equatorial vortices embedded in this flow can occur singly or in extended (E to W) vortex trains. In the latter case, the asymptotes of convergence and divergence connecting the vortex centers and the neutral points may be evident in the surface pressure field as weak low pressure centers or an extended through of low pressure. The trough of low pressure is often referred to as the Equatorial Trough or Intertropical Convergence Zone (ITCZ).

The Equatorial Trough is frequently coincident with low surface wind speeds and high cloudiness. Maximum cloudiness is located over the vortex centers. The zone of cloudiness (sometimes defined in the surface pressure fields) separates the higher surface wind speed regions and lower cloudiness to the south and to the north.

Figure 1 (Annex III) illustrates a model of the equatorial vortex embedded in the 2,000 ft streamline field of the SW Monsoon. Three categories are defined for this model:

Category I: SW to S flow bounded by the equatorial trough (lower surface pressures and higher cloudiness) to the north. Note that cloudiness will increase due to convection generated by orography mainly over SW Thailand.

Category II: Equatorial Trough: zone of lower pressure and high cloudiness, linking the neutral points and vortex centers of the vortex train.

Category III: NE to NW flow bounded by the equatorial trough as defined in Category I above.

Figure 2 (Annex III) shows an example of a vortex train lying across SE Asia.

NE Monsoon Synoptic Model

When the NE Monsoon is established, high pressure systems dominate the Asian continent. The anticyclone over China produces NE outflow from the surface to above 5,000 ft. The Tibetan high lies to the west of the anticyclone over China and the subtropical Pacific anticyclone to the southwest. Ridge lines extend equatorward from these anticyclones marking the location between northerly and southerly flow. The anticyclones are separated by columns and frequently by shallow (usually less than 5,000 ft deep) cyclonic vortices.

The high pressure systems migrate slowly from west to east and shift in latitudinal position. During the transition period, the subtropical anticyclone of the western Pacific frequently encroaches upon Southeast Asia resulting in shallow southerly to southeasterly flow over Thailand. When such incursions follow a northeasterly anticyclonic outbreak, rains extend over much of southeast and northeast Thailand. The southerly flows of the NE Monsoonal period are distinguished from the southerly flow of the SW Monsoon by the fact that the former is shallow (5,000 ft and less), while the latter is deep (> 8,000 ft).

Figure 3 (Annex III) illustrates the model for the anticyclonic flow of the NE Monsoon. Streamlines are shown at 5,000 ft. Four categories are defined for this model:

<u>Category IV</u>: Northeasterly, becoming easterly in the south, flow over Thailand. The anticyclonic outflow from the high pressure (CA) over China is shallow.

<u>Category V</u>: Northerly to northwesterly outflow from the Tibetan anticyclone (TA).

<u>Category VI</u>: Southerly to southeasterly flow on the western side of the Pacific anticyclone (PA). This category includes the transitional period where southeasterlies follow northeasterlies.

<u>Category VII</u>: Anticyclonic columns or weak (shallow) cyclonic vortices separating the major anticyclonic centers.

Figure 4 (Annex III) shows an example of the NE Monsoon.

At each of the surface wind and solar radiation stations in Thailand, it is recommended that every day is classified at two synoptic hours, 00Z (0700) and 12Z (1900) according to the seven categories listed in Chapter 4, Section A for a 10 year period. The required observations are the streamline charts at 00Z and 12Z.

Frequency distributions for each category at each station will define the time changes at that location. By examining the distribution over the country (all stations), the spatial changes in categories will allow a determination of regions. Representative stations in each region can then be chosen. The wind and solar energy potential for the representative station can then be determined for each categories. A likely result is that only a few (1 to 3) categories will contain the bulk of the energy (≥ 70%). Knowledge of the time and space distribution of these dominant categories will provide:

- An assessment of the resources;
- A basis for decision on whether additional measurements are needed;

- Guidance as to where and when to make these measurements;

- Guidance on the kind of wind or solar system which should be used; and

- A framework in which numerical estimates can be carried out and applied in relatively small space scales.

Model Calculation

It appears to be evident from existing data and studies that the potential for Intermediate and Large Wind Energy Conversion Systems is confined to the Gulf of Thailand, its immediate coastline and the Indian Ocean coastal region. Work elsewhere by Garstang and his associates (Garstang et al., 1980 a, 1980 b) has shown that a mesoscale numerical model covering a domain like the Gulf of Thailand is capable of providing a reliable estimate at the locations over the coastal land and sea regions of maximum and minimum wind power potential. The studies indicated that the estimates of wind power by the model are as good as estimates based upon measurements where measurements are available. Since measurements are available at only isolated locations on land and not available at all over the sea, such model calculations are extremely valuable in the assessment of wind power potential.

Furthermore, the model predicts winds at 12 levels in the atmosphere with considerable resolution possible in the lowest 300 m. Realistic boundary layer theory is dependent upon atmospheric stability, surface roughness and heat transfers; and allows a true mean layer wind to be calculated commensurate with the height and area swept by any given potential wind turbine rotor.

Model calculations over the coastal regions of the Gulf of Thailand and over the Gulf of Thailand would be carried out for two of the dominant synoptic regimes. The area covered would be approximately 800 km x 500 km from 14° to 6° N latitude and 98° to 103° E longitude. Estimates of wind power potential would be made for at least every 20 x 20 km grid interval and possibly for every 10 x 10 km grid interval. The resolution of the model calculation would depend upon the computer core storage required by this relatively large domain.

The model would require the following representative values of the two dominant synoptic regimes:

- Large scale synoptic conditions: surface, 850 and 500 mb streamline and pressure field analyses;

- Representative rawinsonde;

- Mean latitude (°N) of domain;

- Land surface conditions:

  albedo
  roughness length
  shelter height mean temperature at initialization
  soil characteristics: density
  specific heat
  diffusivity
  wetness; and

- Sea surface conditions: sea surface temperature of both Gulf of Thailand and Indian Ocean coastal waters.

It was recommended (Garstang, 1981) that the model calculations be carried out at the National Center of Atmospheric Research (NCAR), Boulder, Colorado. The three-dimensional mesoscale numerical model is currently on the NCAR CRAY computer. Running the model at NCAR would be the most efficient approach in terms of time and money.

The consultant would supervise the model calculations and provide the products to the Thai counterpart agencies. The product would consist of spatial distributions of wind and wind power density at various levels (e.g., 10 m, 50 m, 100 m, 150 m) and integrated mean level winds (e.g., integrated over 50 and 100 m) over the domain described above. Grid intervals would be 20 x 20 km or 10 x 10 km. Tabulations of the wind power density for all grid points for each of two numerical simulations would be provided. The choice of atmospheric conditions for the two numerical simulations would be based upon the results of the synoptic classification. The two dominant wind energy regimes would then be chosen.

The results of the numerical predictions would be compared to measurements at the points where data are available. The distribution of wind power density resulting from the model calculations would provide a sound framework within which the wind power potential of the Gulf coast and over the Gulf of Thailand could be assessed. This framework would represent the basis upon which a decision could be made for the deployment of Intermediate and Large Scale WECS. In the absence of model calculation, uncertainty will persist as to the wind power potential over the coastal areas.

A cautionary note is required on the above assessment of using the 3-D model over the Gulf of Thailand and surrounding coastal regions. The model has worked best where the coastal regions have been flat. Where topography in the form of coastal mountain ranges or significant increases in the height (slopes) in the coastal plain exist, results have been less satisfactory. The topographic conditions around the Gulf of Thailand are mixed. The existence of significant mountains on the Malay Peninsula mean that the model results cannot be predicted with certainty. The opinion is that two model runs would be worthwhile in terms of the expected benefits if successful. However, this does mean that the model calculations are experimental and the results are not certain.

F. EXISTING DATA

Solar Radiation

(a) Indirect methods

Analysis of the extensive records of cloudiness, hours of sunshine, visibility and rainfall need to be carried out following in large part the methods laid out by Exell (1978) and Exell and Saricali (1976). In particular, analysis of the frequency distributions of solar energy over the day and for consecutive days with high or low solar energy should be carried out.

Estimates of global radiation from cloud records and from records of the number of hours with sunshine should be carried out separately as well as combined. The validity of the estimates of hours with sunshine, based upon observations of cloudiness, should be determined at the stations where both cloudiness and sunshine records are available. Adjustments for the effect of high cloudiness should be made by incorporating the information available on the amounts of low and middle clouds.

The estimates of global radiation from the more extensive record (in time and space) available today should be carefully compared with the results of Exell and Sarical (1976) and with the direct measurements cited below.

(b) Direct measurements

The existing measurements of global radiation made by the NEA and the Agrometeorological Division of the Meteorological Department should be carefully analyzed. The measurements made by the thermoelectric pyranometers should be analyzed separately from the measurements made by the bimetallic instruments. Comparisons should be made between the daily totals of global radiation measured by both instruments wherever these are co-located.

In the first instance, analyses should be carried out in both (a) and (b) above for time periods commensurate with those used by Exell and Saricali (1976). Analyses on different time scales are described in (c) below and should be subsequently carried out.

Comparisons of results between (a) and (b), and between (a) and (b) and Exell and Sericali (1976) should be made. Discrepancies should be noted and if possible, explained. The end result should be distributions of global radiation and estimates of direct and diffuse radiation for the time intervals used by Exell and Saricali for Thailand. The objective should be to arrive at a first estimate of the solar energy potential of Thailand. This first estimate should represent the framework from which initial planning can be made and against which future observations will be checked. Changes in this framework must be justified on sound grounds requiring additional observations and/or theoretical estimates.

(c) *Use of the synoptic classification*

The measurements and derived quantities described in (a) and (b) above should be compiled for each of the seven synoptic classes over the period (10 years) for which the synoptic classification has been carried out. In cases where the record is much shorter, such as the direct measurement of global radiation, compilation should be over the period of record.

For each category, I through VII, mean values and other statistics for each measurement or derived quantity should be obtained. Thus, category characteristics can be determined and from the knowledge of the distribution in time and space of the categories, estimates on other time and space scales can be made. This will place the existing knowledge in a format which can be interpreted on short time and space scales which then becomes compatible with the new measurements described in the Section on new data which follows.

Wind Energy

All wind records from stations with anemometers above 10 m should be re-analyzed. The analysis should take particular note of the following:

- Height changes of the anemometer at a given station: the historical record of the station should be carefully examined for any changes in height of the anemometer sensor head at that station;

- Calculate the value of the power law exponent, α, at all stations where a change in height of the anemometer took place;

- Normalize all wind speeds to a common height of 10 m keeping day (defined as sunrise + 1 hour to sunset) and night (defined as sunset to sunrise + 1 hour) separate. The calculated exponents should be used if they display a systematic seasonal and/or regional distribution. If not, then $\alpha = 0.14$ should be used;

- Compile the normalized wind speeds by synoptic category and obtain mean values, variances and standard deviations of the wind for each category;

- Rank the categories according to the magnitude of the mean wind speed in each category. Calculate the mean wind power density ($W\ m^{-2}$) for each category;

- Use the frequency distribution of categories from the 10 year sample to determine whether individual categories contain large amounts of wind energy compared to other categories;

- Determine the space and time distributions of wind power density ($W\ m^{-2}$) over Thailand according to the frequency distributions of the dominant categories;

- Obtain standard monthly mean values of wind speed and power density as well as mean values of these quantities for the same intervals of time used in the analysis of the solar energy; and

- Produce a first estimate of wind energy potential for Thailand. As for solar energy, this distribution should be regarded as the <u>first estimate</u> of the wind power potential for Thailand. Future measurements and estimates must be measured against this <u>first estimate</u> and any changes must have the support of additional observations and/or calculations.

G. NEW DATA

Solar Radiation

Analysis of the observations from the newly calibrated radiation instruments should be based upon the synoptic classification scheme. Unless the new data can be placed within the dynamic and statistical contexts of the synoptic classification, considerable time (years) would be required before an adequate sample of new data could be accumulated for analysis. By using synoptic categories, observations can be placed within each category for each day and analyzed in terms of what is known of the frequency distributions of the categories. Thus, within the space of a single SW monsoon an adequate sample of categories I, II and III at different stations will be obtained. The new measurements in the categories can be compared with the old measurements in the same categories. A rational approach for accepting or rejecting the first estimate is thus established.

Analysis of the new measurements will create a refined estimate of solar and wind resources in Thailand which will represent the basis for technical and administrative decisions.

Wind

For the same reason as explained in the analysis of new data of solar radiation, analysis of newly installed anemometers should also be based upon the synoptic classification scheme.

H. TRAINING

The existence of qualified persons is a key point for efficiency of any activity. Solar and wind energy technology is quite new for Thailand, and training is needed for qualification of personnel in this field.

In-Country Training

Meteorological Department

A training course at MET was designed to provide a foundation of basic principles of solar and wind energy for officials from various agencies involved in solar and wind energy activity. The course was to be presented on an academic level. Although it was to include many practical applications, this course was not designed to serve the purpose of providing specific technical and engineering instruction which is required in the maintenance, calibration and operation of solar and wind instruments. Such instruction was to be sought from the appropriate technical and engineering centers which have the necessary equipment and laboratory facilities to offer such courses.

The course to be offered at MET was to deal with both basic physics and physics as applied to the atmospheric system. While the course was to deal with the basic principles upon which measurements of solar and wind energy are found, it was not to deal with the technical or engineering detail of these instruments. The course was designed to deal with concepts of analysis, application and archiving of data. Duration of training was to be approximately one month.

Participants of the training were to hold, at least Bachelor's degrees in science or engineering. One training expert was required to be the lecturer.

Asian Institute of Technology

Courses offered at AIT in the fields of Energy Technology and Computer Application were to be utilized for the project. In the second year of operation, two members of the component were to be trained at AIT in Renewable Energy Resources, where one trainee would focus on energy resource and utilization (solar & wind), and the other on solar & wind instrumentation (calibration & maintenance). In the third year, three persons were to be trained as in the previous year; one in energy resource and utilization (solar & wind), and two in solar & wind utilization (calibration & maintenance). Duration for each training session was one semester, or approximately 3½ months.

Overseas Training

One of the main objectives of the Solar/Wind Resource Assessment Component was to provide calibration of solar and wind instruments which are being used in MET and other agencies. The officials who perform the tasks have to follow up the progress of theoretical and practical applications of solar and wind instruments; therefore, international training for staff members was essential.

The training courses described in "In-Country Training" were not designed to provide the specific technical detail and engineering instruction which is required for calibration, operation and maintenance of solar and wind instruments; such instruction was to be provided by engineering and technical centers equipped with facilities to carry out such training to only one or two select individuals. The content of training was to include theoretical and practical application of instruments, selection of location, installation, calibration, operation, services and maintenance.

The personnel who were to be selected were to be in supervisory positions in charge of the calibration, operation, maintenance and data collection tasks of the solar and wind energy program. Each was to hold a Bachelor's degree in engineering, physics or mathematics. Both individuals were to have completed the training course.

I. CONSULTATION

Foreign Consultant

The application of meteorology to the assessment of solar and wind energy is relatively new to Thailand, and the foreign consultant was required to:

- Evaluate the data collection system and to provide recommendations for strengthening the system; and
- Advise on the initiation of procedures for assessment of solar and wind data for energy productive use.

Local Consultant

Due to the complicated nature of the instruments, observation, and analysis of solar and wind energy, the local consultant was required to advise on:

- Calibration of instruments;
- Siting of measuring instruments;
- Processing of the data for monitoring the measurements;
- Analysis of data for assessment of solar and wind energy availability; and
- Reliability of observations.

J. COOPERATION WITH OTHER AGENCIES

Calibration of Instruments

The Center for Solar Radiation and Wind Calibration was to take care of calibration of solar and wind instruments. Instruments from any agency may be sent for calibration at the Center without charge. The existing instruments at the Observation Division and Agrometeorological Division of the Metrological Department, NEA, Electricity Generating Authority (EGAT) and universities were expected to be calibrated at the Center.

Installation of Instruments

Installation of instruments was needed to meet the requirement of additional measurement. This had to be in cooperation with Divisions in the Meteorological Department, NEA and other agencies, as necessary.

Data Collection

In addition to the measurements made by MET for meteorological purposes, measurements made by NEA and KMIT (see Chapter 2) were to be used in analysis of solar and wind energy potential. Close cooperation was to make the data available in time.

Data Processing

Within the time period of the project, it is expected that MET alone could not complete the analysis of existing and new data. The role of universities in this assessment was very important and effort was given to encourage university participation in the assessment, particularly AIT and KMIT, which are already involved in solar and wind energy technology.

K. PERSONNEL TIME COMMITMENTS

The following table reveals the time commitments and functions for project personnel.

Table 4.3 Personnel time commitments

Personnel		Year 1 (Man Months)	Year 2 (Man Months)	Year 3 (Man Months)	Total
Center for Radiation and Wind Calibration	Instr Eng	24	24	24	72
	Assist Instr Eng	24	36	24	84
Meteorological Department	Meteorologist	12	12	12	36
	Assist Meteor.	24	12	12	48
	Foreign Consultant	9	3	3	15
	Local Consultant	-	7	9	16
Total (Other than Consultant)		84	84	72	240

L. BUDGET

The budget for the project was

Technical Assistance		
	Foreign Consultantation	$ 63,000
	Services (Institution & Support)	$ 49,680
Commodities		
	Spares & Equipment	$ 51,400
	Supplies, Materials & Labor	$ 51,000
Training		
	Overseas	$ 46,500
	Local	$ 9,000
Other		
	NEA	$ 3,030
	Royal Thai Government	$ 13,800

Chapter 5

Techniques and Procedures

TECHNIQUES AND PROCEDURES

In this chapter, the techniques and procedures that were used in the Project designed to assess solar and wind energy are described. This is done section by section as it was in Chapter 4.

A. ORGANIZATION

For maximum efficiency of the operation of the project two centers of activity were established at the Meteorological Department and the Center for Solar Radiation and Wind Calibration.

Meteorological Department

The Meteorological Department represented by Meteorological Studies and Research Sub-Division, Studies and Research Division, was responsible for directing the Project. This Sub-Division consists of three meteorologists and two meteorological observers. The senior level meteorologist, Chief of the Meteorological Studies and Research Sub-Division, was designated as the Project Director.

Center for Solar Radiation and Wind Calibration

The Center was established at the Calibration Sub-Division, Instrumental Division, Bang Na Meteorological Office. It is located about 10 km from MET Head Office. The Center was assigned the responsibilities of:

- Measurements of radiation and wind at the Center;
- Calibration of radiation and wind instruments; and
- Maintenance of equipment.

The chief engineer of the Sub-Division was assigned as the supervisor of the Center. Six persons were hired on a temporary basis as assistant meteorologists and assistant engineers to help the engineer operate the Center.

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B. ADDITIONAL MEASUREMENTS

Considerable efforts were expended in determining the availability and suitability of recording, processing and sensing equipment for the Energy Assessment Program in Thailand. Results of this work led to the detailed specification of equipment and instrumentation. All of the equipment and instrumentation was shipped to Charlottesville, Virginia where it was assembled and tested by Dr. Garstang, consultant of the Project.

Programming of the data loggers was carried out, also by Dr. Garstang, for solar radiation and wind measurements for applications at the Solar and Wind Calibration Center and for field deployment. Similarly, programs were written and tested for data retrieval and interpretation. Special programs were written to yield information on the solar and wind power potential in formats which were quick to retrieve and easy to interpret. Computer program tapes and listings were provided together with instruction and maintenance manuals and tools for the equipment and instrumentation.

Solar Radiation

Following the requirements given in Chapter 4, additional measurements were taken on direct radiation, global radiation and diffuse radiation.

Direct radiation

The instrument for measuring direct radiation is Eppley Normal Incidence Pyrheliometer (NIP). The instrument was attached to an electrically driven equatorial mount and recorded on a cassette tape recorder controlled by a data logger.

Global radiation

The Eppley Precision Spectral Pyranometer (PSP) recorded on a tape recorder and data logger the same as the NIP.

Diffuse radiation

The Eppley Precision Spectral Pyranometer (PSP) was mounted with a shadow band recording on the same system as the NIP and PSP above.

Wind

The additional measurements for wind are wind speed and direction and mobile tower.

Wind speed and direction

Wind speed and wind direction are measured by MET - One Wind Speed Sensor and MET - One Wind Direction Sensor of Campbell Scientific, Inc. The measured data were recorded on a cassette tape recorder controlled by data logger.

Profile measurements

Profile measurements were not approved by USAID, so it was not included in the operation.

Mobile tower

A mobile tower was designed by Dr. Garstang and constructed under the supervision of the project engineer and the Instruments Division workshop. The mobile tower extends to 10 m and can be used at lower heights. It is further designed to accommodate temperature as well as wind speed measurements at two levels.

The mobile tower may be used with a single measurement (wind speed) to survey new sites or obtain site details or it may be used to intercompare with existing sites at the site anemometer level (3.1 m) and simultaneously record wind and temperature at both the 3.1 m and 10 m levels. The purpose here is to obtain information on the height dependence of the wind and to develop appropriate height corrections to the low level wind measurements.

C. MEASUREMENTS METHODS

Measurements of solar radiation and wind are done at the Center and in the field.

Center for Solar Radiation and Wind Calibration

The Center makes observation for both solar radiation and wind. The objectives of the observation are for data collection and calibration of instruments.

Solar radiation

Solar radiation measurements at the Center are direct radiation, global radiation and diffuse radiation. These instruments were installed on the roof of the Calibration Center to serve as radiation reference standard instruments.

- Direct radiation

  An Eppley Normal Incidence Pyrheliometer (NIP) attached to an electrically driven equatorial mount and recording on a cassette tape recorder controlled by a data logger was installed.

- Global radiation

  An Eppley Precision Spectral Pyranometer recorded on the same tape recorder and data logger as the NIP.

- Diffuse Radiation

  An Eppley Precision Spectral Pyranometer (PSP) was mounted with a shadow band, recording on the same system as the NIP and PSP above.

In addition to these three instruments, two existing Angstrom Pyrheliometers of MET, serving as National Standard Pyrheliometers, are also used for direct radiation measurement.

Wind

Wind speed and direction systems were installed to serve as a reference for field units. Exposure of this system on the roof of the Calibration Center precludes its use as a valid measurement of ambient wind. The system, however, can serve as an intercomparison reference to a field unit placed next to it. This wind system with its data logger also serves as the unit on the mobile tower.

Solar Radiation Measurements

The measurements of solar radiation were taken in two steps as described in Chapter 4. They were site survey and installation.

Site survey

The site surveys for solar radiation measurements were performed as follows:

Place	Parameter	Date
Chiang Mai	global radiation	7 April 1983
Songkhla	global radiation	23 May 1983
Chiang Mai	net radiation	19 January 1984
Ubon Ratchathani	global radiation	16-17 May 1984
Khon Kaen	global radiation	31 May 1984

Installation

Installation of solar radiation instruments were made as follows:

Place	Instruments
Center for Solar and Wind Calibration, Bang Na	- Eppley black and white pyranometer. - Eppley precision spectrum pyranometer with shadow band. - Eppley normal incidence pyrheliometer with solar tracker.
Northern Regional Weather Forecasting Center, Chiang Mai	- Eppley black and white pyranometer.
North-Eastern Regional Weather Forecasting Center, Ubon	- Eppley black and white pyranometer.
Southern Regional Weather Forecasting Center, Had Yai, Songkhla	- Eppley black and white pyranometer.
Khon Kaen	- Eppley black and white pyranometer.
Surat Thani	- Eppley black and white pyranometer.

Wind Measurement

The measurements of wind are done as described in Chapter 4: site survey and installation.

Site survey

The site surveys for wind measurement were done as follows:

Place	Date
Bangkok Pilot Station	22 March 1983
Pattaya	26 April 1983
Nakorn Sawan	9 May 1983
Phuket	18-19 June 1983
Ubon Ratchathani	16-17 May 1984
Khon Kaen	31 May 1984
Tak	27 June 1984

Installation

The cup anemometer and wind vane from Campbell Scientific Inc. were installed and are presently used for wind measurement at:

- Center for Solar Radiation and Wind Calibration, Bang Na;
- North-Eastern Regional Weather Forecasting Center, Ubon Ratchathani;
- Khon Kaen;
- Maha Sarakharm (NEA);
- Nakhon Sawan;
- Ratchaburi (NEA);
- Pattaya;
- Rayong;
- Phuket; and
- Surat Thani.

D. MAINTENANCE AND CALIBRATION OF INSTRUMENTS

Maintenance and calibration of instruments were done by the Solar Radiation and Wind Calibration Center. The calibrated instruments were from MET and other agencies.

Center for Maintenance and Calibration

The Solar Radiation and Wind Calibration Center was assigned for maintenance and calibration of solar radiation and wind instruments of the Project, MET, and other agencies as requested.

Standard solar radiation instrument

The solar radiation instruments at the Center are as follow:

- 1 Eppley normal incidence pyrheliometer;
- 1 Eppley precision spectral pyranometer with shadow band;
- 1 Eppley precision spectral pyranometer; and
- 3 Eppley black and white pyranometers.

The instruments above serve as National Standard Instruments for solar radiation measurement and were used for calibration of solar radiation instruments (thermopile) at the Center. The three Eppley black and white pyranometers serve as the secondary standard for field calibration of bimetallic-type solar instruments.

Wind tunnel

An existing closed circuit wind tunnel was renovated by the project engineer and Instrument Division workshop under supervision of Dr. Garstang. Calibration instrumentation (pilot tube and manometer) were purchased from the manufacturer in the USA.

Other facilities

The Solar Radiation and Wind Calibration Center is also equipped with automatic wind speed and wind direction sensors as mentioned previously. Four small-size wind sensor units were available at the Center to be used as spare equipment. In addition, there were two Hewlett-Packard HP-85 micro-computers at the Center. One of them was used as a data recovery unit to transfer recorded data on cassette tape into a computer cartridge or to print-out hard copy. The other was used to make calculations for the calibration of instruments.

Solar Radiation Instruments

In order to have continuous and reliable data, instruments were calibrated and maintained.

Maintenance

Maintenance of solar radiation instruments at Bang Na, Chiang Mai and Had Yai was accomplished as follows:

Station	Time
Bang Na	Continuously
Chiang Mai	1. 6-10 June 1983
	2. 27 July 1983
	3. 24-27 October 1983
	4. 12-13 November 1983
	5. 7-9 December 1983
	6. 22-24 February 1984
	7. 13-14 May 1984
	8. 12-13 June 1984
	9. 6-13 August 1984

Station		Time
Had Yai	1.	12 August 1983
	2.	1-2 September 1983
	3.	30 September 1983
	4.	7-19 November 1983
	5.	9 December 1983
	6.	14 January 1984
	7.	5 February 1984
	8.	22 May 1984
Roi-Et (MET)		27 January 1984
Nong Khai (NEA)		26 July 1983
Udorn Thani		6 April 1984

Calibration

Calibration of solar radiation instruments was performed at the Center for Solar Radiation and Wind Calibration and in the field. At the Center, the calibration of solar radiation instruments was as follows:

Calibration at the Center

Instrument	Date
1. Kipp & Zonen Pyranometer	
- NEA (6)	15 February 1983 (1) 30 May 1983 (2) 1 July 1983 (1) 22 May 1984 (2)
- EGAT (2)	16 January 1984 (1) 4 April 1984 (1)
- Chiang Mai Univ. (1)	2 February 1984
- KMIT (1)	3 April 1984
2. Rimco Pyranometer	
- Agrometeorological Division, MET (10)	February 1983 (6) 12 June 1983 (4)
3. Actinometers	
- Observation Division, MET (1)	24 June 1983

The calibration of solar instruments in the field was performed as follows:

Calibration in the field

(Bimetallic Pyranometer)

Place	Date
Loei (NEA)	8 Mar 83, 16 Feb 84
Udorn Thani (NEA)	12 Apr 83, 24 Mar 84
Nong Khai (NEA)	19 May 83, 28 Apr 84
Mukdahan (NEA)	12 Oct 83, 24 Jun 84
Chiang Rai (NEA)	4 May 83, 12 May 84
Ko Samui (NEA)	16 Jun 83

Wind Instruments

As well as solar radiation instruments, wind instruments were maintained and calibrated for the purpose of continuity and reliability of data.

Maintenance

The maintenance of wind instruments was performed at the following stations:

Place	Date
1. Bang Na	Continuously
2. Nakorn Sawan	1. 27-28 Nov 83 2. 21-22 Feb 84 3. 16 May 84 4. 17 Jun 84 5. Aug 84
3. Rayong	1. 19-20 Aug 83 2. 16 Sep 83 3. 19-20 Oct 83 4. 18 Jan 84 5. 14 Mar 84 6. 17-18 Apr 84 7. 22-25 May 84 8. Aug 84

Place	Date
4. Pattaya	1. 16-18 Aug 83
	2. 14-15 Sep 83
	3. 17-18 Oct 83
	4. 20 Jan 84
	5. 16 Mar 84
	6. 19 Apr 84
	7. 22 May 84
	8. Aug 84
5. Phuket	1. 25 Sep 83
	2. 1-3 Oct 83
	3. 20-22 Nov 83
	4. 12 Jan 84
	5. 5-9 Mar 84
	6. 10-11 Apr 84
	7. 24-26 May 84
	8. 26-28 Jun 84
	9. Aug 84

Calibration

Calibration of wind instruments was performed by bringing the instruments from observing stations to the calibration center. Calibrations were performed at the following stations:

Nakhonsithammarat	Songkhla	Had Yai
Trang	Takua Pa	Phuket Airport
Phuket	Satun	Narathiwat
Surat Thani	Pattani	Ranong
Chumphon	Prachuap Khiri Khan	Hua Hin
Lop Buri	Chaiyaphum	Loei
Nong Khai	Khon Kaen	Roi-Et
Sakon Nakhon	Ubon Ratchathani	Nakhon Ratchasima
Lamphun	Mae Sariang	Mae Hong Son
Chiang Mai	Phrae	Nan
Phayao	Chiang Rai	

Regional Calibration

National Standard Pyheliometers were calibrated with WMO Regional Radiation Center, CRISRO, Division of Atmospheric Research, Australia during March 6-25, 1984.

E. DATA PROCESSING

Most of the data processing was done following Dr. Garstang's design as described in Chapter 4. Model calculation was excluded from the program owing to its expense. The MET did not have the human resources and facilities to handle the processing of data, so KMIT and Dr. Exell of AIT were hired to do the data processing. Details of the data processing process are provided in Chapter 6.

F. TRAINING

Training can be divided into in-country and overseas training.

In-Country Training

In-country training was done at MET and AIT. Each program was different in nature as mentioned in Chapter 4.

Meteorological Department

Twenty three persons attended the training course entitled "Solar and Wind Resources", from December 12, 1983 to January 6, 1984. Lectures were given by Dr. Michael Garstang. Participants of the training were: from MET (15), from the Department of Science Service (1), from KMIT (2), from the Thailand Institute of Scientific and Technical Research (1), from the Electricity Generating Authority of Thailand (11), and from the NEA (3). In addition to these participants, observers from MET, KMIT, and AIT also attended the training.

Asian Institute of Technology

Two officials from MET were trained at AIT during December 1983 - April 1984. One attended courses at the Energy Technology Division; the other attended courses at the Computer Application Division.

Overseas Training

All overseas training was cancelled due to a delay in correspondence between DTEC and institutions in the USA.

G. BUDGET

The total expenditure of the project was approximated to be ฿6,457,835 from the USAID and ฿277,231 from the RTG.

Chapter 6

Analysis of Results

ANALYSIS OF RESULTS

The analysis of solar radiation and wind energy was divided into two cases -- existing data and new data.

A. EXISTING DATA

The analysis of existing data was performed by KMIT under a contract with the MET. The results of the analysis were published under the title "Solar and Wind Energy Potential Assessment", (Suwantrakul et al., 1984). A brief description of the analysis is provided below.

Synoptic Classification

The distribution of the occurence of each synoptic category in Thailand, developed by Garstang, was analyzed. The results show that Category I (SW to S flow bounded by the equatorial trough to the north) and Category IV (northeasterly, becoming easterly in the south, flow over Thailand) are the dominant categories. They occur 72 to 86 percent of the year. Category VII, which represents anticyclonic or weak cyclonic vortices, occurs less than 0.6 percent of the year.

Solar Energy Assessment

Regression coefficients relating the global radiation and sunshine hours at 10 meteorological stations were obtained from simple linear regression analysis. It was then assumed that there exist relationships between these regression coefficients and station latitude. The coefficients of 20 meteorological stations were subsequently obtained by linear interpolation and extrapolation using the established relationship of 10 reference stations. Estimated values of global solar radiation at these 20 meteorological stations were calculated by making use of the acquired regression coefficients and measured sunshine hour data. Radiatio maps of Thailand were prepared from the estimated radiation values. The results show that mean global solar radiation is generally high. Use of solar energy can be made for most applications throughout Thailand.

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Wind Energy Assessment

Surface wind speed data from 62 meteorological stations over 17 years (1966-1982) have been used to assess wind energy availability. Using logarithmic law, the data were normalized to a height of 10 meters and analyzed to give mean wind speed, frequency distribution, power density and Weibull parameters, both excluding and including the calm period. A wind map of Thailand has been prepared. The results show mean wind speed (including a non-calm period) ranging from 5-17 km/hr and varying with location and time. Use can be made of the wind power for water pumping and wind power for electricity generation can be utilized in some specific areas.

B. NEW DATA

The analysis of solar and wind energy data for the year 1983 was performed by Dr. R.H.B. Exell of AIT. The analysis was published separately under the title "Solar and Wind Energy Data of Thailand 1983", (Exell and Sukawat, 1984). A brief description of the analysis is given below.

Solar Energy Assessment

Statistical summaries of specialized solar radiation observations made in Thailand during 1983 were analyzed. The data include hourly observations of direct, global and diffuse solar radiation in Bangkok (Bang Na) and hourly observations of global solar radiation in Chiang Mai and Had Yai. Additional solar radiation data from NEA were used for supplementation. The results of the analysis show that the mean daily solar energy is typically in the range of 10-20 MJ/m^2.

Wind Energy Assessment

Hourly wind observations during 1983 in Bang Na, Pattaya, Rayong and Phuket were analyzed. Wind data obtained from weather observing stations of MET in Chiang Mai, Ubon Ratchathani, Bangkok Pilot Station and Had Yai were used as additional information. Upper wind data from Bang Na were also included in the analysis. It was found that the mean daily wind energy at well-exposed coastal sites can reach the same level as that of solar energy (10-20 MJ/m^2) in some seasons, but is usually less than 5 MJ/m^2.

Chapter 7

Conclusions

CONCLUSIONS

1. The activities of the solar/wind assessment component were centered at the Meteorological Research Sub-Division, Studies and Research Division, Meteorological Department.

2. The Center for Solar Radiation and Wind Calibration was established at the Calibration Sub-Division, Instrumental Division, Bang Na Meteorological Office.

3. Additional measurements are done at 6 stations for solar radiation, and 10 stations for wind. All additional measurements are automatically recorded by dataloggers.

4. There is a problem with continuity of data recorded by the datalogger due to instrument malfunction.

5. Calibration of solar and wind instruments faced problems because of time limitations, human resources and spare instruments.

6. National standard solar radiation instruments were calibrated at WMO Regional Centers in Australia.

7. Maintenance of solar instruments, wind instruments, and a data-logger is hindered by the problem of unavailable spare parts within Thailand.

8. Analysis of existing data by KMIT and new data by Dr. Exell of AIT was completed and published as separate technical reports.

9. In-country training was mostly completed as it was planned, but overseas training was cancelled due to the delays at DTEC.

10. Foreign and local consultants proved very useful.

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CHAPTER 8

Recommendations

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RECOMMENDATIONS

1. Additional measurements of solar radiation and wind should be taken (both in space and time) to yield more representative data for further research.

2. The datalogger used in automatic data recording should be modified for more durability. Spare parts should be sufficiently supplied to ensure continuity of recorded data.

3. Qualified researchers and operators should be assigned to carry on project activities, and should be trained to be able to do the job without the assistance of a consultant.

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ANNEX I

MET AND NEA STATION LOCATIONS

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ANNEX I

Table 1.1 Cloudiness Observation Stations

Station Number	Elevation (MSL)	Time of Observations 00	03	06	09	12	15	18	21	Units	Data Available From	Remarks and Site Location
48-300	267	X	X	X	X	X	X	X	X	0-8	1941	Airport
303	394	X	X	X	X	X	X	X	X	0-8	1932	Airport
310	377	X	X	X	X	X				0-8	1980	
315	235	X	X	X	X	X				0-8	1966	Beside the town
325	212	X	X	X	X	X		X		0-8	1949	Town
327*	312	X	X	X	X	X	X	X	X	0-8	1951	*Near airport Half-hourly 00-24
328	241	X	X	X	X	X	X	X	X	0-8	1943	Airport boundary
329	296	X	X	X	X	X		X		0-8	1980	Farmland
330	161	X	X	X	X	X		X		0-8	1952	Airport
331	200	X	X	X	X	X	X	X	X	0-8	1944	Airport
351	63	X	X	X	X	X		X		0-8	1937	Town
352	174	X	X	X	X	X		X		0-8	1954	Airport
353	253	X	X	X	X	X	X	X	X	0-8	1954	
354	177	X	X	X	X	X	X	X	X	0-8	1936	Airport
356	171	X	X	X	X	X	X	X	X	0-8	1947	Town
357	142	X	X	X	X	X		X		0-8	1942	Airport boundary
375	196	X	X	X	X	X	X	X	X	0-8	1936	Airport
376	121	X	X	X	X	X		X		0-8	1954	Airport
377	142	X	X	X	X	X		X		0-8	1959	Dam
378	44	X	X	X	X	X	X	X	X	0-8	1936	Town
379	114	X	X	X	X	X	X	X	X	0-8	1950	Town
380	80	X	X	X	X	X		X		0-8	1980	Town
381	165	X	X	X	X	X	X	X	X	0-8	1944	Town
383	138	X	X	X	X	X		X		0-8	1956	Town
400	34	X	X	X	X	X	X	X	X	0-8	1938	Airport
403	182	X	X	X	X	X		X		0-8	1956	Town
405	140	X	X	X	X	X		X		0-8	1943	Town
407*	123	X	X	X	X	X	X	X	X	0-8	1951	*Airport Half-hourly 00-24
413	68	X	X	X	X	X				0-8	1965	Town
416	127	X	X	X	X	X				0-8	1966	Town
418	48	X	X	X	X	X				0-8	1965	Clear forest
421	97	X	X	X	X	X				0-8	1965	Town
425	7	X	X	X	X	X		X		0-8	1937	Town
426	10	X	X	X	X	X		X		0-8	1943	Town
430	5	X	X	X	X	X		X		0-8	1937	Town
431	187	X	X	X	X	X	X	X	X	0-8	1936	Town
432	146	X	X	X	X	X	X	X	X	0-8	1943	
450	28	X	X	X	X	X		X		0-8	1943	Town
459*	2	X	X	X	X	X	X	X	X	0-8	1943	*Metropolis Hourly 00-24
456*	4	X	X	X	X	X	X	X	X	0-8	1938	*Airport Half-hourly 00-24
459	1	X	X	X	X	X		X		0-8	1943	Town
460	25	X	X	X	X	X		X		0-8	1958	Island
461	59	X	X	X	X	X	X	X	X	0-8	1980	Hillside near the beach
462	47	X	X	X	X	X	X	X	X	0-8	1937	Town
469	2	X	X	X	X	X		X		0-8	1977	Beach
475	5	X	X	X	X	X	X	X	X	0-8	1940	Beach
477	16	X	X	X	X	X	X	X	X	0-8	1951	Airport
478	3	X	X	X	X	X	X	X	X	0-8	1980	Beach
480	3	X	X	X	X	X	X	X	X	0-8	1937	Town
500	4	X	X	X	X	X	X	X	X	0-8	1937	Beach
501	2	X	X	X	X	X		X		0-8	1944	Beach
517	3	X	X	X	X	X	X	X	X	0-8	1940	Town
532	7	X	X	X	X	X	X	X	X	0-8	1943	Town
550	5	X	X	X	X	X		X		0-8	1967	Island
551	10	X	X	X	X	X		X		0-8	1954	Airport
552	7	X	X	X	X	X		X		0-8	1943	Airport
561	3	X	X	X	X	X		X		0-8	1979	Beside the town
565	6	X	X	X	X	X	X	X	X	0-8	1952	Airport
566	2	X	X	X	X	X				0-8	1981	Island
567	14	X	X	X	X	X	X	X	X	0-8	1945	Airport
568*	4	X	X	X	X	X				0-8	1951	*Navy airport Hourly 00-12
569*	27	X	X	X	X	X	X	X	X	0-8	1973	*Airport Half-hourly 00-24
570	4	X	X	X	X	X	X	X	X	0-8	1977	Farmland
580	5	X	X	X	X	X		X		0-8	1964	Airport
583	2	X	X	X	X	X	X	X	X	0-8	1958	Town
564	2	X	X	X	X	X		X		0-8	1937	Town

ANNEX I

Table I.2 Sunshine Duration Observation Stations

Station Number	Elevation (MSL)	Recorded Data	Units	Data Available From	Remarks and Location Site
48-303	394		Hours	1964	Airport
327	312		Hours	1951	Near airport
353	253		Hours	1960	
356	171		Hours	1960	Town
357	140		Hours	1964	Airport boundary
376	121		Hours	1980	Airport
377	142		Hours	1975	Dam site
378	44		Hours	1953	Town
379	114		Hours	1976	Town
381	165	Hourly	Hours	1957	Town
400	34	Daily	Hours	1956	Airport
405	140	Monthly	Hours	1960	Town
407	123		Hours	1955	Airport
432	146		Hours	1960	
455	2		Hours	1943	Metropolis
461	59		Hours	1980	Hillside near beach
475	5		Hours	1956	Beach
478	3		Hours	1980	Beach
480	3		Hours	1957	Town
551	10		Hours	1957	Airport
565	6		Hours	1956	Airport
568	4		Hours	1957	Navy airport

ANNEX I

Table I.3 Measurements Made at Hydrological Station by NEA

Number	Station	Amphoe	Changwat	Latitude	Longitude	Elevation MSL (m)	Wind Recorder (Automatic)	Wind Recorder	Sunshine	Radiation (Bimetalic)	Radiation (Thermoelectric)
1	Mae Kok	Muang	Chiang Rai	14°56.6'N	99°51.0'E	400	1/77	1/1/77	11/20/76	11/15/75	
2	Sampantakit Farm	Muang	Chiang Rai	19°56.0'N	99°55.0'E	390		1/1/71	1/1/72		
3	Mae Suai Dam Site	Mae Suai	Chiang Rai	19°42.0'N	99°31.2'E	480		7/15/76			
4	Chiang Saen	Chiang Saen	Chiang Rai	20°16.4'N	100°06.0'E	370	10/78	1/1/72	6/5/74		
5	Municipality School	Muang	Phayao	19°10.1'N	99°54.6'E	392		12/17/73	1/1/72		
6	Huai Mae Pong Dam Site	Dok Kham Tai	Phayao	19°04.4'N	100°07.0'E	859		10/11/73	5/15/74		
7	Ban Huai Tham	Dok Kham Tai	Phayao	19°04.4'N	100°04.4'E	430		10/11/73	5/15/74		
8	Chiang Mai	Mae Rim	Chiang Mai	18°56.7'N	98°56.7'E		12/77	12/1/77	12/14/77	2/14/78	1979
9	Ban Mae Ai	Mae Ai	Chiang Mai	20°01.7'N	99°18.4'E	460	1/75	1/1/71	1/1/71		
10	Chiang Khan	Chiang Khan	Loei	17°53.8'N	101°40.1'E	212	10/78	3/1/74		7/1/77	
11	Nong Khai	Muang	Nong Khai	17°52.6'N	102°43.2'E	168	8/78	2/15/72	1/1/72	7/14/77	
12	Ban Som Sa At	Muang	Nong Khai	17°36.5'N	102°44.1'E	169		5/25/73			
13	Ban Tha Bo	Tha Bo	Nong Khai	17°51.3'N	102°36.5'E	169		11/17/78			
14	Ban Na Si	Ban Pha	Udon Thani	17°33.4'N	102°33.4'E	194		5/19/73			
15	Ban Thuan	Ban Pha	Udon Thani	17°33.9'N	102°40.7'E	180		5/21/73	9/13/75	10/1/75	
16	Ban Dong Yen	Ban Pha	Udon Thani	17°34.9'N	102°41.7'E	177		6/11/73			
17	Ban Sri Bun Ruang	Phen	Udon Thani	17°35.4'N	102°43.1'E	172		8/1/73			
18	Khon Kaen	Muang	Khon Kaen	16°20.0'N	102°51.0'E	165	8/78	1/1/62	12/19/75	9/1/76	1979
19	Mukdahan (Na Pho)	Mukdahan	Nakhon Phanom	16°34.8'N	104°44.2'E		8/78	9/3/76	8/18/80	5/11/77	
20	Ubon	Muang	Ubon Rat-chathani	15°13.3'N	104°51.7'E	120	9/76	1/1/62	3/11/80	12/1/75	1979
21	Khong Chaim	Khong Chaim	Ubon Rat chathani	15°19.9'N	105°30.0'E	109		9/11/75			
22	Chachoengsao	Bang Khla	Chachoeng-sao	13°40.1'N	101°13.4'E		3/78	3/1/77	7/1/79	7/28/78	1979
23	Ban Bang San	Phanom	Surat Thani	8°46.3'N	98°47.4'E	25		8/1/72			
24	Ban La Mai	Ko Samui	Surat Thani	9°28.0'N	100°04.3'E	50	9/75	9/12/75	10/9/76	12/17/76	
25	Ban Khlong Muang	Muang	Krabi	8°02.7'N	98°45.9'E	20	11/75	11/1/75	11/25/76	12/1/76	
26	Ban Hin Pha	Ac Luk	Krabi	8°32.9'N	98°44.7'E	37		5/4/75			
27	Tak	Muang	Tak	16°53.0'N	99°09.0'E	121					1/1980
28	Nakhon Sa Wan	Muang	Nakhon Sa Wan	15°48.0'N	100°10.0'E	34					1/1980
29	Nakhon Ratchasima	Muang	Nakhon Rat-chasima	14°58.0'N	102°05.0'E	120					1/1980
30	Prachup Khiri Khan	Muang	Prachup Khiri Khan	11°48.0'N	99°48.0'E	4					1/1980
31	Bangkok	Bangkok	Bangkok								1/1980
32	Songkhla University	Muang	Songkhla								1/1980

Table I.4 Surface Wind Measurements Made at Meteorological Stations

Index Number	Name	Latitude/Longitude	Height of Anemometer (m)	Height AMSL (m)	Type	Frequency Read	Installation Date
48-300	Mae Hong Son	19°18'N/97°50'E	15.00	267.26	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	17 October 1941 17 December 1967
303	Chiang Rai	19°53'N/99°50'E	13.00	394.28	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	28 December 1941 27 October 1970
328	Lampang	18°17'N/99°31'E	12.30	240.84	Dines Anemometer	3 hrs (0100-2200)	23 September 1953
331	Nan	18°46'N/100°46'E	10.50	200.09	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	27 November 1959 27 October 1970
375	Mae Sot	16°40'N/98°33'E	14.00	210.00	Rotating (SIAP)	3 hrs (0100-2200)	27 February 1967
378	Phitsanulok	16°47'N/100°16'E	12.50	44.11	Dines Anemometer Rotating (SIAP)	3 hrs (0100-2200)	18 October 1953 10 October 1978
379	Phetchabun	16°26'N/101°09'E	11.43	117.93	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	15 June 1961 26 October 1970
353	Loei	17°27'N/101°44'E	11.30	252.52	Pressure plate	3 hrs (0100-2200)	23 April 1954
354	Udon Thani	17°23'N/102°48'E	17.50	176.98	Dines Anemometer Rotating (Lambrecht)	3 hrs (0100-2200)	6 April 1954 3 December 1963
356	Sakon Nakhon	17°09'N/104°08'E	14.50	172.00	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	1 September 1954 15 March 1972
381	Khon Kaen	16°26'N/102°50'E	14.50	154.63	Rotating (R. Fuess) Rotating (SIAP)	3 hrs (0100-2200)	14 December 1966 20 May 1977
431	Nakhon Ratchasima	14°58'N/102°05'E	12.20	188.00	Dines Anemometer Rotating (SIAP)	3 hrs (0100-2200)	5 March 1954 13 March 1979
432	Surin	14°53'N/103°30'E	11.10	145.00	Presure plate Rotating (SIAP)	3 hrs (0100-2200)	7 September 1959 1 May 1977
400	Nakhon Sawan	15°48'N/100°10'E	15.00	28.00	Aerovane	3 hrs (0100-2200)	4 February 1961
425	Suphan Buri	14°28'N/100°08'E	15.80	7.00	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	10 September 1955 8 September 1976
450	Kanchanaburi	14°01'N/99°32'E	11.40	28.00	Pressure plate	3 hrs (0100-2200)	2 August 1959
460	Ko Sichang	13°10'N/100°48'E	20.00	24.90	Pressure plate	3 hrs (0100-2200)	15 December 1961
462	Aranyaprathet	13°42'N/102°35'E	14.70	47.00	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	5 March 1941 15 October 1973
480	Chanthaburi	12°36'N/102°07'E	12.00	4.00	Dines Anemometer Rotating (N&Z)	3 hrs (0100-2200)	23 April 1956 3 April 1961
475	Hua Hin	12°35'N/99°57'E	13.48	5.00	Aerovane Dines Anemometer	3 hrs (0100-2200)	13 October 1960 20 January 1965
500	Prachuap Khiri Khan	11°50'N/99°50'E	13.90	3.50	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	22 June 1943 21 May 1973
517	Chumphon	10°29'N/99°11'E	15.00	2.89	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	28 December 1941 16 October 1969
551	Surat Thani	09°07'N/99°21'E	12.50	10.00	Dines Anemometer	3 hrs (0100-2200)	12 February 1957
583	Narathiwat	06°25'N/101°49'E	10.78	3.57	Pressure plate Rotating (SIAP)	3 hrs (0100-2200)	11 June 1958 28 February 1978
532	Ranong	09°59'N/98°37'E	7.90	6.17	Rotating (SIAP)	3 hrs (0100-2200)	27 January 1969
565	Phuket Airport	08°07'N/98°19'E	12.50	4.77	Rotating (SIAP)	3 hrs (0100-2200)	28 January 1975
325	Mae Sariang	18°10'N/97°56'E	10.00	211.04	Rotating (SIAP)	0100, 0700, 1000, 1300, 1600, 1900	27 October 1970
330	Phrae	18°10'N/100°10'E	14.50	160.78	Pressure plate Rotating (SIAP)	0100, 0700, 1000, 1300, 1600, 1900	21 August 1956 29 October 1970

Table I.4 (Continued)

Index Number	Name	Latitude/Longitude	Height of Anemometer (m)	Height AMSL (m)	Type	Frequency Read	Installation Date
48-351	Uttaradit	17°37'N/100°06'E	14.36	62.81	Pressure plate	0100, 0700, 1000,	28 December 1961
					Rotating (SIAP)	1300, 1600, 1900	27 October 1970
376	Tak	16°53'N/99°09'E	16.00	114.89	Pressure plate	0100, 0700, 1000,	21 August 1956
					Rotating (SIAP)	1300, 1600, 1900	1 June 1974
377	Bhumibol Dam	17°15'N/99°01'E	11.00	160.45	Pressure plate	0100, 0700, 1000,	20 August 1959
					Rotating (SIAP)	1300, 1600, 1900	25 January 1977
357	Nakhon Phanom	17°25'N/104°47'E	13.80	140.00	Rotating (SIAP)	0100, 0700, 1000, 1300, 1600, 1900	1 November 1970
383	Mukdahan	16°32'N/104°43'E	10.50	138.00	Pressure plate	0100, 0700, 1000,	15 September 1959
					Rotating (SIAP)	1300, 1600, 1900	6 January 1978
403	Chaiyaphum	15°48'N/102°02'E	14.50	181.00	Pressure plate	0100, 0700, 1000,	10 August 1959
					Rotating (SIAP)	1300, 1600, 1900	27 March 1974
405	Roi Et	16°03'N/103°41'E	13.00	14[illegible].00	Rotating (R. Fuess)	0100, 0700, 1000,	18 March 1954
					Rotating (SIAP)	1300, 1600, 1900	1 July 1977
426	Lop Buri	14°48'N/100°37'E	14.50	13.00	Pressure plate	0100, 0700, 1000,	7 February 1966
					Rotating (SIAP)	1300, 1600, 1900	12 May 1973
430	Prachin Buri	14°03'N/101°22'E	11.50	4.99	Pressure plate	0100, 0700, 1000	18 August 1959
					Rotating (SIAP)	1300, 1600, 1900	10 September 1976
459	Chonburi	13°22'N/105°09'E	12.00	3.00	Pressure plate	0100, 0700, 1000,	15 November 1943
					Rotating (SIAP)	1300, 1600, 1900	10 July 1973
552	Nakhon Si Thammarat	08°28'N/99°58'E	15.00	7.00	Pressure plate	0100, 0700, 1000,	22 June 1955
					Rotating (SIAP)	1300, 1600, 1900	26 March 1973
567	Trang	07°31'N/99°31'E	11.15	14.32	Pressure plate	0100, 0700, 1000,	22 October 1958
					Rotating (SIAP)	1300, 1600, 1900	25 June 1967
327	Chiang Mai	18°47'N/98°59'E	15.00	313.13	Dines Anemometer	Hourly (0000-2400)	19 June 1953
					Rotating (SIAP)		16 January 1976
407	Ubon Ratchathani	15°15'N/104°52'E	12.30	123.00	Dines Anemometer	Hourly (0000-2400)	1 September 1954
					Rotating (SIAP)		9 July 1975
568	Songkhla	07°12'N/100°36'E	14.25	4.75	Rotating (SIAP)	Hourly (0000-2400)	11 September 1973
455	Bangkok Metropolis	13°44'N/100°34'E	23.38	2.30	Dines Anemometer	Hourly (0000-2400)	1 June 1947
					Rotating (SIAP)		15 December 1962
501	Khlong Yai	11°46'N/102°53'E	15.00	6.00	Pressure plate	0700, 1000, 1300,	16 April 1957
					Rotating (SIAP)	1600, 1900	6 April 1978
456	Donmuang	13°55'N/100°36'E	18.80	11.60	Rotating (Koshin Vane)	Half hourly	15 October 1968

SIAP = Societa Italiana Appariech Precisione
N&Z = Negretti and Zambra

ANNEX II

MAPS OF STATIONS

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Figure II.1

Map Showing Solar Radiation Stations of the Project

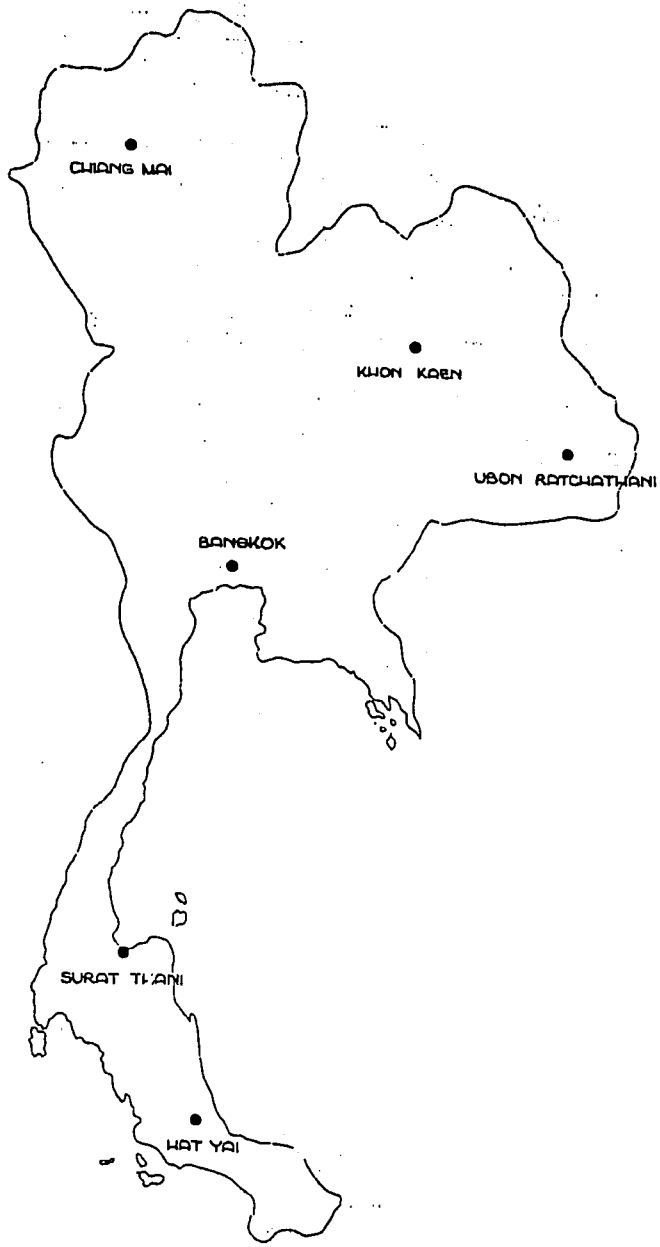

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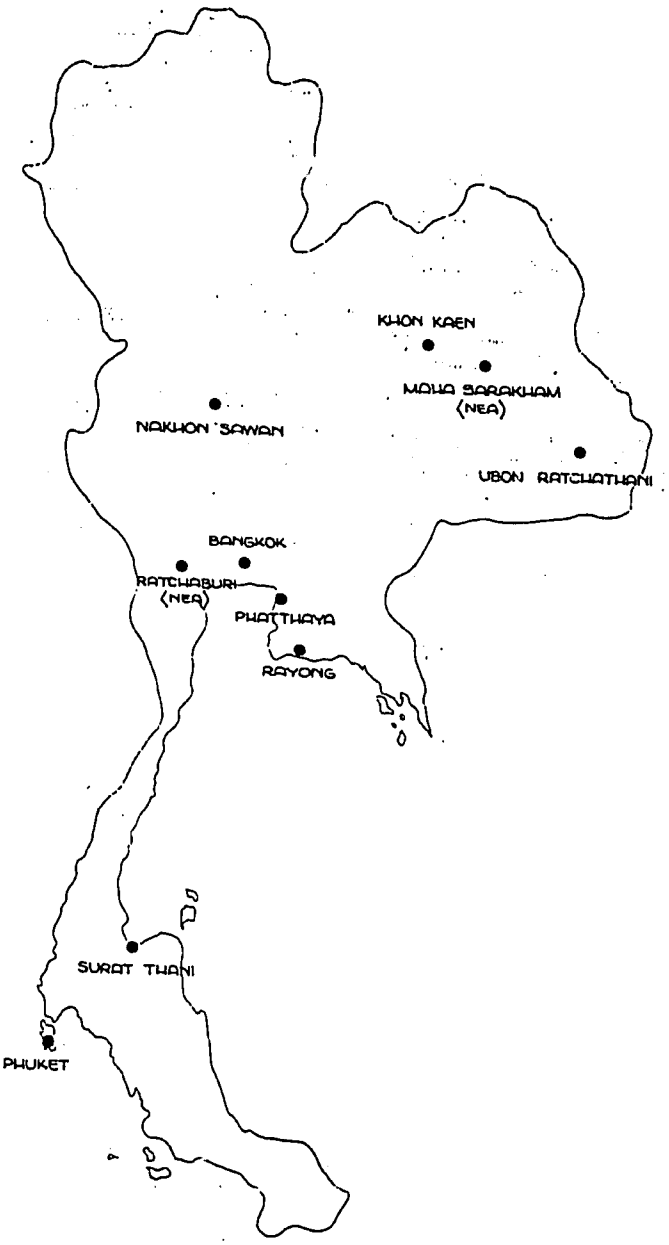
Figure II.2

Map Showing Wind Stations of the Project



ANNEX III

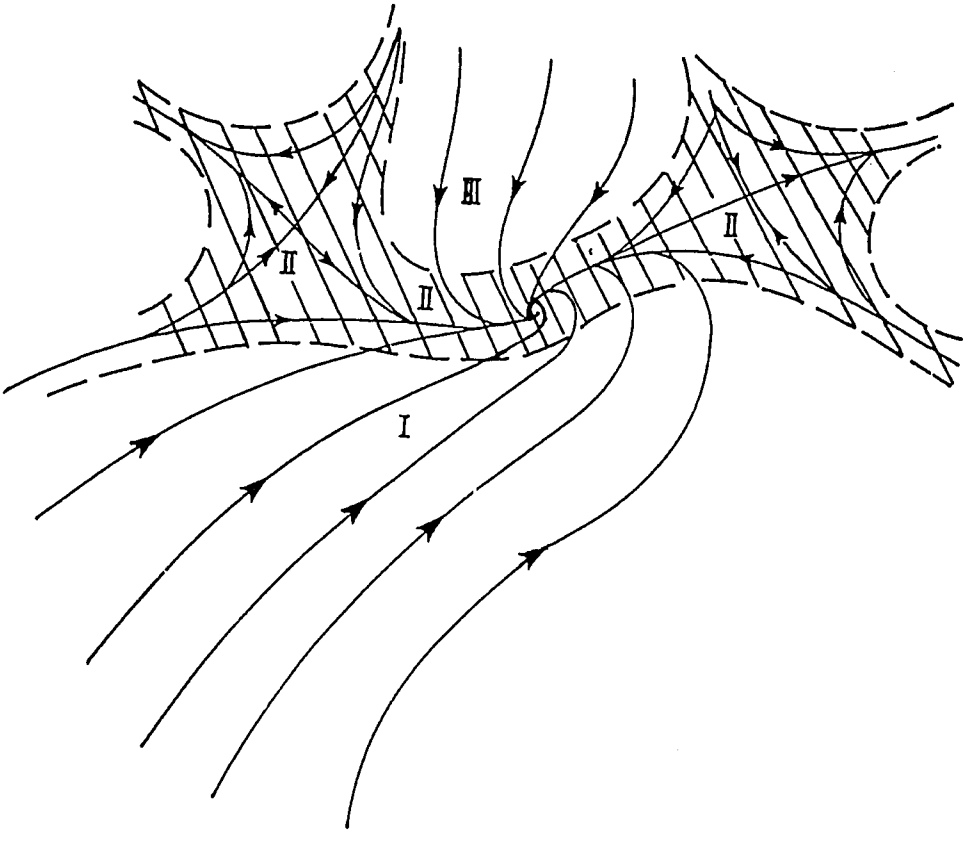
SYNOPTIC CLASSIFICATION

Figure III.1 S.W. Monsoon Synoptic Model (2,000 ft streamlines)

Category I: SW to S flow bounded by equatorial trough cloudiness mostly to N.

Category II: Equatorial trough: zone of high cloudiness, linking neutral point and vortex train.

Category III: NE to NW flow bounded by equatorial trough (cloudiness and low pressure to S).



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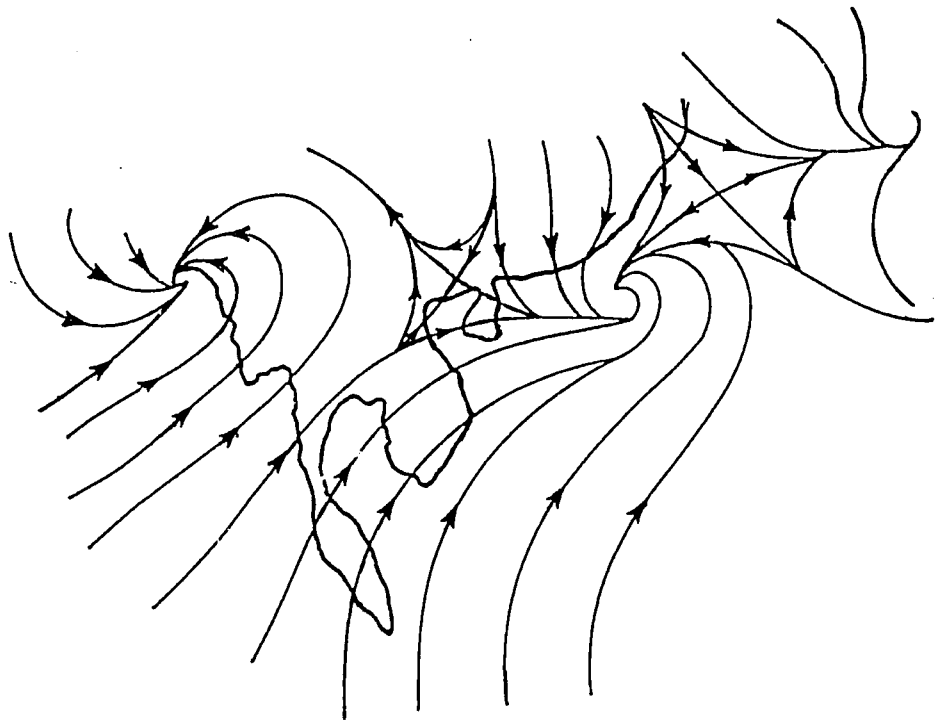

Figure III.2 Example of streamlines over Thailand at 2,000 ft with a vortex train lying to the north of Thailand. Map 00Z, 7 August 1981.

Figure III.3 NW Monsoon Synoptic Model (5,000 ft streamlines, dashed lines are the ridge lines).

Category IV: NE flow out of anticyclone (CA) centered over China.
Category V: NW flow from Tibetan anticyclone (TA).
Category VI: S-SE flow from Pacific anticyclone (PA).
Category VII: Anticyclonic cols.

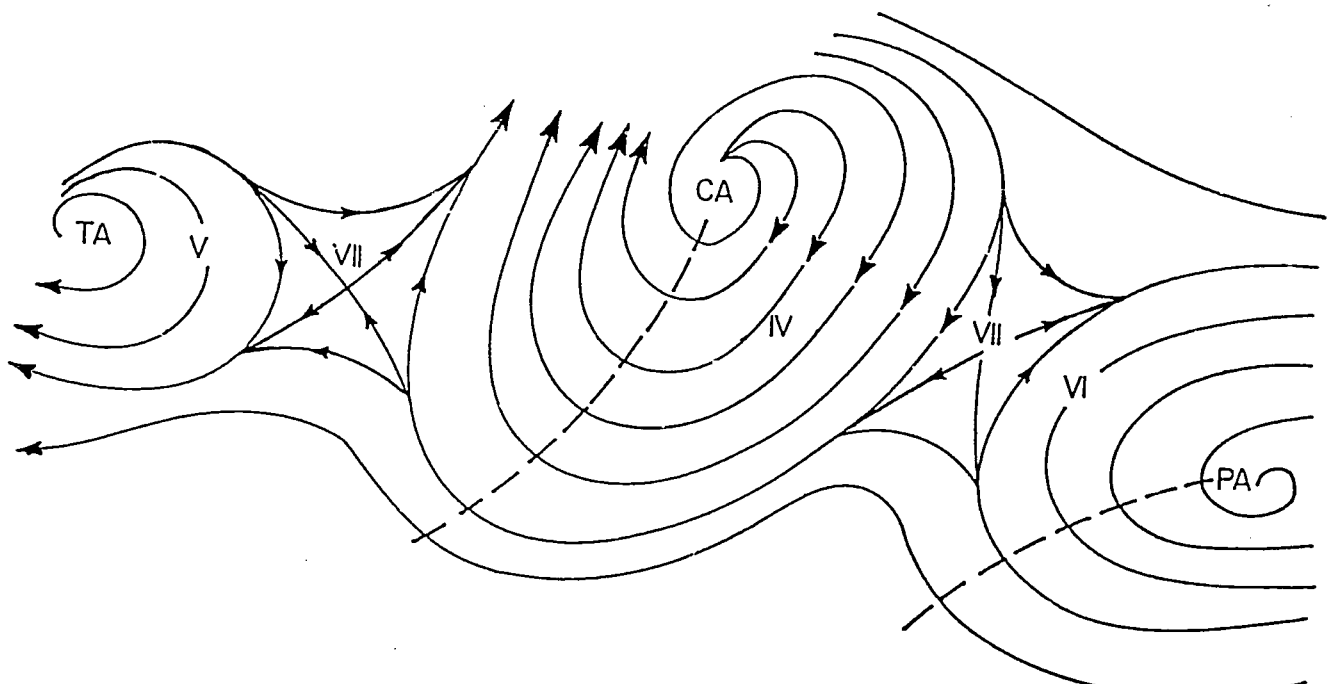

Figure III.4 Example of streamlines over Thailand at 5,000 ft with anticyclonic systems dominating flow. Map 00Z, 10 January 1978.

ANNEX IV

FOREIGN CONSULTANT

72004 MET BK TH

115/2524

12 February 1981

Professor Michael Garstang
Department of Environmental Sciences,
Clark Hall, Charlottes Ville
University of Virginia
Virginia 22903
U.S.A.

Dear Sir,

I have the pleasure to inform you that, following a favourable review of your qualifications, you have been approved to be an expert for Meteorological network and assessment. I am now pleased to extend an official invitation.

Please be informed that under the directives of the Renewable Energy Project Comittee, the expert is requested :

1. to evaluate the data collection system and to recommend strengthening the system ;
2. to advise on the initiation of procedures for assessment of solar and wind data for energy productive use.

Looking forward to hearing from you soon.

Yours sincerely,

(Kajit Bunjitti)
Director-General

cc : Mr. Phol Songpong, Director of Technical Division, The National Energy Administration, Kasatsuk Bridge, Bangkok 5.

Dr. Charles Laws, Technical Division, The Nation Energy Administration, Kasatsuk Bridge, Bangkok 5.

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RENEWABLE ENERGY PROJECT

MEMORANDUM 28 January, 1981

TO: Khun Saranee
Meterological Department

FROM: Charles Laws

RE: Suggested Expert for Meterological network and assessment.

AID has nearly resolved the issues surrounding the component, project and Technical Assistant Experts. I have considered the qualifications, you have identified, and suggest that we request Dr. Michael Garstang to assist your program initiation. I have attached a copy of his resume for your examination.

If he meets your approval would you please send to Khun Phol Sompongs, Project Manager at NEA a letter requesting Garstang's services in

1) the evaluation of the data collection system and recommendations for strengthening the system and
2) recommendations for proceedures for assessment of Solar and Wind data for energy productive use.

Could you also send me a copy of the letter please.

Thank you,

Charles

SIMPSON WEATHER ASSOCIATES
Consulting Meteorologists

February 23, 1981

Mr. Kajit Buajitti
Director-General
Meteorological Department
612 Sukumvit Road
Bangkok 11, Thailand

Dear Mr. Buajitti:

Thank you for your letter of 12 February 1981 ref. #215/2524. I am pleased to accept the responsibility of expert for meteorological network and assessment for the Renewable Energy Project Committee. Our work will be coordinated through META Systems, Inc., Cambridge, Mass. We are ready to proceed as soon as instructions are forwarded to us.

We look forward to working with you in the future.

I am,

Yours sincerely,

Simpson Weather Associates, Inc. by

Michael Garstang
First Vice President and
Professor, Department of
Environmental Sciences

MG/mvm

cc: META Systems

P.O. Drawer 5508, Charlottesville, Virginia 22903 (804) 295-6709 res. (804) 973-7088

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ANNEX V

LOCAL CONSULTANT

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Form 1

Request No. 2

Project Title RNE/Solar/Wind Resource Assessment Agreement No. 493-0304

Agency Meteorological Department Effective Date Aug. 16, 1979

Request for Technical Assistance

In accordance with the approved plan of the Solar/Wind component, request is hereby made for the services of a consultant/subcontractor (Line item 4.1) whose job description is as follows :

Post title : Local consultant for measurement and analysis of solar/wind data.

Date required : 1 March 1983

Duration : Seven months and renewable for the next fiscal year. (2days/month)

Duty station : Bangkok (with field trips as needed in Thailand)

Duties : To advise on
1) calibration of instruments,
2) siting of measuring instruments,
3) processing the data for monitoring the measurements,
4) analysis of data for assessment of solar/wind energy availability.
5) reliability of observation

Qualifications : Doctor degree and experience with solar/wind data assessment. For qualifications of applicant see attached Curriculum Vitae.

Language : English.

Counterpart Personnel : Mrs Soranee Sangmit, Senior Meteorologist, Study and Research Division, Meteorological Department.

Anticipated Accomplishments :

[X] Report
- quarterly
- semi-annual
- final
- working

[ ] Drawings
- Preconstruction drawings
- Drawings as built

[ ] Design
- System Design
- Component Design

[ ] Manual
- Construction
- Operation
- Maintenance

[ ] Others (Please specify)

Signature of a team Leader Mrs S Sangmit

Feb 2, 1983

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Estimated Expenses for Local Consultant

Salary (45 man - days)	฿ 105,000
Perdiem / Lodging	฿ 16,000
Local Travel (5 round trips)	฿ 15,000
Other	฿ 14,000
Total	฿ 150,000

Studies and Research in Meteorology Sub-Division

Meteorological Department

Asian Institute of Technology

P.O. Box 2754 • Bangkok • Thailand • Telephone 5168311-5, 5168321-5, 5168331-5 • Cables AIT-BANGKOK

16 Jan 1983

Mrs Soranee Sangmit
Senior Meteorologist
Study and Research Division
Meteorological Department
612 Sukhumvit Road
Bangkok 10110

Dear Mrs Soranee,

I enclose your "Request for Technical Assistance" form with the items completed as we agreed last week, and my Curriculum Vitae giving the most important information for this post.

I have been informed that the income tax on my salary is 45 %. Therefore in order to obtain a fee of $ 100 net per day I must charge a gross fee of $ 182 per day. I would also require expenses incurred in the course of the work to be paid, such as for local travel on field trips.

I trust that all this is in order, and look forward to collaboration with you in this interesting project.

Yours sincerely,

R.H.B. Exell

เหตุผลการจ้าง Local Consultant

Solar/Wind Component ได้ดำเนินการติดตั้งเครื่องมือตรวจวัดและสอบเทียบเครื่องมือตรวจวัด solar & wind เรียบร้อยแล้วโดยมีเจ้าหน้าที่ทำงานอยู่ที่ศูนย์สอบเทียบและตรวจวัดเป็นผู้ดูแลรักษาซึ่งทางโครงการบ่อยาได้จ้างมาทำงานโดยใช้เงินช่วยเหลือจาก USAID รวม ๖ คน เจ้าหน้าที่ดังกล่าวยังขาดความรู้ความชำนาญในการดำเนินงานทั้งทางด้านความรู้ในเรื่องพลังงานแสงอาทิตย์และลม การตรวจวัด การสอบเทียบ รวมทั้งการเก็บและวิเคราะห์ข้อมูลในรูปแบบคอมพิวเตอร์เพื่อประเมินศักยภาพพลังงานแสงอาทิตย์และลม ส่วนเจ้าหน้าที่ของกรมอุตุนิยมวิทยาเองก็ยังมีความรู้ความชำนาญไม่เพียงพอที่จะทำการควบคุมการดำเนินงานของศูนย์ได้เพราะเครื่องมือตรวจวัดและสอบเทียบที่มีอยู่ที่ศูนย์ขณะนี้เป็นเครื่องมือรุ่นใหม่ที่มีความสลับซับซ้อน ความไวและความละเอียดมาก ถ้าเกิดการผิดพลาดในการตรวจวัด การใช้เครื่องมือและการเคลื่อนย้ายเครื่องมือ (ซึ่งอยู่ในแผนงานที่จะต้องดำเนินการ) จะทำให้ผลการตรวจวัดผลาดเคลื่อนไม่สามารถที่จะใช้ข้อมูลมาการงานได้และทำให้ผลการสอบเทียบ (calibration factor) เครื่องมือวัดผลาดเคลื่อนเป็นผลให้เครื่องมือตรวจวัดที่มีอยู่ทั่วประเทศตรวจวัดข้อมูลผิดพลาดและในที่สุดจะทำให้การประเมินศักยภาพพลังงานแสงอาทิตย์และลมผิดพลาด, แผนงานของโครงการบ่อยาจะต้องนำเครื่องมือดังกล่าวไปติดตั้งตามจังหวัดต่างๆซึ่งในการนี้จะต้องมีการพิจารณาถึงปัญหาที่จะทำการติดตั้งให้เหมาะสมตามหลักวิชา อีกประการหนึ่งข้อมูลต่างๆที่ได้จากการตรวจวัดจะต้องนำเข้ามาprocess and analyses ในการนี้จะต้องนำเอาวิทยาการใหม่ๆมาประยุกต์ใช้ ซึ่งผู้ทำงานด้านนี้จำเป็นต้องได้รับคำแนะนำหรือชี้แนะเกี่ยวกับการวิเคราะห์ข้อมูลเป็นไปตามจุดประสงค์ของโครงการฯจึงจำเป็นต้องจ้าง Local Consultant มาเป็นที่ปรึกษาของโครงการเบื้อง

เนื่องการนี้โครงการบ่อยามีความประสงค์ที่จะจ้าง Dr.Robert H.B.Exell, Associate Professor of Applied Physics จาก Asian Institute of Technology,Bangkok ผู้มีความเชี่ยวชาญในเรื่อง solar/wind energy of Thailand มาเป็นที่ปรึกษาของโครงการบ่อยาฯ ระยะเวลาการทำงานเริ่มตั้งแต่วันที่ ๑ มีนาคม ๒๕๒๖ เป็นเวลา ๗ เดือน รวมเวลาการทำงาน ๒๕ m- days (FY 83)

ANNEX VI

RECOMMENDATIONS OF EVALUATION TEAM

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RESOURCE ASSESSMENT ON SOLAR AND WIND ENERGY

- Meterological Department
- Budget

Total	$270,000
USAID	$254,000
RTG	$16,000

- Work plan approved February 2, 1982
- Thru July 1984 (completion date)

The component has as its objectives to procure solar and wind measurement instrumentation and to collect data using these instruments. The component includes the use of U. S. consultants, training of Thai staff, equipment purchases and the development of wind and solar energy profiles for Thailand. The approved work plan is essentially that prepared by Dr. Michael Garstand, a U. S. consultant with some changes and deletions. The work plan has not been updated to reflect budgetary changes and deletions of major equipment and other activities.

- Much of the work has been delayed because the instruments for calibrating, etc., are not yet here.
- The work plan is very much the work of the U. S. consultant and while the Thai project people understand it, they have not changed it to reflect the project today (budget cuts and change by NEA).
- The newly proposed preparation of wind and solar profiles for Thailand must be planned and, if an output is expected by May, the planning must be completed soon.

There are several ways to complete this preparation of wind and solar profiles and decisions must be made soon. There seems to be a desire to follow the U.S. consultant's plan for this even though they don't feel comfortable with some of it.

This component should be continued but a rapid solar map of Thailand should be prepared immediately using a transform of the hours of sunshine data which is available. A preliminary map has been prepared and this should be reviewed, revised and used, at least as a project document.*

- The Solar/Wind resource survey component should continue to emphasize instrument calibration. It should also be expanded to consider siting of instruments and the rapid preparation of at least a country solar energy profile (SEP) using transforms of the existing hours of sunshine data.

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ANNEX VII

TRAINING COURSE
IN
SOLAR AND WIND RESOURCES
December 12, 1983 - January 6, 1984

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DEPARTMENT OF ENVIRONMENTAL SCIENCES
CLARK HALL . UNIVERSITY OF VIRGINIA . CHARLOTTESVILLE, VIRGINIA 22903
(804) 924-7761

October 10, 1983

Mrs. Soranee Sangmit
Meteorological Department
612 Sukumvit Road
Bangkok 10110
Thailand

Dear Mrs. Soranee:

Enclosed please find the detailed course outline including daily schedule of lectures, laboratories and practicals. I have indicated where it is necessary to be at Bangna but have assumed (perhaps incorrectly) that ALL lectures and all laboratories not scheduled for Bangna will be held at the Meteorological Department, Sukumvit Road.

With regard to the international training of senior instrument technicians I address this question in the introduction of the detailed course outline. Specifically, the course being offered by me is directed at the fundamental scientific principles upon which solar and wind energy conversion is based. It is not, nor can it, address the technical and engineering instruction to which the international training is directed. There are neither the facilities nor the staff at Bangkok which can deal with the specific technical instruction on maintenance, calibration and operation which the select personnel will receive in the United States. Finally, the level of training required of the two individuals is far more specific than will be dealt with in the course which is limited at 25 people.

Please let me know if you find the detailed course outline acceptable as I will now begin to prepare the lectures and laboratories in detail.

We would also like to have our accommodation confirmed as outlined in my last letter. I shall let you know the precise dates/times of arrival in Bangkok shortly. We expect to arrive in Bangkok no later than Sunday 11 December 1983.

Previous page blank

Looking forward to seeing you again. Please give my regards to your colleagues.

Yours sincerely,

Michael Garstang/mvm

Michael Garstang

MG/mvm

Enclosure

Detailed Course Outline: Solar and Wind Resources

December 12, 1983 to January 6, 1984

1. Introduction

This detailed course outline for the course on Solar and Wind Resources supplements the curriculum submitted 3 August 1983.

Forty lecture contact hours and 36 laboratory/practical contact hours are planned. This represents a full university level course in solar and wind resources.

Spacing of the lectures during the day and laboratory practicals during the week is regarded as necessary to allow for completion of assignments and reading.

The course is to be presented on an academic level. Although it will include many practical applications, this course is not intended to serve the purpose of providing specific technical and engineering instruction which is required in the maintenance, calibration and operation of solar and wind instruments. Such instruction should be sought from the appropriate technical and engineering centers which have the necessary equipment and laboratory facilities to offer such a source.

The course being offered at the Meteorological Office at Bangkok from 12 December 1983 - 6 January 1984 will focus upon the fundamental principles upon which solar and wind energy conversion is based. In so doing, the course must deal with both basic physics and with physics as applied to the atmospheric system. While the course will deal with the basic principles upon which measurements of solar and wind energy are founded it will not deal with the detailed technical or engineering detail of these instruments. Finally, the course will deal with concepts of analysis application and archiving of data.

2. Lectures

The lectures in Table I below are numbered 1 to 40 to correspond to two lectures per day each of approximately 1 hour duration. The lecture times each day are suggested to be

0900 to 1000
and
1100 to 1200

Table I. Lecture Schedule.

Lecture #	Subject Material
1	Define electromagnetic radiation: quantum theory: electronic, vibrational and rotational transitions, electromagnetic spectrum, units.
2	Definition of: reflectivity, absorptivity and transmissivity, a black body, a white body, albedo. Plancks Law, Rayleigh-Jeans Law.
3	Wiens displacement law, Stefan-Boltzmans Law, Kirchoffs Law, Rayleigh and Mie scattering, the solar constant.
4	Radiation from the sun, interception by the earth, sun's temperature transfer of radiation through the atmosphere.
5	Radiative balance of the planet, efficiency of fluid engine, solar spectrum, terrestrial spectrum, radiant intensity and specific intensity.
6	Schwartzchild's equation, Beers Law, optical thickness.
7	Disposition of solar radiation (a) without an atmosphere, (b) with an atmosphere (no clouds), and (c) cloudy skies.
8	Radiation and heat balance equations, radiative balance of earth-atmosphere system.
9	Direct measurement of radiation, classification of radiation instruments: photomultipliers, photo conductors, thermocouples and thermistors.
10	Test and review of 1st week's work.
	END FIRST WEEK
11	Radiation instruments: generic and specific classes of instruments.
12	Examples of specific radiation instruments: total radiation - Eppley Pyrradiometer, cosine effect.
13	Direct solar radiation: pyrheliometer, classification of pyrheliometers, Eppley normal incidence pyrheliometer.
14	Diffuse radiation, global radiation, Eppley precision pyranometer and shadow band.
15	Total net radiation, pyrradiometer downward effective radiation, pyranometers and the measurement of longwave radiation.
16	Radiation measurements from satellites: mean features of meteorological satellites, radiometric observations.

Lecture #	Subject Material
17	Utilization of solar energy: heat generation, flat plate collectors, heat exchange, heat storage.
18	Utilization of solar energy (cont.): concentrating collectors, tracking systems, focusing systems, solar ponds.
19	Utilization of solar energy (cont.): photo thermoelectric converters, photo voltaic converters, solar panels.
20	Test and review of 2nd week's work.
	END SECOND WEEK
21	Global and regional distribution of wind: planetary, synoptic, meso- and local-scale wind systems, geostrophic and gradient flow.
22	Local wind systems (cont.): mountain-valley winds, land-sea breezes, flow over rough terrain, numerical formulation and products.
23	Boundary and surface layer theory: formulation of bulk aerodynamic equations, Prandt mixing length, roughness parameter.
24	Formulation of bulk aerodynamic equations (cont.): drag coefficient, friction velocity and logarithmic wind law.
25	Height adjustment of the wind, power laws, formulation, application and adjustment of wind with height.
26	Non-adiabatic conditions, Monin-Obukhov mixing length theory, Richardson Number stability and wind shear.
27	Wind energy conversion: basic theory, Betz limit, coefficients of efficiency.
28	Wind energy climatology, wind measurement strategy and wind measuring systems and anemometer calibration.
29	Wind energy systems: propeller type converters, cross wind converters, augments and advanced converters.
30	Test and review of third week's work.
	END THIRD WEEK
31	Wind energy systems: small energy conversion systems, (small WECS), intermediate and large WECS, wind farms, wake problems.

Lecture #	Subject Material
32	Wind energy systems: applications - domestic, industrial, commercial, agricultural, recreational.
33	Wind statistics, power duration calculations, interaction of power production.
34	Sampling methods for solar and wind energy applications: synoptic control of the energy source and role of synoptic classification.
35	Sampling methods (cont.): synoptic classification for Thailand and associated data compilation.
36	Presentation, quality control and archiving of solar radiation measurements.
37	Presentation, quality control and archiving of wind measurements (cont.).
38	Development of basic solar and wind climatology and production of summaries for solar and wind power assessment.
39	Review of course
40	Final examination
	END COURSE

3. Laboratory-Practical

Laboratories-practicals will be conducted on Monday, Wednesdays and Fridays from 1300 to 1600 hours. These sessions will be closely coordinated with the lectures and will include work to be done at the Calibration Center at Bangna. Times and topics to be covered are listed in Table II.

Table II. Laboratory-Practical Schedule.

Lab #	Topic
1	Electromagnetic spectrum - Meteorological Dept., Sukumvit Rd.
2	Reflection, absorbtion, transmission, Meteor. Dept., Sukumvit Rd.
3	Calculation of radiative temperatures, Meteor. Dept., Sukumvit Rd.
	END FIRST WEEK
4	Eppley pyrradiometer, Bangna
5	Eppley pyrheliometer, Bangna
6	Eppley shaded pyrradiometer, Bangna
	END SECOND WEEK
7	Seasonal and synoptic scale wind fields of Thailand, Meteor. Dept., Sukumvit Rd.
8	Calculations of wind with height: logarithmic profile, Meteor. Dept., Sukumvit Rd.
9	Anemometry and the calibration of wind sensors: wind tunnel, Bangna
	END THIRD WEEK
10	Synoptic classification, Meteor. Dept., Sukumvit Rd.
11	Sampling methodology and archiving, Meteor. Dept., Sukumvit Rd.
12	Free
	END COURSE

ANNEX VIII

REGIONAL CALIBRATION

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U.S. INTERNATIONAL DEVELOPMENT COOPERATION AGENCY
USAID THAILAND
BANGKOK, THAILAND

CABLE : USAID THAILAND

TELEPHONE: 252-8191-9

January 30, 1984

Mr. Sompongse Chantavorapap
Director, Energy Research and
Development Division
NEA Designated Project Manager
National Energy Administration
Kasatsuk Bridge, Rama I Road
Bangkok 10500

Subject: Renewable Nonconventional Energy Project
AID Project No. 493-0304
Solar/Wind Resource Assessment Component

Dear Mr. Sompongse:

In response to your letter No. 0702/999 dated 23 January 1984, USAID hereby concurs in the travel of Mr. Suparerk Tansriratanawong and Mr. Boonlert Archevarahuprok of the Meteorological Department to Aspendale, Australia under the subject Project component for the purpose of calibrating meteorological equipment against regional standard equipment.

Please be advised, however, that for the cost of the round trip air ticket, Bangkok/Melbourne/Bangkok, USAID can authorize only the Orient Airline Association (OAA) round trip excursion fare of $1,132 per each traveller, or a total of $2,264. Limitations imposed on this special fare are (1) that round trip travel be completed within one year, and (2) that the same airline be used for travel in both directions. That is, if Thai Airways is used for the Bangkok/Melbourne travel then Thai Airways must be used also for the return trip. However, this seems to be a modest limitation when compared with the $1,606 saved by use of the OAA fare.

The total estimated budget approved, therefore, is $6,294.

If I can be of further assistance, please don't hesitate to contact me.

Sincerely,

John W. Neave
Chief Engineer/Project Officer
Office of Project and
Engineering Support

cc:Mr. Kittipan, DTEC

Previous Page Blank

CSIRO

Division of Atmospheric Research
Aspendale Vic

Chief of Division
G. B. Tucker

A Division of the Institute of Physical Sciences

Private Bag No. 1 Mordialloc, Vic 3195
Telephone (03) 580 6333
Telex AA34463

GRP:FW

19th December, 1983

Dr. B. Boonsukha,
Director General,
Meteorological Department,
612 Sukumvit Road,
Bangkok 10110
Thailand

Dear Sir,

I am replying to your letter regarding the comparison of your National standard pyrheliometer against the WMO Regional standard.

I would suggest March, 1984 as the most suitable time as regards consistent clear weather conditions. A period of 2 to 3 weeks should be sufficient. There will be no costs made for this comparison.

Could you please send me details of your pyrheliometer, e.g. type, manufacturer, serial number, mode of operation and calibration history.

Also let me know if you have any special requirements, e.g. power supplies, etc.

Yours sincerely,

G.R. Patterson
WMO Regional Radiation Centre.

ว2/2527 9 February 1984

Mr. C. K. Patterson
WMO Regional Radiation Centre,
CSIRO, Division of Atmospheric Research
PRIVATE BAG No. 1,
MORDIALLOC, Vic., 3195
Australia

Dear Sir,

Thank you for your letter dated 19 December 1983 informing us of the calibration expenditure and duration for calibration, we would like to have the comparison done during March 6 - 25, 1984. The details of the instruments are enclosed for your information and our two officials are:

- Mr.Suparerk Tansriratanawong, Acting Cheif, Instrument Test and Calibrations Sub-Division, Meteorological Instruments Division.
- Mr.Boonlert Archevarahuprok, Meteorologist attached to Meteorological Instruments Division.

The arrival date and time will be confirmed by Telex.

Your kind co-operation in this matter is very much appreciated.

Yours sincerely,

B. Boonsukha

(Dr. Boonsorn Boonsukha)
Director-General

ทราบ
กาญจนา/พิมพ์
ทราบ

Encl : as stated

1) Eppley pyrheliometer

Type : Normal incidence

Model : N.I.P.

Manufacturer : The Eppley Laboratory Inc

Serial number : 21950 E 6

Date of test : October 15, 1982

Power supply : 220 V. 1 PH. 50 HZ and dry cell battery.

Calibration constant of instrument : 6.84×10^{-6} volts/watt. meter^{-2}

: 4.77 millivolts/cal. cm^{-2}. min^{-1}

Mode of operation : operated with data logger.

2) Eppley pyrheliometer (2 sets)

Type : Normal incidence

Model : Angstrom

Manufacturer : The Eppley Laboratory Inc

Serial number : 7266, 7259

Date of test : March 9, 1970

Power supply : dry cell battery or 220 V. 1 PH. 50 HZ

Calibration constant : 6.50 cal.cm^{-2}.min^{-1}/amp^2. (for serial number 7266)

: 6.42 cal.cm^{-2}.min^{-1}/amp^2. (for serial number 7259)

Mode of operation : operated with Eppley control unit.

3) Eppley pyrheliometer. (2 sets) (optional)

Type : Normal incidence

Model : NIP, IS

Manufacturer : The Eppley Laboratory Inc.

Serial number : 6401 E 6, 6397 A

Date of test : -

Power Supply : 220 V. 1 PH. 50 HZ

Calibration constant of instrument : 5.83 mV/cal.cm^{-2}.min^{-1} (for 6401 E 6)

: 3.59 mV/cal.cm^{-2}.min^{-1} (for 6397 A)

Mode of operation : operated with data logger.

ANNEX IX

PROCUREMENT

TELEX NO. 453058 CAMPBELL LOGA, UTAH, U.S.A.

DECEMBER 15, 1983.

ATTN : DENNIS J. ANDERSEN

RE YR LETTER OF NOVEMBER 17, 1983. AFTER HAVING CONSIDERED YOUR PRICE QUOTATION, THE COMMODITIES WHICH WILL BE PROCURED FROM YOUR COMPANY ARE AS FOLLOWS: 12 MICROLOGGERS MODEL NO. CR 21. 3 PRINTERS MODEL NO. CR 56 (INCLUDES SC 12 CABLE AND PS 56). 2 CASSETTE INTERFACES MODEL NO. C 20. (INCLUDES SC 25 P) 5 CASSETTE CONNECTOR INTERFACES MODEL NO. SC 235. 12 CASSETTE RECORDERS MODEL NO. RC 235. 8 WIND SPEED SENSORS MODEL NO. 041 A MET ONE. 8 WIND DIRECTION SENSORS MODEL NO 024 A MET ONE. 2 CABLE AND CONNECTORS FOR INTERFACING BETWEEN C 20 AND HP 85 COMPUTER. 8, 20 METERS WIND SPEED CABLE AND CONNECTOR. 8, 20 METERS WIND DIRECTION CABLE AND CONNECTOR WE ARE PRESENTLY SUBMITTING THE SPECIFICATIONS TO THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID) WE WILL PLACE AN ORDER AS SOON AS WE GET APPROVAL FROM USAID AND OTHER AGENCIES CONCERNED RGDS.

DIRECTOR GENERAL

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CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N. • Logan, Utah 84321 • (801) 753-2342
P.O. Box 551 • Fed. I.D. #87-0305157

INVOICE
7794

DATE
25 Jun 84

SHIP TO.

DTEC-RENEWABLE NONCONVENTIONAL
ENERGY PROJECT
METEOROLOGICAL DEPARTMENT
612 SUKUMVIT ROAD
BANGKOK 10110, THAILAND

SOLD TO

OFFICE OF FINANCE
USAID THAILAND, BOX 47
APO SAN FRANCISCO 96346

Funding: Approp: 72-11M1021.3
ID PIO/C 493-0304-9-00062/Letter of Commitment No. 493-0304-19

DUE DATE: 25 Jul 84

YOUR ORDER NO.	OUR ORDER NO.	DATE SHIPPED	VIA	FOB POINT	TERMS
ID-TH-MET-RNE-1	5454	25 Jun 84	CIRCLE AIR	Logan, Utah	NET 30 DAYS

QTY. ORD.	QTY SHPD		DESCRIPTION	PRICE	PER	AMOUNT
12	12	CR21	MICROLOGGER/FMT II	1,632.00		19,584.00
3	3	CR56	PRINTER	1,320.00		3,960.00
12	12	RC235	CASSETTE RECORDER	156.00		1,872.00
2	2	C20	CASSETTE INTERFACE	1,440.00		2,880.00
12	12	SC235	CASSETTE CONNECTOR INTERFACE	54.00		648.00
8	8	014A	MET ONE WIND SPEED SENSOR	282.00		2,256.00
8	8	024A	MET ONE WIND DIRECTION SENSOR	354.00		2,832.00
			Sub-total			$34,032.00

PRODUCTS WARRANTED FOR 12 MONTHS FROM INVOICE DATE

These commodities licensed for ultimate destination Thailand. Diversion contrary to US law is prohibited. I do hereby certify that the items described on the above invoice are of U.S.A. origin and do further certify that the same is true and correct. K. King, Sec. for, CSI.

23 PIECE(S) IN SHIPMENT

053

FREIGHT
INSURANCE
TOTAL DUE

Buyer will be charged a finance fee of 1½% (18% annual interest) per month on any amount past due until paid. Buyer will also be charged reasonable attorney's fees should collection by suit be required.

-154-

THE EPPLEY LABORATORY, INC.
12 Sheffield Ave., Newport, R. I. 02840, U.S.A. Telephone 401 847-1020

EPLAB

Scientific Instruments
for Precision Measurements
Since 1917

March 13, 1984

Meteorological Department
612 Sukumvit Road
Bangkok, 10110, Thailand

Attention: Mrs. Soranee Sangmit
Studies and Research Division

Reference: Contract No. AID-TH-MET-RNE-2 - Eppley #44735

Dear Mrs. Sangmit:

We acknowledge and thank you for the contract for solar radiation measuring instruments as outlined in the contract and the prices listed in our proforma invoice of February 6, 1984.

We have signed the contract but should point out that we have agreed to air shipment. We note that Articles C-4 and C-9.1 call for ocean shipment and we would ask that this be changed to air shipment as a far superior and more economical means of shipment.

We have also written to the Banking and Finance Div., Agency for International Development (AID), 1975 Florida Ave. NW, Washington, D. C. 20523, as indicated in Article C-10 to receive the irrevocable letter of commitment as well as a change in shipping method (see copy of letter attached).

Very truly yours,

George L. Kirk
President

GLK/ag
Enc.

cc: Banking and Finance Div.
AID, Washington, D. C.

THE EPPLEY LABORATORY, INC.
12 Sheffield Ave., Newport, R. I. 02840, U.S.A. Telephone 401 847-1020

EPPLEY
Scientific Instruments for Precision Measurements Since 1917

DATE OF INVOICE
May 11, 1984

TERMS: NET 30 DAYS
NO CASH DISCOUNT

SOLD TO

DTEC-Renewable Nonconventional
Energy Project
Meteorological Department
612 Sukumvit Road
Bangkok, 10110, Thailand

SHIPPED TO

SAME

YOUR P. O. NO. REQ. NO. Letter of Commitment 493-0304-18 OUR S. O. NO. 44735 DATE SHIPPED May 11,1984 VIA Air frt. ppy&add

Contract No. AID-TH-MET-RNE-2

2 ea.	Eppley Normal Incidence Pyrheliometers, Model NIP.	$1,375.00 ea. -$ 2,750.00
	Serial Numbers: 23910E6, 23912E6	
3 ea.	Eppley Precision Spectral Pyranometers, Model PSP.	1,390.00 ea. - 4,170.00
	Serial Numbers: 24153F3, 24154F3, 24155F3	
6 ea.	Eppley Model 8-48 Black and White Pyranometers.	890.00 ea. - 5,340.00
	Serial Numbers: 23638, 23647, 23648, 23649, 23650, 23651	
1 ea.	Eppley Solar Tracker, Model ST3, to operate on 220V 50 Hz.	1,650.00 ea. - 1,650.00
	Serial Number: 8168-5	
1 ea.	Eppley Shadow Band Model SBS.	1,150.00 ea. - 1,150.00
	Serial Number: 8177	
		FOB Newport RI USA $15,060.00
		CIF Bangkok via air freight 458.95
		CIF Bangkok, Thailand $15,518.95

Made in USA
Gen. Lic. G-DEST
Schedule B No. 710,1820

Terms of Payment: In U.S. Funds upon presentation of documents.

" These commodities licensed by the U.S. for ultimate destination BANGKOK; diversion contrary to U.S. law prohibited."

THE EPPLEY LABORATORY, INC.

George L. Kirk, President

CONDITIONS OF SALE

This equipment is sold subject to the mutual agreement that it is warranted by us free from defects of material and construction, which warranty we will make good by replacing or repairing at our laboratory any defective material or construction which becomes apparent within one year after the equipment is received, without charge for this service; but that we assume no liability for consequential damages of any kind, and that the purchaser by the acceptance of this equipment will assume all liability for the consequences of its use or misuse by the purchaser, his employees, or others.

ANNEX X

TIME SCHEDULE

Table X.1

Time Schedule

Activities	Oct 81	Nov 81	Dec 81	Jan 82	Feb 82	Mar 82	Apr 82	May 82	Jun 82	Jul 82	Aug 82	Sep 82
1. Establish center for calibrating solar and wind instruments						←- - -	- - -	- - -	- - -	- - -→		
						←———	———	PIO/C	& APPROVED	———	———	———
1.1 Procurement of instruments						←- - -	- - -→					
1.2 Installation of instruments at Center											←———	———→
								←- - -	- - -	- - -→		

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Table X.1 (continued)

Time Schedule

Activities	Oct 82	Nov 82	Dec 82	Jan 83	Feb 83	Mar 83	Apr 83	May 83	Jun 83	Jul 83	Aug 83	Sep 83
1. Establish center for calibrating solar and wind instruments												
1.1 Procurement of instruments												
1.2 Installation of instruments at Center												

Table X.1 (continued)

Time Schedule

Activities	Oct 82	Nov 82	Dec 82	Jan 83	Feb 83	Mar 83	Apr 83	May 83	Jun 83	Jul 83	Aug 83	Sep 83
2. Development of instruments												
2.1 global radiation instruments												
2.2 anemometers												
3. Calibration at center												
3.1 radiation instruments												
3.2 anemometers												
4. Calibration of field instruments												
4.1 radiation instruments												
4.2 anemometers												
5. Radiation and wind measurements												
6. Compilation of calibrated solar and wind data												
7. Evaluation of existing data												
8. Technical Assistance by local consultant												

Table X.1 (continued)

Time Schedule

Activities	Oct 83	Nov 83	Dec 83	Jan 84	Feb 84	Mar 84	Apr 84	May 84	Jun 84	Jul 84	Aug 84	Sep 84
2. Development of instruments												
2.1 global radiation instruments												
2.2 anemometers												
3. Calibration at center												
3.1 radiation instruments												
3.2 anemometers												
4. Calibration at center												
4.1 radiation instruments												
4.2 anemometers												
5. Radiation and wind measurement												
6. Compilation of calibrated solar and wind data												
7. Evaluation of existing data												
8. Technical assistance by local consultant												

Table X.1 (continued)

Time Schedule

Activities	Oct 83	Nov 83	Dec 83	Jan 84	Feb 84	Mar 84	Apr 84	May 84	Jun 84	Jul 84	Aug 84	Sep 84
9. Evaluation of new data												
10. Regional calibration of radiation instruments in Australia												
11. Procurement of additional instruments and spare parts												
12. Training												
12.1 in country training on Solar/Wind energy by foreign expert												
12.2 training at AIT												
12.3 oversea training (U.S.A.)			not approved									
13. Workshop on Solar/Wind energy assessment							2 days					
						not executed						

Remark: 1. dot lines represent period in which activities are planned to be executed

2. solid lines represent actual executing periods

ANNEX XI

ACTIVITIES

Figure XI.1 Transferring ceremony of Solar/Wind Measuring and Calibrating equipment from USAID (Carol Peasley, Deputy Mission Director) to the Meteorology Department (Dr. Boonsorn Boonsukha) at the Meteorology Department, December 16, 1982.

Figure XI.2 Dr. Michael Garstang, Consultant of the Solar/Wind Component, had come to establish the Center for Solar Radiation and Wind Calibration, and to train Project personnel.

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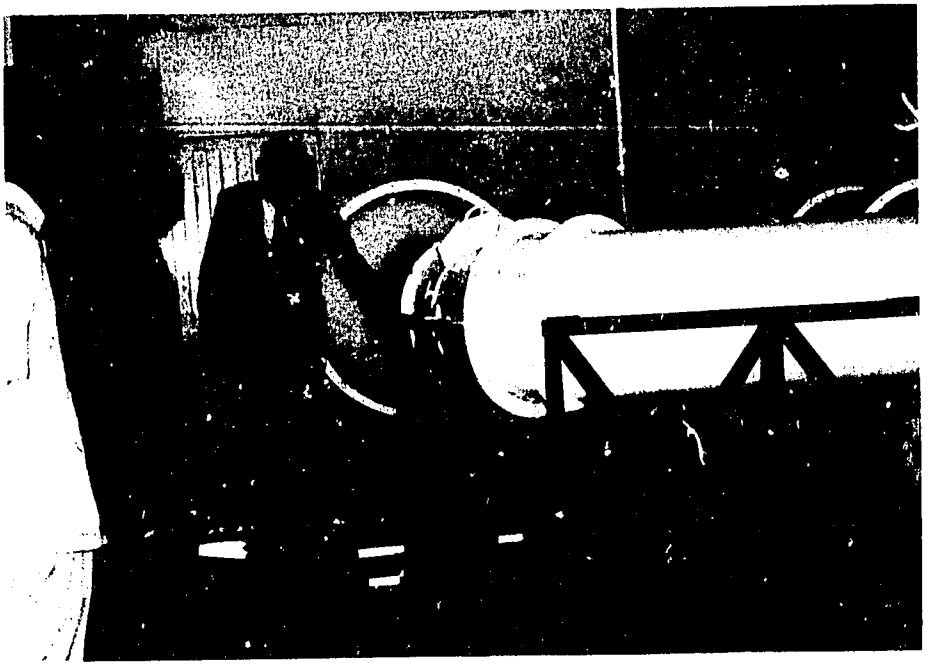

Figure XI.3

Wind tunnel, used in calibration of wind instruments, at the Center for Solar Radiation and Wind Calibration.

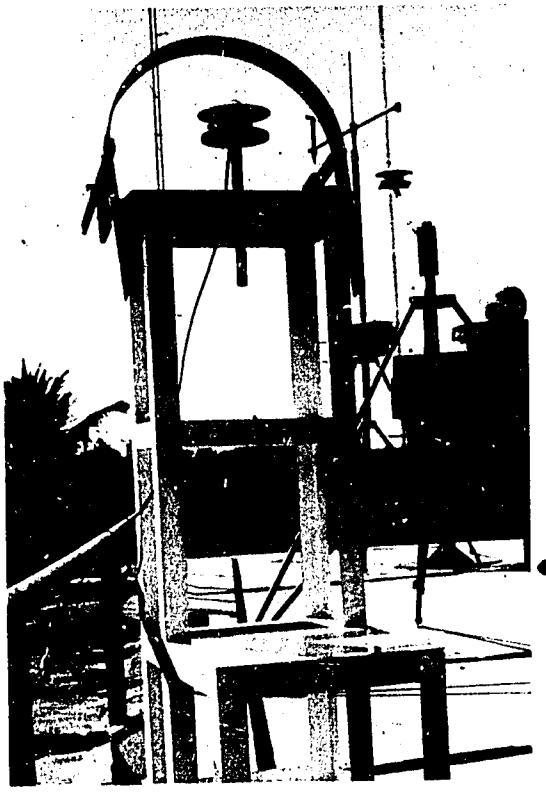

Figure XI.4

Eppley Precision Spectral Pyranometer with Shadow Band, used in diffuse radiation measurement, at the Center for Solar Radiation and Wind Calibration.

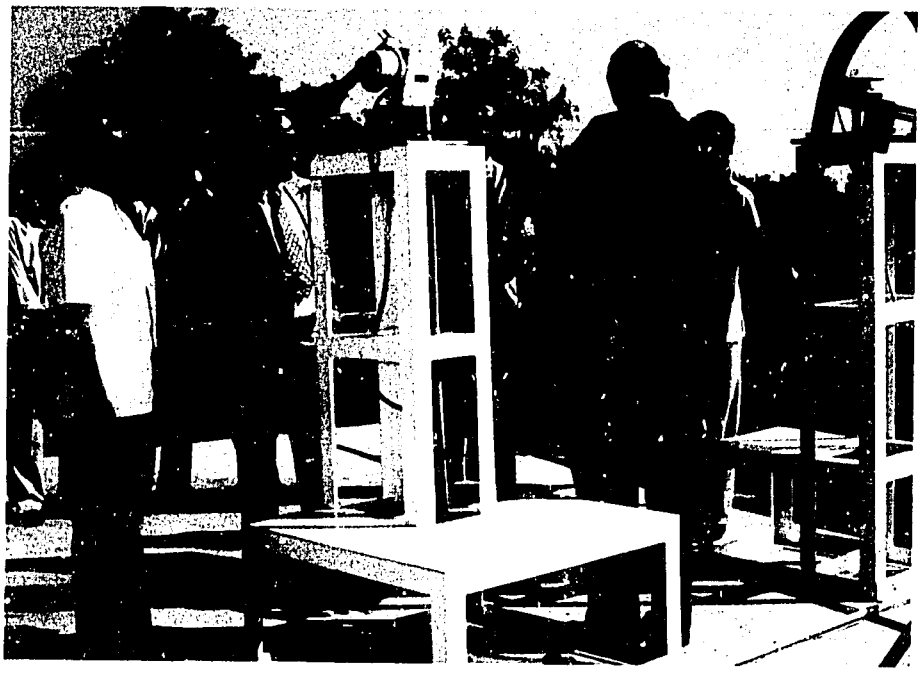

Figure XI.5 Eppley Normal Incidence Pyrheliometer with Solar Tracker for measuring direct solar radiation, at the Center for Solar Radiation and Wind Calibration.

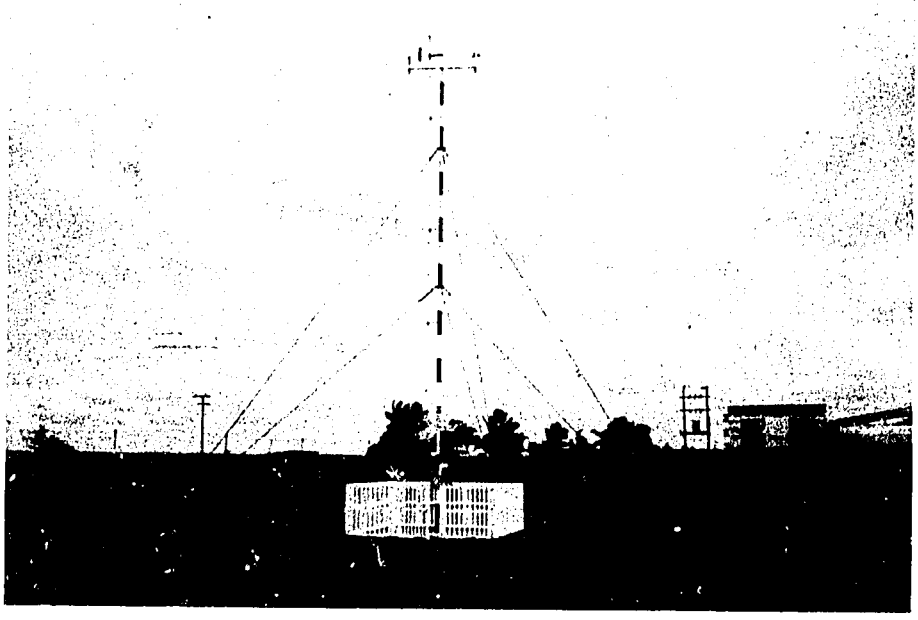

Figure XI.6 Wind monitoring system at Rayong Meteorological Observation station.

Figure XI.7

For wind instrument calibration, the instrument at the station was removed and brought to the Calibration Center.

Figure XI.8

Installation of Black and White Pyranometer at the Hydrological Observation Station, Ban La Mai, Ko Samui, Surat Thani, to calibrate against the bimetallic pyranometer of the station.

Figure XI.9

Installation of wind sensors (anomometer and wind vane) at Hat Yai Airport, Songkhla

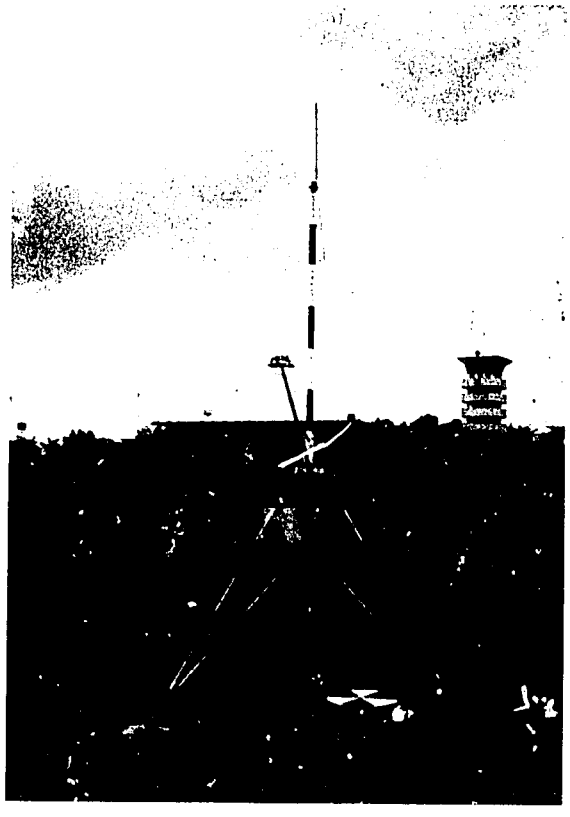

Figure XI.10

Pyranometer for global solar radiation measurement at the Hat Yai Airport, Songkhla.

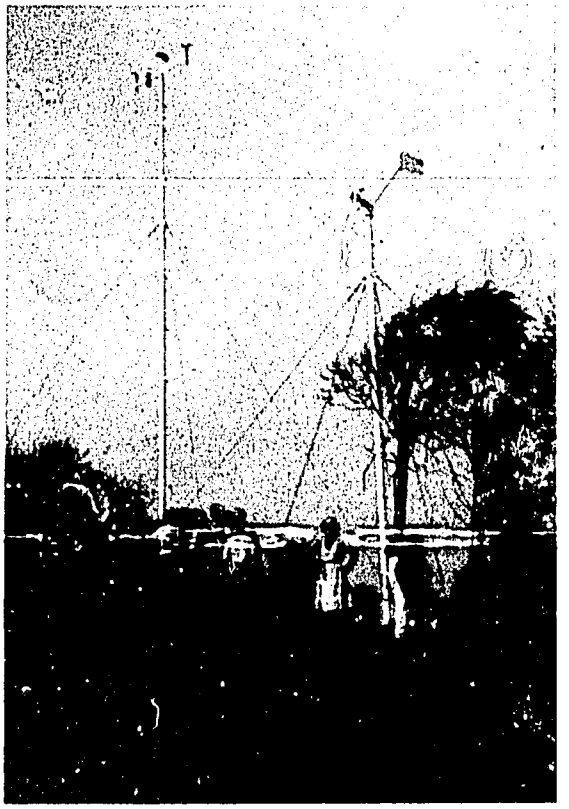

Figure XI.11

Wind monitoring system used in the analysis of wind data for EGAT's wind-generated electricity project located at Khuan Phrom Thiap, Phuket.

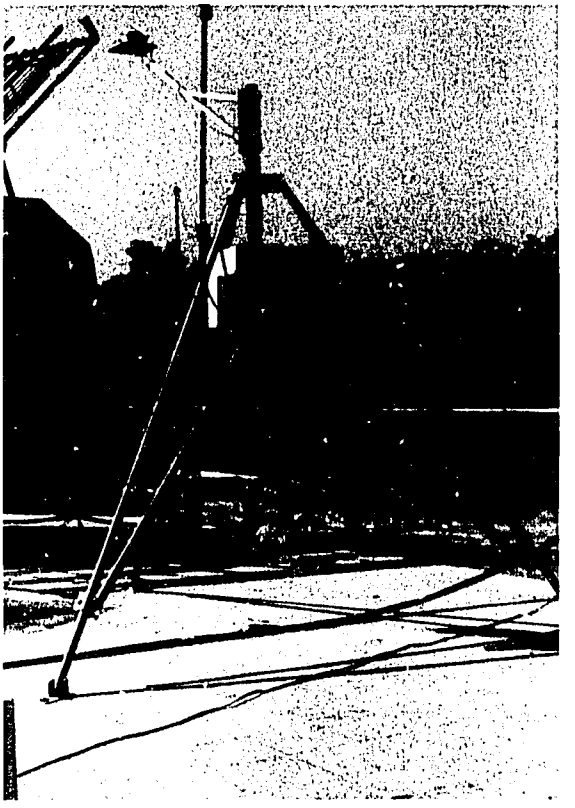

Figure XI.12

Pyranometer and Datalogger at the Center for Solar Radiation and Wind Calibration.

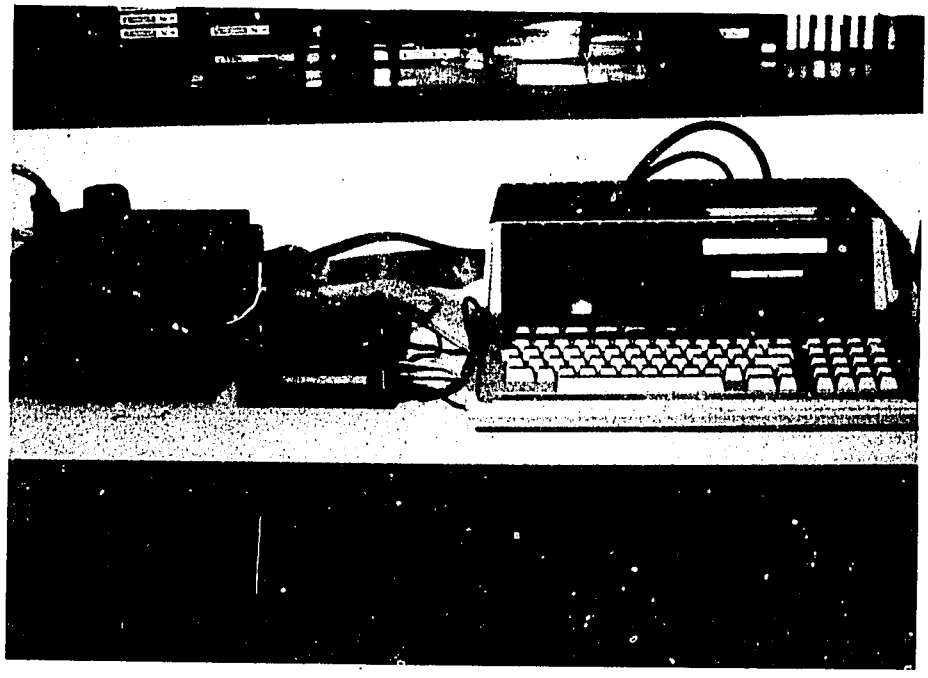

Figure XI.13 Data processing system used in the project.

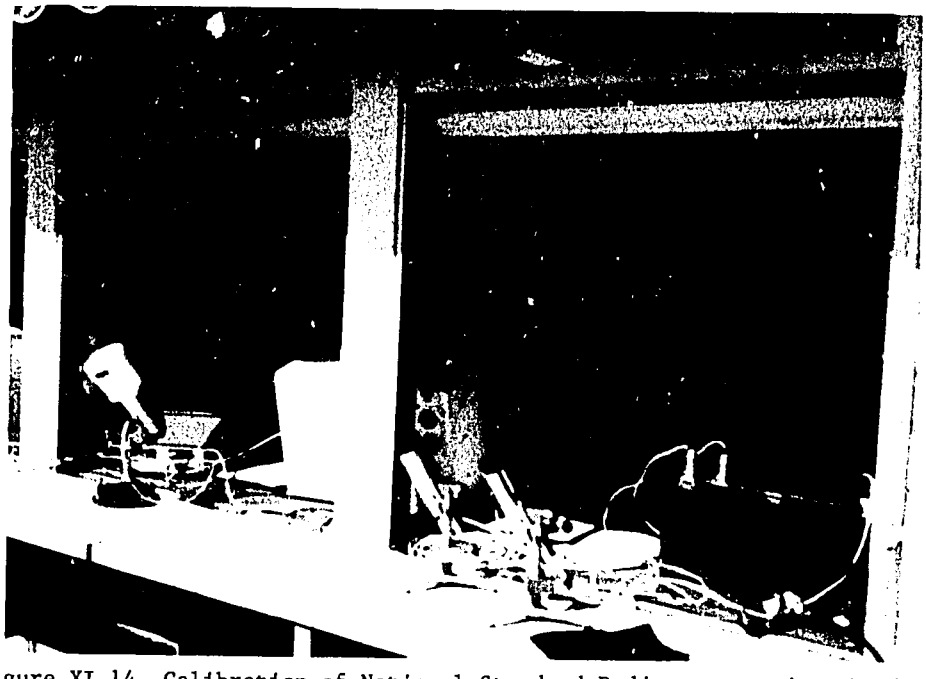

Figure XI.14 Calibration of National Standard Radiometer against Regional Radiation Standard at the WMO Regional Radiation Center, Australia.

Figure XI.15 Staff of the Solar/Wind Resource Assessment Component.

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This report gives general information on the solar radiation and wind energy resource assessment for Thailand using existing data and new data from additional measurements.

The assessment of solar and wind energy was to provide assistance in evaluating the potential for solar and wind energy. The focus of the study was on defining the special and temporal characteristics of solar and wind energy resources in terms of atmospheric constraints.

This report covers both theoretical background and practical aspects of the assessment of solar and wind energy for Thailand. Even though it was not the first time for the assessment of solar and wind energy in Thailand, this assessment is believed to be the most extensive work ever done for the evaluation of solar and wind energy for the country.

The Renewable Nonconventional Energy Project was conceived by the Royal Thai Government and the U.S. Agency for International Development with the aim to reduce Thailand's dependency on imported energy sources by developing and introducing alternative energy resources. Projects carried out under the Renewable Nonconventional Energy Project No. 493-0304 include :

Industrial Biogas
Biomass Gasification
Charcoal Improvement
Energy Master Plan Support
Micro-Hydro Project
National Energy Information Center
Pyrolysis of Rice Husks
Regional Energy Centers
Solar Thermal Processes
Solar/Wind Assessment
Stove Improvement
Village Survey
Village Woodlots
Water Lifting Technology