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A FEASIBILITY STUDY OF WATER LIFTING TECHNOLOGY IN THAILAND

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EXECUTIVE SUMMARY

In this study the results from the implementation of four types of water pumping systems are presented. These include the solar pumping, wind turbine pumping, gasifier, and biogas pumping systems. These pumping projects were implemented with financial assistance from the U.S. Agency for International Development (USAID). Among these four pumping systems, only the solar and wind turbine pumping systems have been installed to date.

One 700-watt solar pump was installed to pump water from a ground water well at Ban Tha Yiam, Sakon Nakhon Province, for domestic consumption. The pumping volume was approximately 6m^3/day with a lifting head of 21.5m. The investment cost of this solar pump was 357,550 Baht (US $ 15,546), of which 235,980 Baht (US$ 10,260) was contributed by USAID. An economic analysis revealed that the benefit-cost ratio (B/C) of this solar pump was 0.49:1, and that the solar pumping system is not yet economically feasible. This is due to the high cost of the solar array.

The other 4,300-watt solar pump was installed at Ban Sukorn, Nakhon Ratchasima Province, to pump water from a storage pond for irrigation purposes. The pumping volume was estimated to be about 480 m^3/day with a lifting head of 5.0 m. The investment cost was 1,094,555 Baht, (US $47,589), of which 944,127 Baht (US 41,049) was contributed by USAID. An economic analysis showed that the benefit-cost ratio of this solar pumping system was 0.42:1, and that the installed system is not economically feasible.

Three windmills were installed at Ban Samoh, Yala Province, to pump water for irrigation purposes. These included two multi-blade windmills and one VITA windmill. The investment costs of these three windmills were 80,000 Baht (US $ 3,478), 56,000 Baht (US $ 2,435) and 45,380 Baht (US$ 1,993), respectively. These windmill costs were contributed by USAID. An economic analysis revealed that the wind turbine water pumping system was not economically feasible, with the benefit-cost ratio ranging from 0.47:1 to 0.81:1.

From this study it can be concluded that the solar and wind turbine pumping systems are not economically feasible at the present time due to their high investment costs. The promotion of these types of renewable energy projects should be postponed until the price of the solar array and the windmills are decreased to a certain value.

Though the installed water pumping systems were found to be not feasible from an economic point of view, there still exist some indirect benefits from such a development. These include initiating the role of cooperation in rural development, fostering close cooperation between local people and the government, and initiating the application of energy technologies for the rural people.

CONCLUSIONS

The study on the development of these renewable evergy projects leads to the following conclusions :

A. THE SOLAR PUMPING SYSTEM AT BAN SUKORN

This solar pumping system has been planned to pump water from the Pradok Reservoir for irrigating the agricultural lands in Ban Sukorn, Nakhon Ratchasima Province. There are a total of 112 households with 646 residents in this village. Most of the villagers are farmers. Rice is the dominant crop. The system is designed so that the nominal maximum power at the standard condition of solar array (100 mW/cm^2 at 25°C) is not less than 4,300 Watts. Four sets of solar arrays, DC motors and self-priming centrifugal pumps were installed. Each solar array consists of 32 modules of solar cells. The designed pumping discharge is 480 m^3/day at 5.0-m lifting head.

The total cost of this system, excluding the cost of the irrigation canal, was 1,094,555 Baht (US$ 47,589) of which 944,127 Baht (US$ 41,049) was contributed by USAID. An economic analysis shows that the benefit-cost ratio of this solar pumping system is 0.42:1, and that the installed system is not economically feasible.

Due to a delay in constructing the irrigation canal, this solar pump has not yet been operational.

B. THE SOLAR PUMPING SYSTEM AT BAN THA YIAM

This system was installed to pump water from a ground water well to serve the villagers in Ban Tha Yiam, Sakon Nakhon Province. There are 57 households with 347 residents in this village. Agriculture is the main occupation of the villagers. Rice is the dominant crop grown in this area. The installed system has been designed so that the nominal maximum power at the standard condition of solar array is not less than 700 Watts. A solar array with 18 modules of solar cells was installed together with a DC. motor and a screw-type pump. The designed flow rate was 10 m^3/day at a 21.5 m head. However, due to an increase in the draw-down level in the ground water well, the daily pumping discharge was approximately 6 m^3/day. The results obtained from the test-run show that the overall efficiency of this system varies between 0.9-1.6%. Its value decreases as the solar panel temperature increases.

The total investment cost for this solar pumping system was 357,550 Baht (US$ 15,546) of which 235,980 Baht (US$ 10,260) was contributed by USAID. An economic analysis reveals that the benefit-cost ratio of this solar system was 0.49:1 and that the system is not economically feasible.

C. THE WIND TURBINE PUMPING SYSTEM AT BAN SAMOH

Two multi-blade and one VITA windmill were installed at Ban Samoh, Yala Province, to pump water from storage ponds for irrigating the village agricultural area. There are 204 households with 868 residents in this village. Most of them are farmers. Rice and rubber are the main crops grown in this area.

The test run of these windmills showed that the windmill speeds and the pump discharges increased linearly with the wind speed. For the large multi-blade windmill, the monthly pump discharge was 274 m^3 at a mean wind speed of 2 m/s and the value increased to 667 m^3 with a mean wind speed of 6 m/s. The overall efficiency decreased as the wind speed increased. A value of 14% was computed for a wind speed of 2 m/s. The volumetric efficiency of the pump unit was as high as 98-99%.

For the VITA windmill, the measured monthly discharge was 5,500 m^3 at a mean wind speed of 3 m/s and the value increased to 12,500 m^3 at a mean wind speed of 6 m/s. The overall efficiency also decreased as the wind speed increased. A value of 3.3% was computed for a wind speed of 4 m/s. The PVC ladder pump was used with this windmill. The volumetric efficiency was 71% at a wind speed of 2 m/s and the value decreased to 63% as the wind speed increased to 6 m/s.

The investment costs of these three windmills were 80,000 Baht (US$ 3,478), 50,000 Baht (US$ 2,435) and 45,830 Baht (US$ 1,993), for the two multi-blade windmills and the VITA windmill, respectively. These windmill costs were contributed by USAID. An economic analysis reveals that the benefit-cost ratio of these windmills varied from 0.47:1 to 0.81:1, and this showed that the wind turbine pumping system is not economically feasible.

RECOMMENDATIONS

The study on the implementation of these pumping systems can lead to the following recommendations:

- Since the solar pumping systems are not financially feasible (compared to diesel engine-pumping systems) at the present time, the promotion of this energy technology should be limited until the cost of the solar array is decreased to a certain value or benefit from having water for irrigation shows that it is suitable for rural development.

- More research should be conducted to investigate the performance of various components of the system, to obtain data necessary for future project designs and to study the problems which might be encountered in the operation and maintenance of such a system.

- The investment costs of the installed windmills are rather high at this time, which makes the project not financially feasible. However, the benefit-cost ratios show that the utilization of windmills are near-term feasible. Therefore, more development of the windmill should be made with an aim of reducing the construction costs and increasing the overall efficiency.

- Since there are some indirect benefits resulting from the participation of the villagers, the system should be maintained and improved so that the utilization of the water lifting technology would be self-sustaining.

- The project would be more successful if some villagers were trained during the installation of the systems and during the testing runs.

- Monitoring activities should be continued to obtain further information concerning benefits on income resulting from providing water for irrigation since the water lifting project needs considerable time to obtain information after installation.

- Efficient utilization of pumped water should be emphasized and villagers should be educated along these lines.

- Villagers' needs and willingness to participate in the project should be carefully studied during the site selection phase in order to assure a more successful outcome during implementation.

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TERMS AND ABBREVIATIONS

AC	=	alternating current
amp.	=	ampere
B/C	=	benefit-cost ratio
BOD	=	biochemical oxygen demand
Btu	=	British thermal unit
bhp	=	brake horsepower
°C	=	degree Celsius
COD	=	chemical oxygen demand
C/N	=	carbon-nitrogen ratio
cm	=	centimeter
DC	=	direct current
ft	=	foot
g	=	gravitational acceleration
HP	=	horsepower
hr	=	hour
in.	=	inch
J	=	joule
kg	=	kilogram
km	=	kilometer
kW	=	kilowatt
kWh	=	kilowatt-hour
lb	=	pound
lt	=	liter
M฿	=	million Baht
MSL	=	mean sea level
MW	=	megawatt
M.6	=	Mathayom 6
m	=	meter
mm	=	millimeter
min.	=	minute
mW	=	milliwatt

NEA	=	National Energy Administration
O & M	=	operation and maintenance
P.6	=	Prathom 6
ppm	=	part per million
rpm	=	revolution per minute
s	=	second
UNDP	=	United Nations Development Programme
V	=	volt
VS	=	volatile solid
W	=	watt
Wp	=	peak watt
wt	=	weight

CHAPTER 1

INTRODUCTION

INTRODUCTION

This report summarizes the results of the installation, operation and maintenance studies of water pumping systems. This project was implemented with financial support from the United States Agency for International Development (USAID) and with technical assistance from the National Energy Administration (NEA). Four types of water pumping systems were considered at the beginning stage of the project. These were the solar water pumping system, wind turbine water pumping system, gasifier water pumping system and biogas water pumping system. Two solar water pumps and three wind turbine water pumps were installed and operated.

A. OVERVIEW OF THE COUNTRY

In this section, a general description of the geographic and climatic conditions, energy and agricultural situation of Thailand is provided to show the background of the country and the need to search for renewable energy sources rather than relying on the fuel oil which must be imported.

Geographic and Climatic Condition of Thailand

The Kingdom of Thailand is located in the Indochina penninsula, within the Southeast Asian continent. Her boundary borders Burma and Laos to the north, Laos and Kampuchea to the east, Burma to the west, and Malaysia to the south. The specific location is given as between latitudes 5° 37' and 20° 27' north and between longitudes 97° 22' and 105° 37' east.

Lying between 6 and 20 degrees north latitude, with a rainy season from mid-May to early November, Thailand's climate is warm and moist. Four torrential rivers, the Ping, Wang, Yom, and Nan that rise in the high mountains of the north descend through the North and Central sections of Thailand, flow through the loam-filled delta and empty into the Gulf of Thailand. This low flat area is known as the Central Plains. Soon after entering the plain, the four rivers join to form the principal river of the country, the Chao Phraya River. This flows for 77 km in a single course and then braids into several channels across the flood plain. These reunite, after being joined by lesser tributaries, and flow into the gulf in two main channels, the Chao Phraya and the Thachin River.

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The southwest and northeast monsoons exert a dominant influence on the climate of Thailand. The southwest monsoon, flowing from the Indian Ocean, brings the warm and moist air mass to the country and normally extends from about mid-May to October. During this period, local atmospheric disturbances are common and quite frequent. They are generated in the form of atmospheric low pressure cells of rather short duration. They are also the chief contributors of rainfall over the country and the basin as well. As the season progresses, cyclonic storms usually originate in the west Pacific Ocean and the China Sea. These storms occasionally approach the basin from the east, but before reaching the basin they cross the mountains of Laos and Kampuchea, where a lot of their energy is dissipated.

With the retreat of the southwest monsoon, the rain decreases rapidly and the northeast monsoon flowing from the cold and dry Asian mainland, starts the winter from November to February. There is very little or no rain during this period. During the months of March to mid-May the weather is hot and dry, it is gradually warmer from the start and April appears to be the hottest month of the year. However, at the end of this period, there will be occasional light rain known as the pre-monsoon rain.

According to the above climatic conditions, the climate of the basin can be separated into two seasons, wet and dry seasons, by the characteristic of rainfall distribution. The wet season is generally defined from May to October, and the dry season is from November to April.

Thailand's Energy and Agricultural Situations

Thailand's economics are primarily based on agriculture. Rice is the main crop. Fuels, other than wood, are mostly imported. In this section, the energy and agricultural situations of Thailand are briefly described.

Thailand's energy situation

Energy is recognized as one of the most essential elements in the development of a country. Thailand has undergone several national economic and development plans since 1961. These development activities have resulted in a rapid increase in energy demand by approximately 8 fold during the past 20 years, from 2,231 million liters of crude oil equivalent in 1962 to 17,489 million liters in 1981. Similarly, the energy consumption per capita increased approximately 5 fold, from 76.0 liters of crude oil equivalent in 1962 to 366.6 liters in 1981.

Statistics show that Thailand depends heavily on imported crude oil and petroleum products, from approximately 50% of the total energy consumption in 1962 to 80% in 1981. An insufficient supply of indigeneous energy has had a serious effect on the national economy. The energy import bill in the year 1982 accounted for 58,799.2 M฿ or approximately 38% of the total import bill.

As a result of the world-wide energy crisis during 1973, the government put great emphasis on the development of indigeneous energy resources and energy conservation strategies. This policy is well recognized in the Fifth National Social and Economic Development Plan. The target can be summarized as follows:

- The energy consumption growth rate has been set at not more than 4.8 percent per annum.

- The petroleum import is fixed at 3 percent or less.

- The share of petroleum in the total energy consumption is to be reduced to 46 percent by the end of this plan (1986).

- The development of natural gas in the Gulf of Thailand is to be accelerated in order to yield 525 million cu.ft. per day by 1986. A gas separation plant of 350 million cu.ft. capacity is also to be completed by that year.

- The hydroelectric power capacity shall be doubled by 1986, from 1,269 MW in 1980 to 2,013 MW in 1986.

- Electricity generation from indigeneous lignite shall be increased from 210 MW in 1980 to 885 MW in 1986.

- Ninety-two percent of the rural villages in Thailand shall be electrified by the end of the plan, from 18,511 villages in 1980 to 50,034 villages in 1986.

- Petroleum reserve and refinery capacity shall be increased, from 36 to 60 days, and from 176,000 barrels per day to 280,000 barrels per day, respectively.

- Other new and renewable energy resources, such as ethanol, fast growing trees, mini-hydro, biogas, agricultural wastes, wind, solar, etc., shall be developed and utilized at the annual equivalent of 220-290 million liters of crude oil by 1986.

Agricultural situation

Thailand is an agricultural country. Agricultural products have been major exports from Thailand for several decades. Rice is the major production item, followed by rubber, maize, and cassava. Table 1.1 shows the yield and production of major crops in Thailand in 1980.

TABLE 1.1 YIELD AND PRODUCTION OF MAJOR CROPS (1980)

Crops	Area Planted (10^6 Rai)	Yield (kg/rai)	Production (10^6 Tons)
Paddy (rice)	47.400	282.9	13.41
Sugar Cane	.738	6,917.9	5.102
Cassava	1.194	2,579.2	3.079
Maize	4.250	400.0	1.700
Coconut	1.856	388.5	.721
Kenaf	2.356	158.2	.373
Rubber	7.775	36.3	.281
Mung beans	1.300	130.7	.170
Ground nuts	.644	192.6	.124
Sorghum	.219	320.0	.07
Soy beans	.300	160.0	.048
Cotton	.581	75.7	.044
Castor beans	.231	128.6	.037
Tobacco	.138	117.0	.020
Sesame	.163		.019

Need for Irrigation

Agricultural production is considered as a national economic indicator of the country. However, in recent years, the agricultural economic growth rate has increased very slowly. Agricultural yields have remained relatively constant and in some cases have decreased. The growth in agricultural output is only due to an expansion of farm land area.

With regard to the national interest, the expansion of farm land area will contribute serious future problems to the country, i.e., deforestation. It is, therefore, necessary to promote and to convince farmers to use other means to increase agricultural yield, such as irrigation, fertilization, mechanization, proper uses of pesticides, etc.

Lack of irrigation is generally recognized as an important obstacle for improving agricultural yields, Irrigation can be achieved by many different approaches, e.g. large reservoir and irrigation canal systems, large electrical pumping stations, small pumping system, etc.

Large scale irrigation project implementations are currently underway by the Royal Irrigation Department and electricial pumping stations have been promoted successfully by the National Energy Administration. Groundwater is one important water source for domestic consumption and irrigation use in many regions. However, it is suitable for small scale irrigation only and commonly a diesel pump is used in such development.

Data on the total farm land area and the area served by existing irrigation projects are shown in Table 1.2. It was found that the area under irrigation is small compared to the overall agricultural area.

TABLE 1.2 TOTAL AGRICULTURAL AREA VS. IRRIGATED AREA

Region	Agricultural Area (10^6 rai)			Irrigated Area	
	rice field	other crops	total	x 10^6 rai	Percent
Northeast	29.2	19.5	48.7	1.6	3.29
Central	13.7	18.5	32.2	11.9	36.96
North	12.5	17.1	29.6	1.8	6.08
South	3.6	8.7	12.3	0.7	5.69
Total	59.0	63.8	122.8	16.0	13.03

Paddy rice plantations are mostly rain-fed. The average rainfall is 1,500 mm and is sufficient for production of the first rice crop.

For the second crop, agricultural activities are practiced only in irrigated areas, approximately 16 million rai as compared with 123 million rai of total cultivated area.

Most of the irrigated areas are in the Central region. In the Northeast, where the total cultivated area is the largest, the irrigated area is only 1.6 million rai.

B. OBJECTIVES OF THE STUDY

The objectives of this study are as follows :

1. To introduce water pumping technologies for field application in rural areas. These include solar water pumping, wind turbine water pumping, gasifier water pumping and biogas water pumping.

2. To monitor and test those systems to obtain the results necessary for techno-economical evaluation.

C. SIGNIFICANCE OF THE STUDY

The idea of using renewable energy for pumping water in Thailand has recently stimulated many technologists and development planners. However, little information is available for development planners to make any decisions concerning the feasibility of a renewable technology. Therefore, this project was formulated in order to get first hand, reliable, necessary data and experience for the management of a renewable energy water lifting project. Impacts of the study can be classified as follows :

Short Term Impacts

The short term impacts of the study include :

- Research & development activities will be formulated to solve hidden problems faced during project implementation;

- A large implementation project will be formulated for those water-lifting technologies which are feasible;

- Incentive measure for subsidizing those technologies which are near-term feasible will be investigated;

- Guidelines for manpower and budget allocations will be outlined for the government institute which will implement the renewable water-pumping project; and

- Valuable field results will be available for comparisons with other projects.

Long Term Impacts

The long term impacts of the study include :

- Proven, renewable energy water-pumping technology may be recognized on the national level, as well as the village level;

- The Sixth National Economic and Social Development Plan (1987-1991) may include suitable renewable energy water-lifting technology activities in the rural development section and/or in the energy development section; and

- Guidelines will be available for government decisions relating to the formation of a renewable energy equipment manufacturing factory in the country, as well as, for research institutions involved in research & development efforts which are geared towards obtaining necessary in-country technology.

D. SCOPE OF WORK

Energy sources for supplying water for irrigation are varied. However, in the context of this study, we will focus on small scale irrigation at a place where water is available to individual farmers or to a small community where the land area is not greater than 200 rai. Based on these criteria, solar energy technology, wind energy technology, gasification technology and biogas technology have been selected.

CHAPTER 2

REVIEW OF LITERATURE

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REVIEW OF LITERATURE

In this chapter, available reports and documents concerning the development of various renewable energy technologies are reviewed and summarized. These include solar energy technology, wind energy technology, gasification energy technology and biogas energy technology.

A. SOLAR ENERGY TECHNOLOGY

At present, utilization of solar energy can be classified into 2 main categories, i.e. the solar thermal system and the solar electrical system.

Solar Thermal System

Technologies utilizing the solar thermal process were developed in the 1870's. A solar steam engine of several horsepower was developed by Mouchot and Pifre in France in 1870. A 50-HP solar irrigation pumping engine was fabricated and tested by Shuman and Bous in Egypt in 1913. Later, internal combustion engines were developed. These engines became available at cheaper prices and were very efficient. Therefore, the developed solar pumping system was replaced by these engines.

After the world oil energy crisis, interest once again was paid to the development of the solar pumping system. The most recent developments in the solar thermal pumping system involve the use of organic solutions as a working fluid, in contrast to the pioneer work that used steam as a working fluid.

Recently, the Sofretes Company placed approximately 50 solar thermal pumps on the market. However, field results show that this was not a good time for marketing these items. Nevertheless, several organizations are still putting efforts into developing new variations of the solar- thermal pumping system, e.g. Ormat (Israel), Dornier (West Germany), Solar Pump Coorporation (USA), Hindustan Brown Boveri (India), Sun Power Systems (USA), Grinakers (Pty.) Ltd. (Johannesburg), etc.

At this point it can be concluded that, at the time of project planning, there was no potentially viable solar thermal pumping system available on a commercial basis in the world market. However, promising developments are slated to come out in the near future.

Solar Electrical System

The conversion of solar energy into electricity can be achieved by a photovoltaic process, therefore, this system is sometimes referred to

as a photovoltaic system. This technology was developed in early 1839. However, utilization as an energy source was very slow due to its very high investment cost. Even so, this technology has been used for powering satellites.

In recent year, advancements in electronic development have resulted in the production of solar cells which are more efficient with less cost. In contrast, the prices of conventional fuels have been sharply increasing. Thus, the use of solar cells for electricity generation has received more attention.

The only type of photovoltaic cell commercially available today is the silicon cell, in the mono-crystalline and polycrystalline form. Cell efficiency is within the 10-14% range for monocrystalline cells and 9-10% for polycrystalline cells.

Tremendous efforts by researchers and scientists in various regions of the world have provided relevant information indicating the production of 'new' photovoltaic cells in the near future. These 'new' solar cells will be either higher in performance or lower in cost, and may be made from other materials, e.g., gallium-arsenide cells, cuprous sulfide cells, or cadmium sulfide cells, etc.

The cost of silicon solar cells has dropped substantially ; from US $ 2,000/Wp in 1958 to US $ 30/Wp in 1976, and to US $ 8/Wp in 1983. With improvements in the manufacturing processes and techniques, the cost of solar cells is expected to be reduced to approximately US $ 0.50/Wp by 1990 (1980 price).

Photovoltaic Pumping System

A photovoltaic pumping system usually consists of a photovoltaic (solar cell) array, a battery, a motor and pump set, and a controller.

A recent investigation of solar water pumping technology (UNDP Project GLO/78/004, executed by the World Bank) revealed that there were numerous relatively minor problems being experienced during the project field testing of 12 solar pump systems in Mali, the Philippines and the Sudan. These problems were due to incorrect wiring, poor electrical terminal & connection, electronic failure, broken module cover glasses, air locks in the suction pipe, footvalves jamming or leaking, etc. It is anticipated that these problems can be solved as more experience is obtained during the course of solar pump development.

B. WIND ENERGY TECHNOLOGY

One traditional form of energy used for several centuries is wind energy. Several types of windmills are commonly seen being used for brine pumping along the Gulf of Thailand and for rice irrigation in the Chao Phraya delta. In this section information concerning wind energy technology and its potential use in Thailand is reviewed.

Wind Energy Potential in Thailand

The output of a windmill depends on the wind speed available at the site. Wind velocity continually varies in both magnitude and direction. However, it is broadly predictable over a significant time period. Statistics show that there is approximately a 7-14 km/hour average wind speed available in Thailand. A recent study predicted that the highest mean wind speed occurs along the coastline and in the southern part of Thailand. The wind power density ranges from 7.6 W/m^2 at Mae Hong Son to 71.8 W/m^2 at Songkhla. Table 2.1 summarizes the average wind power potential in various parts of Thailand.

Wind Energy Development Technology

At present there are three basic types of windmills; the slow-speed sail rotor type, the high-speed wooden rotor type and the multi-blade steel rotor type.

Windmills of multi-blade type are now used for pumping water for consumption and household needs. For irrigation needs, improved windmills of a sail rotor type are being promoted. However, the high speed wooden blade type is rarely seen since it requires a higher starting wind speed. Table 2.2 shows an estimate of windmills presently in use.

C. GASIFICATION ENERGY TECHNOLOGY

Gasification Technology was utilized in Thailand during the late World War II period when fossil fuels were scarce. However, this technology was abandoned in the post war years when low petroleum prices reappeared.

Interest in utilizing this technology again become high after the world energy crisis of the 1970's. The technology attracted researchers and government planners around the world as it appeared to be suitable for use in rural areas to run engines for shaft power or for producing electricity.

Run on a locally available wood or charcoal, a gasifier converts biomass fuels into a combustible gas, mainly carbon monoxide (CO), which can be used to substitute up to 80% of the diesel fuel needed for diesel engines or entirely substitute the gasoline fuel used in gasoline engines.

Availability of Biomass Material

Wood and charcoal are major fuel sources for rural people. They are available locally and inexpensively compared to other conventional

TABLE 2.1

AVERAGE WIND POWER POTENTIAL

Place	Wind Power Potential (kw/km^2)	Place	Wind Power Potential (kw/km^2)
Bangkok	6.184	Kanchanaburi	8.509
Koh Samui	29.592	Koh Sichang	19.038
Khon Kaen	5.448	Phumipol Dam	6.576
Khlong Yai	8.379	Chantaburi	3.977
Chonburi	14.216	Chum Phon	24.125
Chaiyaphum	9.515	Chiang Rai	3.800
Chiang Mai	5.507	Sap Muang	6.561
Don Muang	40.970	Trang	20.728
Tak	10.577	Nakhon Phanom	5.324
Korat	4.391	Prachuap Khri Khan	17.996
Nakorn Sri Thammarat	8.722	Narathiwat	11.943
Nan	2.122	Pattani	12.021
Prachin Buri	5.411	Phetchabun	6.184
Phitsanulok	2.010	Phuket	6.121
Phrae	5.349	Mukdahan	11.020
Phuket Airport	28.968	Mae Sariang	2.440
Mae Sot	11.227	Roi-et	6.775
Mae Hong Son	1.525	Lop Buri	7.537
Ranong	8.163	Lam Pang	3.081
Loei	5.239	Songkhla	32.799
Sakhon Nakhon	9.885	Surin	4.279
Suparn Buri	9.091	Sattahip	36.292
Surat Thani	4.732	Hat Yai	16.972
Nong Kai	4.099	Aranyaprathet	4.360
Hua Hin	13.120	Udon Thani	2.483
Uttaradit	1.364	Ubon Ratchathani	17.372

Source : Panich, Banterng, Boonchai and Kwan, (1981)

TABLE 2.2 WINDMILLS USED FOR WATER PUMPING IN THAILAND

Nomenclature	No. in Use	Manufacturer	Price (Baht)	Technical Data
A. *Popular windmills used*				
Bamboo Mat Sail Type	3,000	Villager, Local factory	9,500	Blade Diameter: 6-8 m Pumping Capacity: 46 m^3/hr Total Lift Head: 0.6 m Wind Velocity: 13 km/hr
2-4 Wooden Blades Type (Cha Chueng Sao)	3,000	Villager, Local factory	1,200	Blade Diameter: 6-8 m Pumping Capacity: 90 m^3/hr Total Lift Head: 0.9 m Wind Velocity: 21 km/hr
Multi-Blade Type (U.S.A.)	1,500	Thai U.S.A.	See Table 3.1	See Table 3.1
Multi-Blade Type	300	Chonburi	Unknown	Unknown
B. *New developed windmills*				
Sail Wing Type (NEA)	20	National Energy Administration	12,000	
Sail Wing Type (K.U.)	3	Kasetsart University	12,000	Blade Diameter: 4 m Pumping Capacity: 1.7 m^3/hr Total Lift Head: 4.5 m Wind Velocity: 10-12 km/hr
Cycle Wheel Type	2	Songkhla University	12,000	Blade Diameter: 3.2 m Shaft Power 125 w Wind Velocity: 3 m/s
Multi-Blade Type	8	King Mongkut's Institute of Technology	33,000	Blade Diameter 3-4 m Piston Diameter 4 m No data test
Sail Wing Type	20	American Volunteer	Unknown	Designed by Sahores
Savorous Type	10	Several Organizations	Unknown	Low efficiency
Augmented Turbine	2	Kamthorn' Plysummit	Unknown	Sail Wing Data: 3.8 m Turbine Diameter 1.2 m Height of Turbine: 1.2 m Pumping Capacity: 0.46 m^3/min Total Lift Head: 0.5 m Wind Velocity: 10 km/hr

Source: National Research Council, Bangkok (1981)

fuels. Charcoal is the best fuel source to feed a gasifier. However, considering the fact that there is a loss in energy of approximately 70 percent in converting wood to charcoal, it appears that wood would be the better choice. Unfortunately, there are few acceptable small wood gasifiers on the world market today that are able to produce tar free gases suitable for use in an internal combustion engine.

Another unfortunate fact is that even though wood fuels seem to be substantial available locally (as shown in Table 2.3), energywise, the quantity of wood (1,289 million m^3) is roughly comparable to only 1,000 million barrels of crude oil or approximately 6% of the total national energy consumption in 1982. Nevertheless, wood fuels are presently an important resource; first as a source of cooking fuel for rural people ; secondly, as a resource in the wood industry; and third, for use by the country as a natural forest.

Therefore, if the wood or charcoal gasifier is to be promoted on a national scale, it is essential that the woodlot plantation be implemented where the gasifier is used.

Fast growing tree species suitable for Thailand's soil and climatic condition are the *Eucalyptus Camaldulesis* and the *Casuarina Junghuniana*. Table 2.4 shows the estimated yield of these tree species.

TABLE 2.3 AREA AND PRODUCTIVITY OF FORESTS IN THAILAND

Region	Area (million ha)	Productivity (m^3/ha)	Growing stock Volume (10^6 m^3)
North	11.3	53	599
Northeast	7.8	29	223
Central	4.7	46	220
South	3.2	77	247
Total	27.0	48	1,289

TABLE 2.4 YIELD OF SELECTED FAST GROWING TREES

Species	Yield (m^3/ha/year)
Eucalyptus camaldulesis (moderate management, 5 years old)	18-75
Casuarina junghuniana (intensive management, 5 years rotation)	13-44
Other (poor management, 10 years old)	10-15

Present Status of the Technology

Combustible gases from biomass can be produced from a device called a gasifier. This device may be classified into three basic types : Updraft gasifier, downdraft gasifier, and crossdraft gasifier.

In the updraft gasifier, the air is taken in through a grate at the bottom of the gasifier and the biomass fuel is fed from the top. The direction of air flow is reversed in the case of a downdraft gasifier. In the crossdraft gasifier, air is introduced through a horizontal nozzle in the wall of the gasifier and the gas is taken out the opposite side. The main difference between the updraft and downdraft gasifiers is that more combustible gases are generated in the updraft gasifier and more clean gases are produced in the downdraft gasifier when generating combustible gases for an internal combustion engine. As stated earlier, gasification technology was once abandoned because it was not economical compared with the cheaper fossil fuels during and after the post-war period. Also, there are many minor problems associated with the use of gasifier engines ; they require intensive maintenance, they are difficult to start, they require a skilled operator, there is a health hazard if not used properly and no design currently exists for a gasifier that is able to use all types of biomass and charcoal.

It is therefore not surprising that many research and development activities in Thailand (as shown in Table 2.5) are attempting to improve the weakness associated with a gasifier and to demonstrate that it is an economical energy choice.

TABLE 2.5 RESEARCH AND DEVELOPMENT ACTIVITIES IN THAILAND

Institute	Gasifier type and engine	Fuel	End use	Status
1. Department of Agricultural Technology	Updraft 5 HP Gasoline engine	Charcoal	Water pumping	Under improvement since 1980
2. Prince of Songkhla University	Downdraft 5 HP gasoline engine coupled to 2 kWe generator	Commercial charcoal, Rubber tree charcoal	Electricity	Experimental plant operated more than 500 hr since 1980
	Downdraft 35 HP gasoline engine driving a 10 kWe generator	Commercial charcoal, Rubber tree charcoal, Rubber tree wood, Coconut shell	Electricity	In operation for approximately 1,000 hr
	Downdraft 24 HP diesel engine driving a 10 kWe generator	Commercial charcoal, Rubber tree charcoal, Rubber tree wood	Electricity	Under performance
3. Chulalongkorn University	Downdraft 500 We	Charcoal	Electricity	Under construction
	Downdraft 7 HP	Cubed rice straw	Water pumping	Under construction
	Downdraft 14 HP	Wood	Water pumping	Under construction
	Fluidized bed	Rice Husk		Being planned
	Downdraft 25 kWe	Corn cobs, wood chips	Electricity	Under construction
	Downdraft 40 kWe	Rice Husks	Electricity	Being planned
4. King Mongkut's Institute of Technology (North Bangkok Campus)	Updraft	Charcoal	Water pumping	Under improvement since 1981
5. Department of Public Works	Downdraft 25 HP gasoline engine coupled to 15 kWe generator	Charcoal , wood	Electricity	In operation since 1982
6. National Security Command Headquaters	Downdraft 12 kWe	Charcoal	Electricity	In operation at Kumdogmai village in Udorn Thani province since 1982

TABLE 2.5 (CONT.)

Institute	Gasifier type and engine	Fuel	End use	Status
7. Ministry of Industry	Downdraft 12 kWe	Charcoal, wood	Electricity	Field test to start in 1983
8. Kampangphet Provincial Public Works office	Downdraft 5 kWe	Charcoal	Electricity	In operation
9. Patumwan Technical Institute	Downdraft 16 HP engine coupled to generator	Charcoal	Electricity	Under improvement since 1982
	Downdraft 12 kWe	Charcoal	Electricity	
10. The Royal Forest Department (RFD)	Downdraft 10 kWe	Wood	Electricity	Under improvement since 1982
11. National Energy Administration (NEA)	Downdraft 5 HP gasoline engine	Charcoal, wood	Water pumping	Under performance testing
	Downdraft 30 HP gasoline engine coupled to 10 kWe generator	Charcoal, wood	Electricity	Test scheme to start July 1983

TABLE 2.5 (CONT.)

Institute	Gasoline type and engine	Fuel	End use	Status
12. Private sector Kanjanaburi				
	Updraft 120 HP diesel engine	Charcoal	Passenger boat	In operation on the River Qai in Kanjanaburi Province since 1981
	Updraft 260 HP diesel engine	Charcoal	Rice mill	In operation at Amnuaypol mill in Supanburi province since 1981
	Updraft	Charcoal	Electricity	In operation
13. Prasathong cinema Supanburi	Updraft	Charcoal	Electricity	In operation since 1981
14. Private sector, Petchabul	Updraft 260 HP diesel engine driving a compressor 150 HP	Charcoal, lignite	Ice-making	In operation since 1981
15. Private sector, Chacherngsao	Updraft 160 HP diesel engine	Rice husk	Electricity	In operation since 1982
16. Srimaharacha Co.,	Downdraft 12 kWe	Charcoal, wood	Electricity	Under improvement since 1980
17. V.S. Factory	Downdraft	Wood, anthracite	Burner	Under improvement for commercialization since 1983

Source : National Energy Administration

D. BIOGAS ENERGY TECHNOLOGY

Overview

Biogas has been known for decades. Sanitary engineers are familiar with the treatment of domestic sewage sludge and organic wastes by methane digestion. A methane is a container which keeps organic wastes in such a manner that natural bacterial degradation of the organic matter occurs in the absence of oxygen. In other words, methane digestion is an anaerobic process in which organic wastes are converted to methane gas and carbon dioxide. For animal manures, the anaerobic process yields approximately 55-65 percent methane, 35-45 percent carbon dioxide and very small amounts of nitrogen, hydrogen, oxygen, and hydrogen sulfide.

In anaerobic digestion, organic matters are mixed with large populations of micro-organisms under the absence of oxygen. Initially, there is no methane formation. Complex organic materials such as fats, proteins and carbohydrates are biologically converted to organic fatty acids by acid-forming bacteria. Later on, the organic acids are converted to methane and carbon dioxide by methane forming bacteria.

The gases yielded from the process are commonly known as biogas. It is combustible and can be used as a substitute for fossil fuel for lighting, cooking, gas engines, gas refrigerators, etc.

Availability of Biomass Material for Biogas Generation

Various biomass materials and organic wastes can be used as a raw material for a methane digester. At present, animal manures are the most popular choice for rural people. Other materials can be used but they need to satisfy certain conditions if high energy gas is required. For an agricultural country like Thailand, these biomass materials are available in excess, provided a proper collection is instituted.

Status of Technology

Biogas digesters have been utilized by the Sanitation Division of the Health Department in rural areas since 1970. These were primarily introduced for public health and welfare reasons as the biogas digester gets rid of undesirable wastes that can cause serious diseases among rural people.

Later on, the National Energy Administration began an extensive program for the demonstration and promotion of biogas digesters in order to produce combustible gas fertilizer in addition to the environmental and health protection aspect.

Several biogas digester designs exist in Thailand at present. The Chinese and Indian designs have been modified and adapted to suit Thailands

local conditions. Several other types of biogas digesters also exist, e.g. the Thai water jar type and the Taiwan rubber bag type.

The promotion of biogas utilization as an energy substitute has begun recently. The campaign is considered to be a joint venture by the National Energy Administration (NEA) and several public and private organizations, e.g. the Health Department, the Public Welfare Department, the Agricultural Extension Department, the Co-operative Promotion Department, the Community Development Department, the Office of Accelerated Rural Development, etc.

Table 2.6 shows the number of biogas digesters available in Thailand, as compiled by the NEA in 1984. During 1970-1983, there were more than 4,953 biogas digesters in the country. Two were community biogas plants for electricity production for a typical sized village in the Northeastern region.

TABLE 2.6 NUMBER OF BIOGAS DIGESTERS IN THAILAND

Year	No.of Digesters
1970-1976	207
1977	41
1978	23
1979	151
1980	370
1981	643
1982	1,668*
1983	1,790*

Remark : * incomplete information

Biogas utilization can be applied to cooking, lighting, heating, electrical power or mechanical power. Some adjustment or adaptation of the energy equipment is needed in order to operate them with a biogas. Table 2.7 indicates the typical rate of biogas consumption for various equipments under normal operating conditions.

TABLE 2.7 BIOGAS CONSUMPTION FOR TYPICAL EQUIPMENT

Item	Consumption
Lighting	2.5-3 ft^3 per mantle per hour
Cooking	11-16 ft^3 per hour per 2-4 in, burner 12-15 ft^3 per person per day
Gas Refrigerator	1.1 ft^3 per hour per cubic foot
Gasoline Engine	1.7 ft^3 per bhp per hour

CHAPTER 3

BASIC DESIGN OF THE STUDY

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BASIC DESIGN OF THE STUDY

In this chapter the system performance, the basic design considerations plus the operation and maintenance of four types of water pumping systems are described. These include the solar water pumping system, the wind turbine water pumping system, the gasifier water pumping system and the biogas water pumping system.

A. SOLAR PUMPING SYSTEM

System Performance

The solar water pumping system consists of a number of solar cells, a direct current (DC) motor, and a water pump. The solar cells convert the solar energy into an electrical energy; this is known as a photovoltaic system. The electricity produced is then used to drive the DC motor and the water pump. This water pumping system holds great promise for small-scale irrigation and for supplying a community domestic water supply.

The key element of the solar module is the silicon solar cell. Each solar cell has an electrical potential of about one-half volt when exposed to bright sunlight. Peak power will be produced at 0.45 to 0.48 volts per cell. The amperage of a cell is dependent on the cell's area. An assembly of these solar cells, wired in series, makes up a solar module. To produce the required ampere-hours/day for a water pumping system a number of modules are assembled on a support structure making an array with the required output.

A photovoltaic array consists of several photovoltaic (solar cell) panels which are arranged in series and parallel according to specific purposes. Each panel converts sunlight to electricity through silicon cells which are approximately 100 mm in diameter and either square or triangular in shape. Each cell produces 25 milliamperes of direct current per square centimeter under a solar irradiance of 1 kW/m^2 at 25 Celcius and approximately 0.5 volts under nominal operating conditions. These cells are usually connected in a series or 'string' to build a voltage up to a required level. The cells are sandwiched to form a rectangular panel and covered with either glass or clear plastic.

An important feature of a solar panel (module) is that it should be rugged and capable of resisting ultra-violet radiation, thermal cycling, shock, moisture penetration, etc, in order to sustain its performance even under severe operating conditions.

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A solar module is usually rated in terms of 'Peak Watt', i.e., the power a module can produce at an irradiance of 100 Watts per cm^2 at 25 Celcius.

The battery stores the electrical energy which is produced through an electrochemical process. In the photovoltaic system, a battery can store excess energy and deliver electricity to load when there is no solar radiation. Therefore, the addition of a battery in a system will facilitate operation, guarantee that a system will provide power at any time, and act as a power buffer between an array output and load. However, several disadvantages are also built-in when using a battery, for example, high capital investment, and extra control equipment is needed to regulate the charging operations.

Batteries are usually rated in terms of their ampere-hour capacity. Other important specifications include : rated voltage, operating temperature, self-discharge rate, rated current, life-cycle, size, weight and cost.

A motor & pump set in solar pumping applications has a variety of combinations. For a motor, there are choices between : a brush or brushless direct current (DC) motor, an alternating current (AC) motor with DC to AC inverter, or a motor with a maximum power point tracker. For the pump, there is a choice of : a centrifugal pump, a rotary pump, a piston pump or a submersible pump, etc.

Today, there is no designated motor and pump combination which would generally be accepted as the best. In the selection of a motor and pump set, the following should be considered : the water requirement and head conditions, the meshing between the motor and pump set with the solar cell array, the water needs and its duration, environmental and operating conditions, etc.

Nevertheless, experiences to date have lead to the following conclusions :

- For systems up 1 HP, a DC motor with a permanent magnet is generally used ;

- For systems of 1-3 HP, a DC motor of a shunt field type or an AC motor are most commonly accepted ;

- For systems above 3 HP,

- A maximun power point tracker is an electronic controller used to mesh the power from a solar array to the load. This device may cause some breakdown during operation. Therefore, if the system is well designed, the deployment of the controller in the system is unnecessary ;

- When a dynamic head dominates, a centrifugal pump is favored, while in other cases, batteries or sophisticated controls should be used to reduce

useful energy losses from mismatching ; and

- The introduction of batteries or sophisticated controls are expensive and require extra maintenance.

The pump/motor should be securely mounted to a foundation that is level and free from movement in an area clear of materials that could interfere with the operation of the unit. It should be located as near the source of water as practical to minimize the vertical lift of water to the pump and so that a short suction pipe with a minimum number of fittings can be used to keep the pipe friction loss as low as possible.

A strainer should be installed at the inlet end of the suction pipe to prevent solids from clogging the pump. The selection of the pipe size is dependent on the flow rate.

If possible, shelter should be provided for the pump and motor unit to protect them from the weather. Adequate space around the pump should be provided for service and ventilation when it is running.

A typical system efficiency may be set for each component as follows :

array cell	11%	
connection	95%	
motor	85%	
pump	50-55%	
pipe work	95%	
battery	80%	(if used, otherwise 100%)
impedance mismatch	70-90%	(if using an electronic controller, 24%)
other miscellaneous	90%	
Total for system	2.1-3.9%	

The efficiency of a photovoltaic pumping system varies depending on many factors e.g.,the combination of components, the efficiency of components, operating conditions, etc.

Basic Design Considerations

In the design of a solar water pumping system the following items should be considered.

General requirements

- The system should be designed to survive particular local climatic conditions. In areas prone to typhoons or hurricanes, it may be necessary to provide for the rapid dismantling and removal to safety of the array ;

- Pumps and motors should be provided with sunshades whenever possible, but the unit must remain well ventilated if air-cooled ;

- Materials exposed to solar radiation (such as plastics) should have proven durability ;

- Modules should be individually packed to avoid damage in transit. The safety of the contents should not be dependent on receiving special handling treatment ;

- Detailed instructions should be provided, in the local language, for the correct assembly of the system. Also included should be a components list, maintenance and operating instructions and guidance on how to achieve the best output. All documents should be written in simple terms ; and

- The need for routine mainterance lubrication and readjustments should be minimized and avoided if possible.

Array and module requirements

- The array should be manufactured with a lifetime guarantee of at least 5 years against faulty quality with no more than 10% degradation of performance ;

- Small modules (less than a 20 W nominal rating) are preferred ;

- It should be installed either with a laminated glass or an impervious and ultra-violet resistant plastic cover ;

- Optimum module cell efficiency should exceed 11% ;

- There should be no air gap between the cell encapsulant and the cover glass ;

- It should be equipped with generously sized (brass) terminals with grip screws or with appropriate plug and socket connectors ;

- Array nominal voltage under peak sunlight conditions should be around 50 V; higher voltages will not be safe, while lower voltages will mean higher currents and larger resistive losses ; and

- Quality assurance and testing to a satisfactory standard should be specified by the manufacturer. Module or array performance should be specified on the basis of tests to a stated international standard. The module/array area to which array efficiency is referred must be clearly defined.

Motor and pump

- A DC permanent magnet motor is preferred unless the alternative is shown to be of comparable efficiency ;

- Full load motor efficiency should exceed 85% ;

- Half-load motor efficiency should exceed 75% ;

- Motor bearings and other components should be sized for a life in excess of 10,000 hours ;

- Submersible units are preferred to eliminate suction problems.

- If the motor is not submersible, couplings between the motor and pump should permit significant motor and pump angular and/or parallel misalignment.

- Motor and pump bearings should be entirely independent, except in the case of integral submersible motor-pump units ;

- Thermal cut-out is required on the motor, unless the motor can sustain continuous stalled conditions with the maximum array current ;

- The pump's optimum efficiency should be in excess of 50% ;

- The pump should be capable of self-priming in the event of a leaking footvalve (where fitted) ;

- Impeller material, clearances and passages should be suitable for use with water containing suspended silt and/or corrosive salts. Open impellers are preferred ;

- Where necessary, a suitable strainer for larger particles should be provided and should be sized so as to have a negligible effect on performance while clear ;

- Pump should have bearings sized for 10,000 hours of operation and should be supplied with spare seals plus any other consumables to cover that period of operation; ball bearings with greased seals are preferred ;

- Pump characteristics should permit stable operation at sub-optimum speeds ;

- The pump should be capable of running dry without serious damage if not a submersible type ; alternatively, a fail-safe method of protection from running when dry should be provided. (with seals designed to suit) ; and

- Pipework and fittings should be correctly optimized for minimum system cost, rather than minimum pipework cost; all pipework should be supplied with system to length specified for head and site.

Specifications for the Installed Solar Pumping Systems

In purchasing solar pumping units for this project, the following specifications were given.

General requirements

- The systems shall be provided for DC pumping to be used for irrigation or water supply. Each system shall include ;

  - Photovoltaic modules and array support structure ;
  - Required motor and pump set(s);
  - One spare motor and pump set ;
  - All necessary control equipment and wiring ;
  - A voltmeter and an ampere meter to measure voltage and current from the solar cell array ;
  - All fixings and auxiliaries necessary for complete construction ;
  - All special tools needed for assembly and maintenance ;
  - Spare parts recommended for three full years of operation (including motor brushes, if applicable) ; and
  - Any other components necessary or recommended in order to provide reliable, safe operation and/or optimum efficiency.

- All components except fuses and lamps shall be guaranteed against defects in design, workmanship and material for a period of 1 year.

- Each system shall be designed to operate under the following environmental conditions :

  - Ambient air temperature between 0° C - 45° C
  - Relative humidity up to 95% at an ambient temperature of 40° C;
  - Wind speed up to 100 kilometers per hour ;
  - Water source temperature up to 35° C ;
  - Water source containing particles not exceeding 0.3 mm ; and
  - Annual average daily insolation is 17.6 MJ/m^2 per day.

- Each system shall be able to pump water when solar radiation is more than 400 $watts/m^2$.

- The solar cell unit shall be a single crystalline silicon type and the solar module shall be a complete, sealed unit consisting of a number of solar cells in series or series-parallel combination. Solar arrays are a number of solar modules connected in a series or series-parallel combination and mounted in an array frame.

- The solar cell module shall have a conversion efficiency equal to or greater than 8% when measured under standard conditions of 100 mW/cm^2 at 25°C cell temperature.

- Electrical termination shall be either screw-type or cable, suitably sealed at the entry to the solar module. All terminals shall be electrically isolated from any metal frame or support.

- The surface of the module shall be tough transparent plastic or toughened glass capable of withstanding, without damage any stresses imposed as a result of temperature cycling, wind pressure resulting from wind velocity, and other environmental changes.

- The solar array shall be mounted on a flat surface with the range of angle adjustment (the incline angle) variable from 15 to 35 degrees.

- The array frame material shall resist corrosion when installed in tropical conditions. Stainless steel, aluminium and hot dipped galvanized mile steel are considered to be satisfactory array frame materials.

- All fasteners and associated components shall be compatible with the array frame and solar modules used, to avoid corrosion. Modules shall be mounted so that they can be removed from the front by one person and all cables and interconnections shall be arranged for easy replacement.

- Where a number of solar modules are connected in series-parallel combinations, the operation of any one parallel string of modules shall not affect the operation of any other string in the event of (a) failure of a module(s) in a parallel string, and/or (b) shading of a module(s) in a parallel string. Blocking or isolating diodes shall be connected in series with each parallel series of modules.

- All cables shall be generous in cross-section, to limit resistive losses at full power to no more than 5% ; blocking diodes to result in no more than 2% loss at full power.

In this water pumping project, 3 units of solar water pumps were installed. These included a 4,300-watt unit for irrigation purposes, a 700-watt unit for domestic water supply, and a 300-watt unit for a micro-irrigation system. The designs of these solar pumping units were as follows :-

The 4,300-watt irrigation system

- The system was designed for installation at Sukorn Village, Chumphuang District, Nakhon Ratchasima Province; latitude 14° 58' N. , longitude 102° 07' E; elevation of station 188 meters above MSL; average ambient temperature 27°C;

- The nominal maximum power at the standard condition (100 mW/cm^2 at 25°C) of the solar cell shall be at least 4,300 watts to assure, with

adequate safety factor, a total water discharge of more than 480 m^3/day at 5 meters head (static suction lift is 3±1 meters) ;

- The maximum number of motor and pump sets employed in the system shall be 5 units (not including the spare set). All units shall be identical ;

- Permanent magnet DC.motor(s) shall be employed with an efficiency of more than 75% of their design rating. The pump(s) shall be of the self-priming, centrifugal type ;

- The solar array frame shall be designed so that it is suitable to install on a concrete slab with the lower edge of the frame 1.5 meters above the ground ;

- The system shall include an automatic cut-out with automatic reset to protect the system from excessive temperature, voltage or current ; and

- The system shall include monitoring/control box(es) designed for tropical conditions and high ambient temperatures for the following items :

  - Maximum power controller or maximum power point tracker, if employed ;

  - Automatic cut-out with automatic reset, if employed ; and

  - A voltmeter and ampere meter to measure voltage and current from the solar cell array.

The 700-watt water supply system

- The system is designed for installation at Ban Tha Yiam (Village 1), Non Hom, Sakon Nakhon Province ; latitude 17°N, longitude 104°E; average ambient temperature 27°C ;

- The well characteristics are as follows :

  - Draw-down depth 9.5 m for static water level ;

  - Maximum permissible pumping rate 0.94 liters/sec ;

  - Chlorine is less than 30 ppm ;

  - Iron is less than 2.5 ppm ;

  - pH is 7.8 ;

  - Total hardness is 142 ppm as $CaCO_3$;

  - Total dissolved solid is 248 ppm ;

  - Static water level is 8 m below ground level ; and

  - Depth of casing is 24 meters.

- The nominal maximum power at the standard condition (100 mW/cm^2 at 25° C) of the solar cells shall be at least 700 watts to assure, with adequate safety factors, a total system water discharge of more than 10 m^3/day at 21.5 meters total dynamic head ;

- A permanent magnet DC motor shall be employed with an efficiency of more than 75% of its design rating . The pump shall be a centrifugal pump or a suitable substitute recommended by the contractor. If a piston pump is employed, a maximum power controller shall be required ;

- The solar array frame shall be designed so that it is suitable for installation on a concrete slab with the lower edge of the frame 1.5 m above the ground ;

- The system shall include an automatic cut-out with automatic reset to protect the system from excessive temperatures, voltage or current ;

- The system shall include monitoring control box(es) designed for tropical conditions and high ambient temperatures for the following items :

  - Maximum power controller, if employed ;

  - Automatic cut-out with automatic reset, if employed ;

  - Voltmeter and ampere meter to measure voltage and current from the solar cell array ;

- All necessary piping and connections shall be provided. Pipe drop to the well shall be approximately 12 meters.

The 300-watt micro-irrigation system

- The nominal maximum power at the standard condition (100 mW/cm^2 at 25° C) of the solar cell modules shall be at least 300 watts to assure, with adequate safety factors, a water discharge of more than 50 m^3/day at 3 m head ;

- The system shall not employ a battery ;

- A DC motor shall be employed and be of the permanent magnet type ; its efficiency shall be more than 75% at the design condition. The pump shall be a self priming centrifugal pump or a suitable substitute recommended by the contractor ; and

- The system shall include a strainer, a flexible pipe or hose of not less than 3 m in length for suction, and a flexible pipe or hose of not less than 5 m in length for discharge.

B. WIND TURBINE PUMPING SYSTEM

System Performance

The wind turbine is a device which converts wind energy into mechanical energy. This mechanical energy is then used to drive a water pump. A positive displacement pump is used in this installation. This system was used for farm irrigation several hundred years age.

Technical Design

For locally made windmills in Thailand, very little information on technical performance is available. This is partly due to the fact that there is no acceptable standard testing precedure. Some typical windmill performance data are taken from manufacturer's information sheets.

Thai U.S.A. windmills

These are steel multiblade windmills 8-20 ft. in diameter. The Thai U.S.A. windmill has 20-45 blades with a piston pump 2.5-18 inches in diameter. It is claimed that these windmills can lift water at very low speeds. Table 3.1 shows typical performance data for these windmills, manufactured at the Thai U.S.A. Industrial Factory, Bangkok.

Vita windmill

The Vita windmill is designed for irrigation where a large volume of water is needed at low head. The rotor of this type of windmill is approximately 6 m in diameter with 8 bamboo or laminated wood blades. A modified rotary chain ladder pump with a 4-10 in diameter is used. Power extracted from the wind stream is transmitted to a pump by a 4-inch industrial belt.

The VITA windmill was recently developed in Thailand by Volunteers in Technical Assistance, Asia field office (VITA, Asia field office). At present, they are being manufactured and marketed by the Windmill Pump Co., Ltd., Thailand. The cost of one complete system is 45,000-78,000 Baht.

The VITA windmill, V-8 type, has a maximum pumping rate of 4,000 liters per minute with a starting wind speed of 3 meters per second and a maximum design wind speed of 140 kilometers per hour. The manufacturer claims that the unit has a 15 year working life (75,000 hours) with a water cost of approximately 0.02 Baht per m^3 of water pumped when being operated at 3.3 m/s and one meter lift.

The NEA sail type windmill

The National Energy Administration (NEA) has developed a low cost windmill which is easily fabricated from locally available materials.

TABLE 3.1 TECHNICAL DATA OF THAI U.S.A. WINDMILL

Blade Dia. (ft.)	Height (m.)	No. of Blade	Piston Dia. (in.)	Water pumped (lt/hr)	Wind Velocity (km/hr)	Price (Baht)	Note
8	15	20	2.5	1,200	10	28,000	1) Price effective Sept 27, 1982
10	15	30	3	2,000	10	35,000	
12	15	30	4.5	2,500	10	51,000	2) Excluding installation cost
14	15	30	6	6,000	10	64,000	
14	15	30	10	12,000	10	71,500	3) Installation cost charge is 3,500-4,500 Baht, depending on distance.
16	15	45	12	16,000	10	93,000	
18	15	45	16	20,000	10	100,000	
20	15	45	18	24,000	10	120,000	

The unit is a typical old-fashioned sail type windmill. However, several improvements have been made. The NEA Sail Type windmill (model WE 002) has 8 sail wings attached to 5.40 m long wooden spars. Each sail wing is made of a plastic coated fabric within area of 2.4 m^2. The rotor diameter is 6 meters with a steel shaft for mechanical power transmission. The piston pump is a single stroke type with a displacement of 125 mm. The piston rod is 76 mm in diameter and is made with a thick PVC piston bore and a camel leather piston ring.

Specifications of the Installed Windmills

In this study, three windmills were installed in Ban Samoh, Tambon Ta-tong, Amphoe Raman, Yala Province. These included two multiblade windmills, and a VITA type (V-20B) windmill.

The multi-blade windmill

- Each blade is made of a galvanized steel sheet fixed on the L-shaped steel frame. The diameter of the wind blade is 3.05 m (10 ft). This wind blade is installed on a steel support at an elevation of 12 m above ground level ;

- The water pumping system is a single stoke type with a piston diameter of 7.5 cm (3 inches). The stoke length is 7.5 cm (3 inches) ; and

- The water well is a dug well with the water table 4.50 m below ground level.

The V-20B type vita windmill

- There are 25 blades made of bamboo and fixed to an L-shaped steel frame. The center of the blades is approximately 7.5 m above ground level ;

- Water pumping is accomplished by using a PVC ladder pump with a 6-inch diameter ; and

- This windmill will provide high starting torgue and low speed which is suitable for the ladder pump. The blades can start the pump with a wind speed of 4 m/s and will continue rotating as long as the wind speed does not drop below 2 m/s.

C. GASIFIER PUMPING SYSTEM

The gasifier pumping system consists of a reactor, a feeding bin, a gas cleaner and cooler, a mixing box, an internal combustion engine and pump set. (Figure 3.1)

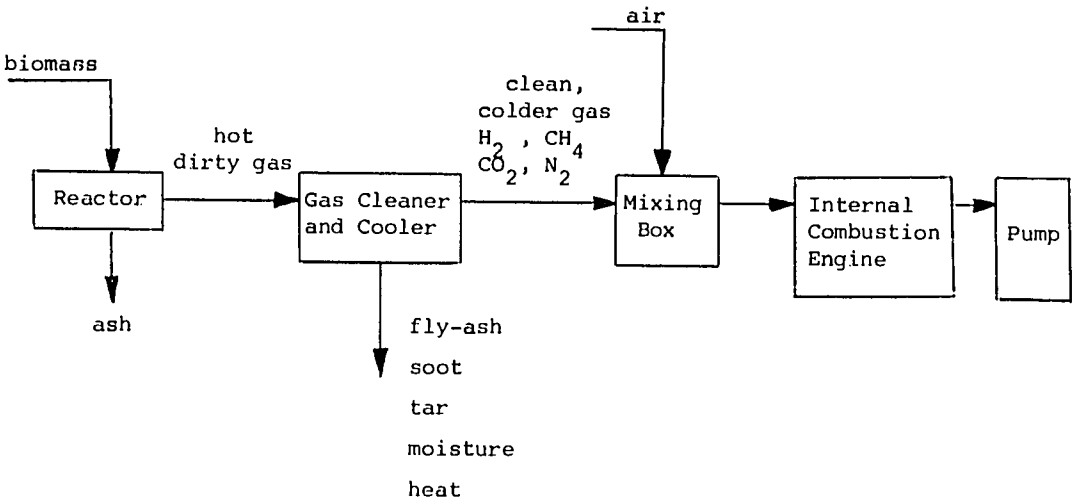

FIGURE 3.1 BLOCK DIAGRAM OF GASIFIER PUMPING SYSTEM

Combustible gas is extracted from wood or other biomass by burning the material with limited air. This is referred to as gasification. The gas produced consists mostly of carbon monoxide (CO), hydrogen (H_2), methane (CH_4) and the incombustible components : carbon dioxide (CO_2) and nitrogen (N_2).

The reactor is the main gasifier component where the gasification process takes place. Solid biomass (usually charcoal or wood chips) is fed in from the top, ash is collected and removed at the bottom, and the gas produced leaves through a side outlet. This gas is hot and contains impurities. The gas cleaner and cooler removes the impurities to make it clean and lowers the temperature of the gas to make it denser so that more of it will enter the engine to give a greater power output.

The gasifier reactor may be classified into three types, i.e. cross-flow, updraft and downdraft. The name describes the airflow direction from the entry of air to the exit of the produced gas. The two latter types are generally used. The updraft reactor produces a gas with a slightly higher energy content while the downdraft reactor produces a cleaner gas.

The gas cleaner removes the impurities from the gas. The three methods used the cyclone separator, gas scrubber, and the impingement filter. The cyclone separator removes suspended solid particles in the gas, such as soot and fly ash, by centrifugal force. The scrubber removes the condensable solid particles. The impingement filter collects impurities as gas passes through it.

The gas cooling method used for stationary application is the water-cooling type. This method is generally used with a gas scrubber and is accomplished by having water falling down thru cascading panels as the gas rising up.

The mixing box of the gasifier system is located adjacent to the carburetor and is composed of pipings with two valves connected to the acceleration pedal. One valve controls air flow while the other controls the flow of the gas.

Technical Design

The special requirements for the gasifier pumping system to be installed are as follows :-

- The gasifier shall be a downdraft type and shall accept hard fuel approximately sized in cubes, 0.5 to 3 inches in dimension and with moisture content up to 30% wet basis. *Eucalyptus camaldulesis* is considered as a fuel wood ;

- The gasifier shall be able to operate continuously for at least 4 hours without an interruption of gas supply ;

- The gasifier system shall have a feature for explosion control and for detection of carbon monoxide leakage ;

- The gasifier shall be mounted on a trailer so that it can be easily transported and shall have a basic instrumentation package for monitoring temperature and pressure ;

- A flare stack shall be provided to dispose of excess ;

- The calorific value of the gas produced shall be higher than 120 Btu/ft^3 ;

- The engine may be either a diesel or gasoline-type. If diesel, the engine must be capable of running on diesel fuel and/or producer gas. (Diesel fuel consumption shall not be over 20% of the total energy consumption). The engine shall deliver a rated power of not more than 30 kW.

- The engine cooling system shall be either an air-cooled or water-cooled type. If water-cooled, the system shall be capable of utilizing water being delivered from the pump ;

- Additional gas clean-up and cooling equipment (scrubbers and condensers) sufficient to provide reliable engine operation should be included ;

- Pumps shall be of the propeller, self-priming centrifugal type or other suitable substitute ;

- Coupling between pump and engine shall be a direct type or other suitable substitute ;

- The pump shall provide a water discharge of not less than 250 lt/s, the static suction lift shall be up to 3 m while the designed total dynamic head is 5 m ; and

- Auxiliary parts shall include two strainers for single suction pumps or three strainers for double suction pumps. The size of the strainer shall be approximately 1.5 times the diameter of the suction port. Suitable reducers shall be included.

Details of the Purchased Unit

The following are the details of the North American gasifier purchased by NEA :

Capacity

- Gasifier output :
  - 20 kWe continuous
  - 30 kWe intermittent

- Operating limits :
  - 5 kWe minimum continuous
  - 20 kWe maximum continuous

- Load following :
  - less than 1 second response to a 25% load increase

- Engine :
  - Ford Model 2.3L, Continuous Duty 38 HP.
  - The rating for low Btu gas: 60% of rated horsepower

Fuel

- Optimum size :
  - 1-inch cubic minimum
  - 4-inch cubic maximum

- Moisture content :
  - 15% optimum
  - 30% maximum

- Gasifier performance :
  - fuel consumption increases with an increase in moisture content
  - decreases in performance with fuel under and over size
  - design performance
    - 20 kWe
    - 25 shaft horsepower @ 2,000 rpm.
    - 50 lbs. wood per hour

- Fuel processing :
  - harvest wood source
  - process while high in moisture content
  - store and dry
  - fuel reactor at less than 30% moisture content
  - recommended fuel processing equipment :
    Kopo (see attached data)

Gasifier power generation system

- Operation :
  - Start up
    empty ash and water
    check engine oil and water
    light flare pilot
    fuel reactor
    check valve positions
    ignite fuel in reactor
    start electric blower
    purge cooling and cleaning system
    start engine
    connect load
    estimated total time: 20-30 minutes

  - Shut down
    engine ignition off
    set valves
    go home
    estimated time: 1 minute

- Fuel charge :
  - one charge: 50 lbs. (dry wt)
  - estimated total loading time: 1 to 2 minutes
  - frequency: once every 2 hrs. at kWe.
  - recharging can be done while running reactor

- Effect of running out of fuel :
  - Btu level of gas to the engine will drop and the engine will no longer follow the load, possibly stall

- Gasifier maintenance :
  - lubricate grate shaft bearing once a month (grease gun)
  - remove ash and char daily (small hand trowel)
  - remove excess water daily from overflow tank
  - normal English automotive tools plus pipe wrenches are used for all normal maintenance on the gasifier.
  - skill required for operation : no special skills
  - reactor shut down during above maintenance

- Engine/pump maintenance
  - all normal maintenance and tools for engines and pumps
  - no cleaning required for tars or soot
  - skills required include those for a competent engine operator with knowledge of pump operation.

- Environmental considerations
  - Solid wastes are inert and can be placed in a land fill or used as a soil amendment. Estimated solid waste production per day: 13.75 lbs.

  - liquid wastes are composed of water condensates, with small fractions of black carbon soot and ash. These may be put in a domestic sewer with no shock loading effect on any conventional sewage system. No tars are produced in the gasifier. A land treatment system with special consideration for temperature extremes should be used if no other system is available North American Gasifier Corporation is available for consulting on waste treatment.

- Heat loss rates (estimated) :
  - reactor 30,000 Btu/hr.
  - heat exchanger 10,000 Btu/hr.
  - engine cooling jacket 60,000 Btu/hr.
  - engine exhaust 35,000 Btu/hr.

- Gas components :
  - H_2 = 5%
  - CO_2 = 3%
  - O_2 = 1%
  - CH_4 = 1%
  - N_2 = 62%
  - CO = 28%
  - moisture content : saturated at ambient
  - tar content : none

- Uses :
  - This is a new product design which eliminates tar production. Designed specifically for Third World application where technical expertise is at a minimum and operational conditions are the most severe.

Manual

All manuals and instructions will be included with the gasifier when shipped.

Price

• Reactor, blower, scrubber, holding tank, heat exchanger, demister, flare, pilot, all piping and valves, engine modifications and special tools.	US$ 13,567.60
• Engine/pump ITT Marlow model/4D2 to include heat exchanger for engine water jacket, trailer with engine and gasifier mounted.	US$ 4,547.50

Total F.O.B.	US $	18,115.10
Freight & Insurance	US $	3,115.90
Total	US $	21,231.00

D. BIOGAS PUMPING SYSTEM

System Performance

This system consists of a digester tank, an internal combustion engine and a pump. The biogas produced from the digester will be used as a fuel for the engine to drive the water pump.

Biogas which is composed mainly of methane (CH_4) and carbon dioxide (CO_2) is a by-product of anaerobic fermentation process. Anaerobic bacteria breaks down organic matter from complex forms into simple forms of organic acids. These acids are then further converted biochemically to methane, carbon dioxide and new bacteria cells.

Animal manure is usually utilized as a raw material for biogas production. Human excreta and some vegetations can also be used. The value of the carbon-nitrogen ratio (C/N) is considered an important factor that characterizes the property of these raw materials. The value should not exceed 35:1 (Singh, 1972).

Technical Design

Although a large number of biogas plants have been installed in various parts of the world, the criteria for both the design and operation of this process are not yet satisfactorily established. This is because of the variety of raw materials and other environmental factors which affect the fermentation process in the reactor. In this section, general criteria which should be considered in the design are presented (Pitak, 1978).

Loading rate

Loading rate can be defined in various terms such as hydraulic loading which is controlled by influent flow rate, and organic loadings which use organic matters input to the system (termed as BOD or COD) as a controller. Another parameter, solid loading, employs the amount of influent volatile solids in controlling the unit function.

The conventional loading rates are the ones mostly employed and are a very important parameter in anaerobic digestion. The volatile solid (VS) loading rates for biogas units can be generally divided into 2 categories :

1. Conventional VS loading, and
2. High rate VS loading

The conventional loading rates are the ones usually employed in sewage sludge digestion, while the high rate loading rates are adopted only in certain biogas plants. Some advantages of the high rate biogas plants include : minimizing the digester volume, and a reduction of the high organic materials; less water dilution required and consequently less liquid effluent for final disposal. However, excessive VS loading in a biogas plant could result in still effluent slurry and an accumulation of ammonia in the system which is inhibitory to the methanogenic bacteria.

A summary of biogas VS loadings as reported by various investigators is presented in Table 3.2.

TABLE 3.2 VOLATILE SOLID LOADING RATES USED IN VARIOUS BIOGAS PLANTS (AFTER PYLE, 1976)

Digester Size (m^3)	Loading Rate (kg VS/m^3/ day)	Faeces Type	Reference
1.5	15.5	Pig	PYLE (1976)
0.015	0.48-3.2	Pig	HOBSON and SHAW (1973)
2.8	0.6	Cow	PYLE (1976)
185.0	2.4	Pig	LAPP et al (1975)
5.5	0.8	Pig	CHUNG et al (1975)

The VS loading rate is theoretically related to the rate and quantity of gas production; higher loadings will result in more gas production. From their intensive digestion study using pig manure as the food in a 15-liter digester, HOBSON and SHAW (1973) found that the gas production for a loading of 0.06 lb VS/ft^3/day was 3.5 lt/day and this production increased to 11.8 lt/day with a loading of 0.2 lb VS/ft^3/day. However, further increases in VS loading could possibly lead to a failure of the biogas system.

Digester detention time and feed dilution ratio

The detention time is the parameter used to control the flow of raw materials feeding into the digester or the time available for the anaerobic bacteria to metabolize the waste. The detention time for a continuous, no sludge recycle biogas plant is equal to its hydraulic detention time, hence its relationship with the feed dilution ratio. The digester detention time directly affects the concentration of organic matter and the content of the manure slurry in the influent. The higher the detention time the more concentrated and condensed the sulrry of raw materials being fed, which in turn can cause insufficient metabolism at high solids content i.e. more than 10% solids (TAIGANIDES et al, 1963).

The use of a feed dilution ratio as a design parameter for the biogas process in the rural areas is obviously more convenient than using the term digester detention time. However, the latter is utilized more frequently in mathematical modelling of any biological processes. Table 3.3 shows various detention times and feed dilution ratios of biogas plants with successful operation.

TABLE 3.3 THE OPERATING DETENTION TIME AND DILUTION RATIO. (AFTER PYLE, 1976)

Manure Type	Detention Time	Dilution Ratio Manure:Water	References
Cow	25-30	1 : 1	PATEL (1971)
Poultry	3-10	1 : 2	PATEL (1971)
Pig	6-16	1 : 1	CHUNG et al (1975)
Cow	30-40	1 : 1	SINGH (1972)

Feed composition

The anaerobic process is dependent upon anaerobic bacteria, which requires nitrogen, phosphorus and other nutrients at trace quantities for their growth. Each animal munure posses different C/N ratios in which, if a proper portion of them are mixed (i.e. C/N ratio = 20:1 to 30:1) maximum gas production can be obtained (Singh, 1972).

Basic factor for digester sizing

Biogas plants are used for various purposes and there are many procedures in plants operation. There are several basic types of digesters and each has its own advantages and drawbacks. Digesters can be divided into batch type or continuous type depending upon the flow system, or specified as fixed cover type or moving gas holder type. However, the two important basic factors that are used in designing any biogas plants are quantity of gas production required and availability of raw material.

Quantity of Gas Production Required

The gas production required can be estimated according to the period of gas usage and number of people utilizing the gas. The gas consumption data as estimated by SINGH (1972) is shown in Table 3.4.

Besides cooking and lighting, biogas can also be used for refrigerators with the rate of consumption in liter/hr. Nevertheless, the gas

TABLE 3.4 METHANE GAS CONSUMPTION FOR VARIOUS GAS FACILITIES

Application	Specification	Gas Consumption lt/hr.
Gas Cooking	5 cm dia Burner	325.6
	10 cm dia Burner	467.2
	15 cm dia Burner	637.1
Gas Lighting	for one person	354.0
	1 Mantle Lamp	70.8
	2 Mantle Lamp	141.6
	3 Mantle Lamp	170.0

requirements for different families will vary slightly depending on the design of the appliances, the methane content, and the gas delivery pressure. The population equivalent will specify the gas usage for that family. Therefore the total gas consumption could be roughly calculated from Table 3.4 as stated previously. This amount of gas consumption can be used as a basis for digester sizing design.

Availability of Raw Materials

The quantity of raw materials used for a biogas plant must be adequate for the plant requirements and their characteristics should be suitable for plant operation. The gas yield from the raw materials varies with the type of manure and its water content. The amount of manure available can be estimated by a head count or from the weight of the animal. The amount of manure that can be expected from different types of animals is shown in Table 3.5 (BARGER, 1976).

The availability of raw materials also depends upon the mode of manure collection and livestock condition. The confinement of livestock is not always possible nor desirable because crowded livestock are likely to contact diseases. Actually about 90% of the manure produced by large animals can be collected and 60% for poultry in good confinement with bedding. BARGER (1976) estimated that 50% of the manure would be lost during grazing. From this calculation, the amount of manure could be roughly estimated from Table 3.5 and multiplied by the collecting correction factor. Thus the roughly available volatile solids could be known and the gas yield from these manures could be estimated.

TABLE 3.5 WEIGHT OF EXCRETA PRODUCED PER DAY BY DIFFERENT ANIMALS

Animals	kg Faeces/Head	Live Weight (kg)	kg Faeces/Day	kg Faeces/100 kg Live Weight
Cow, Buffalo	3-10	454	23.6	5.2
Horse	5.25	586	16.3	4.2
Pig	2.8-3.7	73	3.4	4.7
Sheep	-	30	1.4	4.5
Poultry	0.12-0.25	2.3	0.11	0.047

Sizing the digester

Digester sizing can be generally determined from the two aforementioned basic factors. Three methods in which digesters can be sized include :

1. By selecting a fixed detention time and the total daily volume of influent is known

2. By having a fixed volume for every population equivalent in the waste.

3. By setting a fixed loading of volatile solids per volume of digester.

A combination of methods 1 and 3 seems to be efficient in designing a digester size. With the fixed loading determined, the capacity of the digester could be calculated by using total weight of the influent volatile solids divided by fixed volatile solid loading. Hence,

$$\text{Volume of Digester} = \frac{\text{Total weight of VS(kg VS/d)}}{\text{Loading rate (kg VS/m}^3\text{/day)}}$$

The selected detention time will indicate the volume of the influent feeding into the digester (as m^3/day) which is the dilution factor required for that manure.

Details of the Specified Biogas Pumping System

The following are details of the biogas pumping system specified in this study.

Slurry mixing trough

The slurry mixing trough will be 0.06 m high, 3.00 m long and 1.20 m wide. There is a steel pipe, 0.30 m in diameter, connecting this mixing trough to the distribution channel. The surface of the walls and the bottom of the mixing trough must be smooth and non-corrosive. The foundation of the trough must be adequately stable.

Distribution channel

The distribution channel will be 0.50 wide, 11.30 m long with a 5% slope. The bottom of the channel must be smooth so that the mixed slurry can flow to the digestion tanks steadily.

Digestion tanks

There will be three cylindrical digestion tanks with stainless steel covers. Each tank will be 3.30 m in diameter.

Engine and pump

- The engine used for this biogas pumping system is a benzene engine with a 10 HP capacity ;

- The water pump is a self-priming centrifugal pump with a discharge rate of 200 lt/min. and with a lifting head of 25 m ; and

- The engine and the pump will be installed on the same base connected with a belt drive.

CHAPTER 4

FIELD EXPERIMENTS

FIELD EXPERIMENTS

In this study only two types of water pumping systems were installed, i.e. the solar water pumping system and the wind turbine water pumping system. In this chapter the results obtained from field experiments are presented with an aim of demonstrating and determining the performance characteristics and overall efficiency of each unit.

A. SITE SELECTION

Criteria for Site Selection

In selecting the site for water pumping installation the following criteria were used :

- There exists a source of adequate water quality and quantity all year round;
- The demand of water is high throughout the year;
- The service road to the site is in good condition so that installation, operation and maintenance can be undertaken with little difficulty;
- There is no electricity distribution network in the area; and
- The villagers are willing to cooperate with the responsible officials in the installation, operation and maintenance of the project.

Selected Sites for Solar Water Pumping Installation

The 4,300-watt irrigation system was installed at Ban Sukorn, Tambon Chum Puang, Amphoe Chum Puang, Nakhon Ratchasima Province. This village is located approximately 90 km southeast of the city of Nakhon Ratchasima. The total area of this village is 6,265 rai (10.024 km²). The area has a gentle slope from the northwestern part to the southern and southeastern parts of the village. Most of the area is cultivated for growing paddy rice. There is a stream, named *Lam Pradok*, in the southeastern section of Ban Sukorn. A storage weir creates a reservoir covering a total area of 1,446 rai (2,314 km²) with a storage capacity of 8 million m³. This storage reservoir is called *Ang Pradok* (Pradok Reservoir). The 4300-watt solar water pump was installed to pump water from this reservoir to irrigate the Ban Sukorn area.

Problem Page Missing

The 700-watt solar pump was installed at Ban Tha Yiam, Tambon Non Hom, Amphoe Muang, Sakon Nakhon Province. The village area is flat, consisting of agricultural lands and forest areas. This pumping system was installed to pump water from groundwater wells for domestic use by 57 households in this area.

Selected Sites for Wind Turbine Pumping Installation

Three windmills were installed to pump water from a storage pond and a shallow well for agricultural purposes in Ban Samoh village, Tambon Ta-tong, Amphoe Raman, Yala Province. This village is situated approximately 21 km to the east of the city of Yala. The total village area is 5,060 rai (8.1 km^2). About 60 percent of the area is utilized for agricultural lands. The main crops cultivated are rice, rubber, vegetables and some upland crops.

B. SOCIO-ECONOMIC CHARACTERISTICS OF BAN SUKORN, TAMBON CHUM PUANG

In this section the results obtained from the socio-economic study of Ban Sukorn, Tambon Chum Puang, Amphoe Chum Puang, Nakhon Ratchasima are summarized. The study was undertaken bu the survey group of the Energy Economics Division, NEA. The field survey was conducted during 22 June 1983-21 July 1983. Altogether, 56 households (from a total of 115 village households) were randomly selected for questionnaire interviewing.

Location and Topography

Ban Sukorn is situated approximately 90 km southeast of the city of Nakhon Ratchasima. The village area covers approximately 6,265 rai of which 1,425 rai is public land. The topography of the area is characterized by a gentle slope extending from the northwestern part to the southeastern part of the village. There is a stream named *Lam Pradok* which flows through the southeastern part of the area. A weir with a sluice gate is located on this stream. This weir has created a storage reservoir with a surface area of 1,446 rai and with a storage capacity of 8 million m^3. The impounded water has been used for irrigation and domestic consumption.

Village Characteristics

In all, there are 112 households in Ban Sukorn (June 1983). These households are separated into 3 groups, namely Ban Sukorn Group, Ban Pradok Group, and Ban Ta Lum Tong Group. Ban Sukorn Group is the largest with 81 households situated in the northeastern part of the area. Ban Pradok Group, with 26 households, is situated approximately 350 m to the west of Ban Sukorn Group, approximately 500-600 m from these two groups.

Houses in Ban Sukorn are mostly one story structures with an elevated floor and a galvanized steel roof. These houses are normally located close to the service roads in the village. There are three main roads connecting Ban Sukorn and the civic centers of Amphoe Pimai, Amphoe Chum Puang and Amphoe Pratai. The road connecting Ban Sukorn and Amphoe Pimai is approximately 32 km in total length. This is a lateritic road. Most of the villagers (85%) use this route in travelling to the town. The second route, from Ban Sukorn to Amphoe Chum Puang is a dirt road which becomes muddy during the rainy season. Only 14% of the villagers use this route in travelling to Amphoe Chum Puang to buy household goods and agricultural input. The total length is approximately 7 km. The third route, from Ban Sukorn to Amphoe Pratai, is also a dirt road approximately 12 km in total length. The condition of this road is rather poor and the villagers use this route only when necessary.

During the rainy season, normally from September to November, travel along these access roads is not possible. During this period villagers travel by boat along the Pradok stream and the Nam Mun River to Amphoe Chum Puang, approximately 16 km in total distance.

There is one primary school in the village which offers classes to the Prathom-6 level. Besides the school, there is one Buddhist temple named Wat Mongkolrasbamrung. Both school and temple are located within the Ban Pradok area.

Population and Households

There are a total of 112 households with 646 residents in Ban Sukorn Village. The numbers of male and female residents are 277 and 369, respectively. On the average, each household has 5.8 members. Most of the villagers (58 percent) are between 5-25 years old.

Education

Approximately 24 percent of the villagers are in school. Most attend the primary school (P.1-P.6) level. Another 56 percent have finished studying and the remaining 20 percent have never attended school. For those who have completed their studies, most (98%) finished the primary school level (P.6). For those who have never attended a school, 52 percent are too young(0-5 years old) and 35 percent are older than 46 years.

Occupation

Most parts of Ban Sukorn area are flat and there is a storage reservoir located close to the village. Therefore, most of the villagers list agriculture as their main occupation. Besides agriculture, some of the villagers work as hired laborers and some work as traders (Table 4.1).

TABLE 4.1 MAIN OCCUPATION OF HOUSEHOLD HEADS

Occupation	Farming	Hired Laborer	Trading	Others
Percent of Sampled Household Heads	87.50	5.36	3.57	3.57

Besides the above mentioned main occupations, approximately 64.29 percent of the sampled household heads also engage in subsidiary occupations. The most popular subsidiary occupation is pot molding. Others earn additional money from vegetables or other crops or from other occupations (Table 4.2)

Labor Force

Most of the labor force is engaged in farming. There are four periods which require intensive labor i.e.

- June-July, when the farmers cultivate their paddy field; some also harvest their dry land rice;

TABLE 4.2 SUBSIDIARY OCCUPATION OF HOUSEHOLD HEADS

Percent of Sampled Household Heads		Subsidiary Occupation					
w/o subsidiary Occupation	with sub-sidiary occupation	Paddy growing	Vegetable growing	Hired laborer	Trading	Pot Molding	Others
35.71	64.29	11.10	16.67	5.56	5.56	44.44	16.67

- August-October, when most farmers do their farm work from the morning till the evening,

- December-February, when the farmers harvest their crops. They work very hard from 5.00 AM until 10.00 PM; and

- March-May, when the farmers start cultivating dry land rice.

Hired laborers are primarily needed during the harvesting period, from January to February.

During the March-June period, when the farmers have finished harvesting their crops and the school is closed, most households engage in their subsidiary occupation for additional household income.

Land Use and Land Holding

Most parts of the village area are used for growing paddy rice. This land use accounts for approximately 36.43 rai per household. However, as much as 6.27 rai per household is left uncultivated. The remaining lands are used for residential purposes, growing other crops and orchards (Table 4.3).

With regard to land holding status, these are four types, i.e. owner, rental, rent-free, and others (Table 4.3).

TABLE 4.3 LAND USE AND LAND HOLDINGS

Rai/Household

Type of Land Holding	Area (rai)	Type of Land Use				
		residen-tial	orchard	upland crop	Paddy rice	abandoned
Owner	38.88	0.94	0.28	0.52	31.00	6.14
Tenant	2.78	-	-	0.15	2.63	-
Rent-free	1.94	0.01	0.05	-	1.75	0.13
Others	1.05	-	-	-	1.05	-
Total	44.65	0.95	0.33	0.67	36.43	6.27
Percent	100.00	2.14	0.74	1.49	81.59	14.04

Agriculture

The Ban Sukorn village area is mostly flat land. The area utilized for agricultural purposes covers approximately 2,005 rai. The main crop grown is paddy rice which can be further classified as wet land rice and dry land rice. Besides paddy, cassava and vegetables are also grown in this area.

Wet land rice

Wet land rice is cultivated in the area surrounding the village. Most of the cultivation is of a rain-fed type. Cultivation starts at the beginning off the rainy season, which is around mid-June and the rice will be harvested in December-January. The yield depends on the amount and periods of rainfall during the year. In a draught year, the yield is low and the harvested rice will be kept for household consumption only. In a year with adequate rainfall, the yield will be high and the excess rice will be sold to merchants in the town.

During periods of heavy rainfall, the paddy fields located close to the Pradok Reservoir will be flooded and damaged. The variation in water levels in the Pradok Reservoir relies on the water level in the Nam Mun River.

Dry land rice

Approximately 36 percent of the total households engage in dry land rice growing. However, the cultivated area is rather small, with an average of only 2.8 rai per household. The dry land rice is grown after the wet land rice is harvested. Most of the dry land rice fields are located close to the Pradok Reservoir where water is pumped for irrigation.

Cassava

Cassava is also grown but only in a small quantity. Cassava growing requires less time and effort than paddy rice and other crops. The growing period is about 9-12 months.

Vegetables

Vegetables are primarily grown for household consumption, with the exception of cucumbers, which are sold to nearby villages for additional household income.

Agricultural production

As previously mentioned, agriculture in the Ban Sukorn area is mostly a rain-fed type. Therefore, production is based on the amount of rainfall each year.

The average yield of wet land rice is approximately 7,520 kg per household which costs about 19,900 Baht (US$ 865.22). About 48 percent of the production is used for household consumption, 47 percent is sold and the other 5 percent is used to pay off debts.

The production of cassava totals approximately per rai. All of this production is sold to a merchant. The annual income from cassava is approximately 198 Baht (US$ 8.61) per household.

Table 4.4 summarize the average productions and incomes derived from wet land rice, dry land rice and cassava in Ban Sukorn village.

TABLE 4.4 AGRICULTURAL PRODUCTIONS AND INCOMES IN BAN SUKORN VILLAGE

Crop	Cultivated Area (rai/ household)	Production		Household Consumption (kg)	Paid for Dept (kg)	Sale	
		kg/rai	kg/house-hold			amount (kg)	cost (฿)
Wet land rice	35.80	210	7,520	3,525	403	3,592	9,483
Dry land rice	0.99	305	302	184	7	111	296
Cassava	0.18	1,850	333	-	-	333	198

Agricultural input

Table 4.5 summarizes various items of agricultural input for wet land rice, dry land rice and cassava growing in the Ban Sukorn area. The major expenses are for fertilizer and labor. In all, the total expenses for wet land rice, dry land rice and cassava growing are 3,561 Baht (US$ 154.83), 436 Baht (18.96) and 42 Baht (US$ 1.83) per household, respectively.

TABLE 4.5 AGRICULTURAL INPUT FOR VARIOUS TYPES OF CROPS GROWN IN BAN SUKORN VILLAGE

Crop	Input (Baht/rai)						Overall Expense	
	Seed	Pesti-cide	Ferti-lizer	Labor force	Fuel	Others	Baht/rai	Baht/house-hold
Wet land rice	0.15	2.51	47.24	43.81	4.25	1.52	99.47	3,560.57
Dry land rice	2.70	25.50	160.45	253.51	-	2.70	439.46	435.64
Cassava	-	-	-	233.00	-	-	233.00	41.61

Household Economics

Household income

Besides the income from selling agricultural products, additional income can be gained from other occupations, such as laborer, household industries, animal raising, and trading. The annual income derived from these occupations are shown in Table 4.6. In all, the annual income per household is approximately 16,609 Baht (US$ 722.13) in addition to the income gained from farming.

TABLE 4.6 ANNUAL INCOMES FROM OTHER OCCUPATIONS

Occupation	Annual Income (Baht/household)
Laborer	8,190.68
Household industries	2,361.14
Trading	480.36
Animal raising	4,885.71
Land renting	387.23
Vegetables	303.57
Total	16,608.69

Household expenditure

Table 4.7 summarizes the annual expenditures per household in Ban Sukorn village. The largest expenditure is for food and clothing which is considered as a "regular" expense. This costs each household an average of 6,836 Baht (US$ 297.22) per year. The irregular expenses include repairs, participation in social activities, etc. The investment item is mainly for agricultural equipment, and for household industries. In total, the average annual expenditure is approximately 24,100 Baht (US$ 1,047.83) per household.

Indebtedness

Approximately 87.5 percent of the households in Ban Sukorn are indebted, primarily for agricultural inputs. The main source of loans are relatives, neighbors and the Bank for Agriculture and Cooperatives. On the average, the debt per household is 3,690 Baht (US$ 160.43).

TABLE 4.7 HOUSEHOLD EXPENDITURES

Item	Annual Expense (Baht/household)
Regular (food,clothes,etc.)	6,836.16
Irregular (repairs, etc.)	5,387.61
Investment	3,811.72
Agricultural Inputs	4,037.72
Fuel	1,533.37
Others	2,493.71
Total	24,100.29

Water Demand

Water usage in Ban Sukorn village is mainly for agriculture and domestic consumption. The wet land rice cultivation is based on rain water only. From the interviews, 77 percent of the sampled households reported that there was adequate water for wet land rice cultivation whereas the other 23 percent reported there was not enough water.

For dry land rice growing, most of the cultivated area is located close to the Pradok Reservoir where water is pumped for irrigation. About 79 percent of the households engaged in dry land rice growing reported that there was adequate water, while the other 21 percent gave a negative answer.

For cassava and other field crops, cultivation is entirely based on rain water. For vegetables the water used in growing is pumped from the Pradok Reservoir or other dug wells in the village. Most of the households engaged in growing crops reported there was adequate water.

The main source of drinking water is rain water which is kept in individual storage tanks. Some households also use water from the dug wells while the others use the reservoir water. On the average, the demand of drinking water is approximately 33 liters per household per day and the demand for other domestic uses is approximately 165 liters per household per day.

With regards to the village irrigation system, the Pimai District Irrigation Office has installed a pumping station at the Pradok Reservoir. The reservoir water is pumped to an area located close to the reservoir. Only 34 percent of the total households in the village receive any benefits from this irrigation system. The remaining 66 percent receive no benefit at all. Considering the irrigated area, only 4.6 percent of the total paddy fields in the village can be irrigated by this pumping system.

C. SOCIO-ECONOMIC CHARACTERISTICS OF BAN THA YIAM, TAMBON NON HOM

In this section, the results of the socio-economic study of Ban Tha Yiam, Tambon Non Hom, Amphoe Muang, Sakon Nakhon Province, are summarized. This study was conducted by the Energy Economics Division of NEA during 20 June 1983-21 July 1983. In all, 29 of the 57 households were selected for questionnaire interviewing.

Location and Topography

Ban Tha Yiam is situated close to the Nam Phung River approximately 21 km from the civic center of Sakon Nakhon Province. The terrain is rather flat and some parts are a forest area. The total village area is approximately 2,230 rai (3,568 km^2).

Village Characteristics

Most households are situated close to the service roads in the village. The eastern and southern parts of the village are bounded by the Nam Phung River. Most of them are situated close to each other. However, as the population increased, a number of newly formed households dispersed to the northern part of the village area.

Houses in Ban Tha Yiam village are mostly one story homes with galvanized steel or thatch roofs, bamboo or wooden plank walls and wooden plank floors.

There is one Buddhist temple, named Wat Sawang Arom, located in the western part of the village. This temple is used for various religious activities and is also the place where meetings are held.

There is one primary school located between Ban Tha Yiam and Ban Nam Phung. This school provides classes up to the Prathom 6 level. There are 6 teachers and 108 students (June 1983). For those who want to continue their studies they must go to a secondary school in the district.

Ban Tha Yiam village can be approached by two access roads. The first route connects Ban Tha Yiam with the City of Sakon Nakhon Province, a distance of approximately 21 km. The first 14 km from the center of the province is an asphalt road. The remaining 7 km is a lateritic road. The second route also connects Ban Tha Yiam with the City of Sakon Nakhon Province. The first section from the province is the same as that of the first route, but there is another branch from Ban Huai Pla Yai passing Ban Kham Phung Kao, Ban Nam Phung and Ban Tha Yiam. Most of the villagers use the public bus in travelling to the City.

The residents of this village use their native language, the Phu Thai dialect, which is distinguished from the normal Northeastern language. All of them are Buddhist.

Population and Households

There are a total of 57 households with 347 residents in Ban Tha Yiam village. The numbers of male and female residents are 168 and 179, respectively. The average number of household members is 6.1 per household. Most of the population are between 5-25 years old (53 percent of the male residents and 48 percent of the female residents).

Education

Approximately 35 percent of the residents of Ban Tha Yiam village are in school. Most of the students (81 percent) are in the primary school. The other 16.67 percent are in a secondary school and the remaining 2.33 percent are in a technical school. For those who have finished studying, 97.22 percent finished the primary school level (P.6). The other 1.85 percent finished at the higher level.

Occupation

Similar to other rural villages in the country, the main occupation of Ban Tha Yiam villagers is agriculture, in which 93 percent of the sampled households are engaged. The remaining 7 percent work as a laborer or do some trading (Table 4.8).

TABLE 4.8 MAIN OCCUPATION OF HOUSEHOLD HEADS

Occupation	Farming	Hired Laborer	Trading
Percent of Sampled Household Heads	93.10	3.45	3.45

Besides these main occupations, about 40 percent of the sampled household heads also have a subsidiary occupation. Fifty percent work as a laborer, fourteen percent do some trading and the remaining thirty-six percent have other occupations, such as animal husbandry, household industries, firewood processing, etc (Table 4.9).

TABLE 4.9 SUBSIDIARY OCCUPATION OF HOUSEHOLD HEADS

Percent of Sampled Household Heads		Subsidiary Occupation		
w/o subsidiary occupation	With subsidiary occupation	Hired laborer	Trading	Others
62.07	37.93	49.99	13.64	36.36

Labor Force

Most of the labor force is used in farming, especially during the growing and harvesting periods. For those households which grow paddy rice, hired laborers are required from June to September. For those who grow field crops, the cultivation period is normally in April, May and June. Approximately 48 percent of the sampled households hired a laborer to help them do the farming during a peak load period.

During January-March when the villagers have finished harvesting their crops, most labor forces will be idle. Some of them will work at their subsidiary occupation during this period.

Land Use and Land Holdings

Though the main occupation of the villagers in Ban Tha Yiam is agriculture, as much as 54 percent of the village area is left uncultivated. The areas cultivated for paddy, field crops or orchards account for 41 percent of the village area. Another four percent of the area is used for residential purposes (Table 4.10).

TABLE 4.10 LAND USE AND LAND HOLDING IN BAN THA YIAM VILLAGE

Rai/Household

Type of Land Ownership Documents	Area (rai)	Type of Land Use					
		residen-tial	orchard	field crops	paddy rice	uncultivated	rent
Nor Sor 3	23.16	1.18	0.45	2.11	6.46	11.61	1.35
Sor Khor 1	1.56	-	-	0.07	0.17	1.32	-
Nor Sor 2	0.86	-	-	0.07	0.34	0.45	-
No document	1.12	-	-	-	-	1.12	-
Total	26.7	1.18	0.45	2.25	6.97	14.5	1.35
Percent	100.0	4.4	1.7	8.4	26.1	54.3	5.1

Agriculture

About 58 percent of the village area is considered as agricultural lands. However, as mentioned in the preceding section, some parts of these lands are left uncultivated. Among the agricultural lands, 34 percent are paddy fields, and the remaining 66 percent are crop fields. Besides agricultural lands in this area, some villagers also own agricultural lands in the nearby area outside the village. Altogether, the total agricultural area owned by the villagers of Ban Tha Yiam accounts for approximately 1,615 rai, or 28.33 rai per household.

The major crops grown in this village include paddy rice, cassava, and kenaf. Tobacco, tomatoes and some vegetables are also grown.

Since most households are rather poor, the investment in agriculture is very low and old style cultivation methods are normally used. Tables 4.11 and 4.12 show the average investment cost for each type of crop grown in this village.

TABLE 4.11 AGRICULTURAL INPUT (BAHT PER RAI)

Crop \ Input	Seed	Pesti-cide	Ferti-lizer	Labor	Equip-ment	Repairs	Fuel	Others	Total
Paddy rice	-	0.22	2.70	27.37	2.75	1.98	0.22	8.28	43.52
Upland rice	-	0.68	-	7.46	-	-	-	-	8.14
Cassava	1.36	-	-	31.59	-	-	-	18.18	51.13
Kenaf	-	-	-	28.27	-	0.67	-	12.91	41.85
Tomato	40.00	87.50	87.50	-	-	-	-	-	215.00
Tobacco	-	129.50	240.00	-	-	-	-	59.00	428.50
Vegetables	133.33	-	-	-	-	-	-	-	133.33

TABLE 4.12 AGRICULTURAL INPUT (BAHT PER HOUSEHOLD PER ANNUM)

Crop \ Input	Seed	Pesti-cide	Ferti-lizer	Labor	Equip-ment	Repairs	Fuel	Others	Total
Paddy rice	-	1.72	30.21	216.37	21.72	15.69	1.72	65.48	352.91
Upland rice	-	0.62	-	7.59	-	-	-	-	8.21
Cassava	0.97	-	-	23.97	-	-	-	13.79	38.73
Kenaf	-	-	-	36.55	-	-	-	16.69	54.10
Tomato	4.14	9.05	9.05	-	-	-	-	-	22.24
Tobacco	-	8.93	16.55	-	-	-	-	4.07	29.55
Vegetables	6.90	-	-	-	-	-	-	-	6.90

Table 4.13 summarizes the cultivated area and the annual production per household for each type of crop grown in Ban Tha Yiam. The average yield is rather low. On the average, the annual income gained from agriculture is only 1,450 Baht per household.

TABLE 4.13 AGRICULTURAL PRODUCTION AND ANNUAL INCOME

Crop	Cultivated Area (rai/household)	Production (kg)	Household Consumption &Seed (kg)	Paid for a Debt (kg)	Sale	
					kg	Baht
Paddy rice	7.91	1,367	1,296	34	37	109
Upland rice	1.02	126	126	-	-	-
Cassava	0.76	357	-	-	357	348
Kenaf	1.96	171	-	-	171	701
Tomato	0.10	121	-	-	121	121
Tobacco	0.07	11	0.5	-	10.5	171
Vegetables	0.04	0.6	0.6	-	-	-

Household Economy

Household income

Though a large portion of the village area is cultivated for paddy and upland rice, most produced rice is kept for household consumption. The annual income from farming is mostly obtained from the selling of other crops, such as kenaf and cassava. However, in determining the annual income from agriculture, the produced rice is estimated in monetary terms and added to the income obtained from the selling of other crops. Table 4.14 summarizes the annual net income derived from agricultural lands in Ban Tha Yiam village. In total, the annual net income per household from agriculture is approximately 5,041 Baht (US$ 219.17).

TABLE 4.14 ANNUAL NET INCOME FROM AGRICULTURE

Crop	Net Income (Baht/Household)
Rice	3,841
Cassava	309
Kenaf	647
Others	244
Total	5,041

Besides income from agriculture, each household still gains additional income from other occupations, including hired laborer, household industries, trading, animal husbandry, etc. Table 4.15 summarizes the average annual income per household derived from these occupations. In total, approximately 8,320 Baht (US$ 361.74) per household is obtained annually.

TABLE 4.15 ANNUAL INCOMES FROM OTHER OCCUPATIONS

Occupation	Annual Income (Baht/Household)
Hired laborer	3,321
Household industries	567
Trading	650
Animal husbandry	2,896
Others	886
Total	8,320

Household expenditures

In examining household expenditures, agricultural inputs cost approximatel 513 Baht (US$ 22.30) per household (Table 4.13). For household consumption expenses and investments, it is found that annually each household averages 8,158 Baht (US$ 354.70). Table 4.16 shows that the main item of household expenditure is for food and clothing, etc., items which are considered as "regular" expenses. "Regular" expenses account for 6,344 Baht (US$ 275.83) per household or 78 percent of the total household expenditure.

TABLE 4.16 HOUSEHOLD EXPENDITURES

Item	Annual Expense (Baht/Household)
Regular	6,344
Non-regular	1,762
Investment	52
Total	8,158

Indebtedness

Approximately 45 percent of the household heads are in debt. The main sources of loans are from the Bank of Agriculture and Cooperatives and from relatives or friends. On the average, loans are approximately 4,948 Baht (US$ 215.13) per household.

Water Demand

Agriculture in the Ban Tha Yiam area is mainly a rain fed type. However, some cultivated areas receive water from other sources, such as the Nam Phung River, the Huai Khaen Reservoir, the Huai Kho Reservoir, and the Huai I-Noon diversion weir.

For paddy rice cultivation, about 56 percent of the sampled households utilized rain water. The remaining 44 percent used water from the above mentioned sources. For upland rice, cultivation is based on rain water only, and so the cultivation is normally started in May, which is the beginning of the rainy season. For cassava and kenaf, cultivation is usually begun in March or April and growth is based on rain water.

Most of the farmers in the Ban Tha Yiam area reported that the available water was inadequate.

With regard to the existing irrigation system, farmers in the Ban Tha Yiam area can be separated into 3 groups : (1) those whose cultivated lands are fully irrigated by the existing irrigation system; (2) those whose lands are partially irrigated; and (3) those who do not receive any benefits from the existing irrigation system. The percentage of these 3 groups are 14%, 45% and 41% of the total households, respectively.

Regarding water for domestic use, ground water wells are the main source. There are 8 ground water wells in this area. The average water demand is approximately 190 liters per household for domestic consumption.

D. SOCIO-ECONOMIC CHARACTERISTICS OF BAN SAMOH, TAMBON TA-TONG

The results obtained from the socio-economic study of Ban Samoh, Tambon Ta-tong, Amphoe Raman, Yala Province, are summarized in this section. The study was carried out by the Energy Economics Division of NEA in February 1983. 52 households were randomly selected from the total number of 204 households for questionnaire interviewing.

Location and Topography

Ban Samoh is situated approximately 21 km to the east of the city of Yala. The topography is characterized by a concave ground surface, so surface water from the nearby regions drains into this area, leaving the agricultural lands flooded most of a year.

Village Characteristics

Households in this village are separated into 4 groups as follows :

Ban Samoh and Pa-on Group This group is the center of the village. There are a total of 90 households. Most of the residents are Buddhist. Some parts of the area are hilly. Most houses in this group are one story with elevated floors.

Ban Bukebalo Group This group is situated about 1 km north of the Pa-on group. Most houses are one story and are situated on both sides of the service roads. The area is also hilly. The total number of households is 36; most of the residents are Thai Muslim.

Ban Koh Group This group is situated about 1 km northwest of the Ban Samoh group. Most of the area is flat. Settlement in this group was well planned with houses located on both sides of the road which passes through the area. There are several house styles including two-story houses, one-story houses with elevated floors, houses with thatch roofs, etc. There are 40 households. Most of the residents are Buddhist.

Ban Champoon Group This group is situated approximately 1 km south of the Ban Samoh group. Most houses in this group have galvanized steel or thatch walls. There are 38 households in this group. Most of the residents are Thai-Muslim.

The Ban Samoh village can be reached via two access roads. The first route consists of an asphalt road from the city of Yala with a lateritic road branching from the main asphalt road at Tambon Wong Phaya leading to the village. The total distance between the village and the city of Yala along this route is 21 km. Most villagers prefer to use this route.

The second route connects the village with the civic center of Amphoe Raman. The road connecting the city of Yala and Amphoe Raman is an asphalt road 26 km long. The road from Amphoe Raman to the village is a lateritic road, 9 km in length. The villagers seldom use this route since there is no public bus.

Communications between each group in the village is fairly convenient. There are lateritic roads connecting each household group with the Ban Samoh group in the center.

Population and Households

There are a total of 204 households with 868 residents in Ban Samoh village. Most of the villagers are 15-25 years old (55 percent of the male residents and 44 percent of the female residents).

Education

At present there are two primary schools in Ban Samoh village, namely Wat Rangsitaram school and Ban Champoon school. There are 110 students in Wat Rangsitaram school studying in the P.1-P.6 level. Almost all students are Buddhist. There are 7 teachers in this school. There are 67 students and 5 teachers at the Ban Champoon school. All students are Muslim.

In all, the number of household members in school (both inside and outside the village) is 182. About 49 percent of them are studying at the P.1-P.4 level, 25 percent are studying at the P.5-P.6 level, and the other 13 percent are higher than the primary school level.

Regarding those household members who have completed their studies, 67 percent finished P.4 level or lower, and 16 percent finished P.5-P.6 level. Only 17 percent finished higher than the primary school level.

Approximately 31 percent of the villagers have never received any formal education. Among these 61 percent are female and 39 percent are male.

Religion and Language

Roughly 36 percent of the residents in Ban Samoh village are Muslim, the remaining 64 percent are Buddhist. The Muslim residents mostly speak the Yawee language which is different from the Thai dialect; and those who have not attained school will seldomly speak Thai. However, most of the young residents can use the Thai language very well.

Occupation

The main occupation of the villagers in Ban Samoh village is agriculture. Rice and rubber are the main crops grown in this area. Some households still grow other upland crops and vegetables either to increase their household income or for household consumption.

Animals are raised mainly for household consumption. Chickens are very popular in this area.

Agriculture

The total agricultural area in Ban Samoh is approximately 3,060 rai or about 60 percent of the village area. About 1,900 rai is cultivated for paddy rice, another 760 rai is cultivated for rubber or other tree crops, and the remaining 400 rai is used for upland crops. On the average, each household cultivates 15 rai of agricultural land.

The main crops cultivated in this area are rice and rubber. Rice is grown mainly for household consumption. Only 13 percent of the households have enough rice for sale. About 63 percent of the households have their own planting area for rubber trees, the remaining 37 percent work as laborers on the rubber planting lands.

The average rice yield is 216 kg/rai ranging from 180 kg/rai in the Ban Bukebalo group to 230 kg/rai in the Ban Samoh group (Table 4.17). The average gross income from rice production is 756 Baht (US$ 32.9) per rai.

TABLE 4.17 RICE PRODUCTION AND ANNUAL INCOME

Group	Production		For seeding (kg)	For household consumption (kg)	For sale (kg)
	Kg/rai	Baht/rai			
Ban Champoon	201	703	6.2	188.2	6.6
Ban Bukebalo	180	614	3.4	128.4	48.2
Ban Koh	194	681	6.4	168.0	19.6
Ban Samo and Pa-on	230	804	4.6	169.1	56.3
Overall Average	216	756	6.3	167.7	42.0

An average of 73 kg/rai of rubber is produced annually. The production the in Ban Samoh group is highest (84.8 kg/rai). Table 4.18 shows the production and annual income from rubber planting.

TABLE 4.18 RUBBER PRODUCTION AND ANNUAL INCOME

Group	Annual Production	
	kg	Baht
Ban Champoon	39.2	424
Ban Bukebalo	66.1	826
Ban Koh	53.9	700
Ban Samo and Pa-on	84.8	1,057
Overall Average	73.0	908

Household Economy

Household income

Household income is separated into 2 items, i.e. agricultural income and non-agricultural income.

The average agricultural income in the Ban Samoh and Pa-on group is highest with a gross income of 33,003 Baht (US$ 1,435) and a net income of 24,442 Baht (US$ 1,063) per household. Ban Champoon has the lowest, with a gross income of 6,003 Baht (US$ 261) and a net income of 4,830 Baht (US$ 210). The average gross and net incomes of the entire village are 20,310 Baht (US$ 883) and 15,007 Baht (US$ 652) per household, respectively (Table 4.19-4.20).

Non-agricultural income includes those incomes derived from working as a laborer, trading, household industries, and others. The overall average in this village is 10,429 Baht (US$ 453) per household (Table 4.21).

Table 4.22 shows the total net incomes of various groups in Ban Samoh village. The average for the entire village is 25,436 Baht (US$ 1,106) per household.

TABLE 4.19 AGRICULTURAL GROSS INCOME

Baht/Household

Crop \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Rice	-	-	176	2,331	1,063
Rubber	5,704	9,312	14,992	30,257	18,994
Others	299	80		415	253
Total	6,003	9,392	15,168	33,003	20,310

TABLE 4.20 AGRICULTURAL NET INCOME

Baht/Household

Crop \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Rice	-	-	-	123	54
Rubber	4,575	8,017	9,667	24,008	14,754
Others	255	80	-	311	199
Total	4,830	8,097	9,667	24,442	15,007

TABLE 4.21 NON-AGRICULTURAL NET INCOME

Baht/Household

Income \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Average Non-agri-cultural Net Income	3,020	10,977	1,440	17,334	10,429

TABLE 4.22 TOTAL NET INCOME

Baht/Household

Income \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Agricultural	4,830	8,097	9,667	24,442	15,007
Non-agricultural	3,020	10,977	1,440	17,334	10,429
Total	7,850	19,074	11,107	41,776	25,436

Household expenditure

Total household expenditure can be classified as the expenses for agricultural inputs and non-agricultural expenses. For agricultural input, an average of 5,303 Baht (US$ 231) per household is paid annually (Table 4.23). Non-agricultural expenses are further classified as regular and non-regular expenses. An average of 20,549 Baht (US$ 893) per household is paid annually for these two items (Table 4.24). The total annual expenditure is therefore 25,852 Baht (US$ 1,124) per household (Table 4.25).

TABLE 4.23 AGRICULTURAL INPUT

Baht/Household

Crop \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Rice	-	-	176	2,208	1,009
Rubber	1,129	1,295	5,325	6,249	4,240
Others	44	-	-	104	54
Total	1,173	1,295	5,501	8,561	5,303

TABLE 4.24 NON- AGRICULTURAL EXPENSE

Baht/Household

Item \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Regular	9,954	11,059	12,130	29,514	19,205
Non-regular	171	639	1,664	1,978	1,344
Total	10,125	11,698	13,794	31,492	20,549

TABLE 4.25 TOTAL HOUSEHOLD EXPENDITURE

Baht/Household

Item \ Group	Ban Champoon	Ban Bukebalo	Ban Koh	Ban Samoh & Pa-on	Overall Average
Agricultural	1,173	1,295	5,501	8,561	5,303
Non-agricultural	10,125	11,698	13,794	31,492	20,549
Total	11,298	12,993	19,295	40,053	25,852

Water Supply

The main sources of water for agricultural purposes in Ban Samoh village are rain-water, shallow wells, ground water wells, diversion weir and other natural storage ponds. For paddy rice cultivation, 79 percent of the cultivating households rely on rain-water, the other 16 percent receive water from the diversion weir and the remaining 5 percent use other sources. Most of them (82 percent) reported that there was adequate water. For the cultivation of other upland crops and vegetables, most farmers rely on rain-water or shallow wells.

The main sources of water for domestic use are rain-water, ground water wells and shallow wells.

E. INSTALLATION AND EXPERIMENTAL STUDY

In this section, the installation and field experiments of two types of water pumping systems, namely solar water pumping and wind turbine water pumping, are reported. Two solar water pumps were installed, one at Ban Sukorn and the another at Ban Tha Yiam. Three wind turbine water pumps were installed at Ban Samoh. It was planned to install the gasifier system in Si Saket Province. However, owing to the delay in supplying the gasifier to be imported, this system has not yet been installed. It was planned to install the biogas system in Maha Sarakharm Province but due to the limited implementation time, the experimental results will not be reported.

Solar Water Pump at Ban Sukorn

A 4,300-watt solar water pumping system was installed at Ban Sukorn to pump water from the Pradok Reservoir into an irrigation canal which serves those paddy fields in Ban Sukorn village. There were a total of 4 identical sets of solar cells, motors, and pumps. The CSB 100D model of ARCO Solar, Inc. was used. Each set consisted of a solar array, a direct current (DC) induction motor, a self priming centrifugal pump, and some auxiliary parts.

The solar array installed at Ban Sukorn was designed so that the nominal maximum power at the standard condition (100 mW/cm^2 at 25°C) would be at least 4,300 watts to assure, with an adequate safety factor, a total water discharge of not less than 480 m^3/day at 5-m head. The installed unit consisted of 4 arrays. Each had 32 modules of solar cells. The output voltage was 58 volts.

The DC induction motors installed at Ban Sukorn village had 1 horsepower each. The rated voltage was 58 volts and the rated current was 18 amp. There was a 2,500 rpm revolution that could run in either direction by merely reversing terminal polarity.

The self-priming centrifugal pumps were connected with the motors. According to the specifications, the CSB 100D was recommended for applications requiring 25-50 feet of total head and flow rates of 20-75 gallons per minute. Pump speed varies with the intensity of the sunlight, i.e. The pump starts running slowly early in the morning, building up to maximum speed as the sun climbs and tapering off in the afternoon. Photos 4.1-4.6 illustrate the installed solar pumping system at Ban Sukorn.

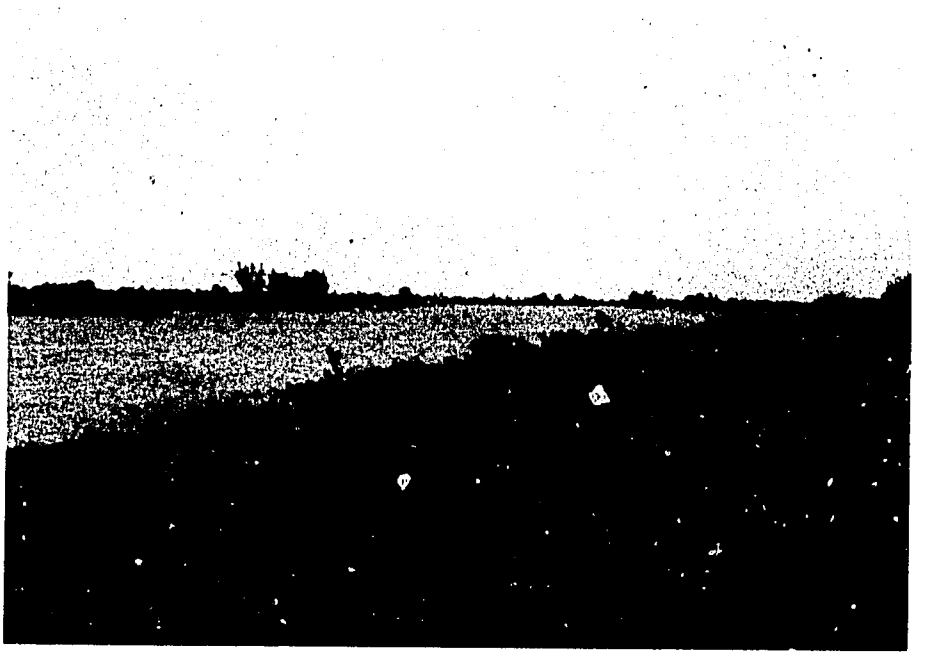

PHOTO 4.1 THE PRADOK RESERVOIR, BAN SUKORN

PHOTO 4.2 VILLAGERS' PARTICIPATION

PHOTO 4.3 LAND PREPARATION AT BAN SUKORN

PHOTO 4.4 CONCRETE BASE CONSTRUCTION AT BAN SUKORN

PHOTO 4.5 SOLAR PANEL INSTALLATION AT BAN SUKORN

PHOTO 4.6 THE 4,300-WP SOLAR CELL PUMPING SYSTEM AT BAN SUKORN

Solar Water Pump at Ban Tha Yiam

A 700-watt solar water pumping system was installed at Ban Tha Yiam to pump water from a ground water well to a storage tank of 10 m^3 in capacity. A piping system was connected from this storage tank to another 4 distribution tanks each with a capacity of 1.5 m^3 located in various parts of Ban Tha Yiam village. The system consists of a solar array, a DC motor, a screw-pump, a 10 m^3 distribution tanks and a piping system.

The solar array at Ban Tha Yiam was designed so that the nominal maximum power at the standard condition (100 mW/cm^2 at 25°C) would be at least 700 watts to assure, with adequate safety factors, a total discharge of more than 10 m^3/day at 21.5 m total head. The installed unit consisted of 1 array with 18 modules of solar cells.

The water pump at Ban Tha Yiam was a screw type. The diameter of the shaft tube was 3.5 inches and the tube extended about 18 m below the ground surface.

The DC motor which ran the screw pump was from the SR53 series with 1 HP. It has a rated voltage of 90 volts, a rated current of 9.5 amp, and a rated speed of 1,750 rpm.

Photos 4.7-4.10 illustrate the installed solar pumping system at Ban Tha Yiam.

PHOTO 4.7 BAN THA YIAM, SAKON NAKHON PROVINCE

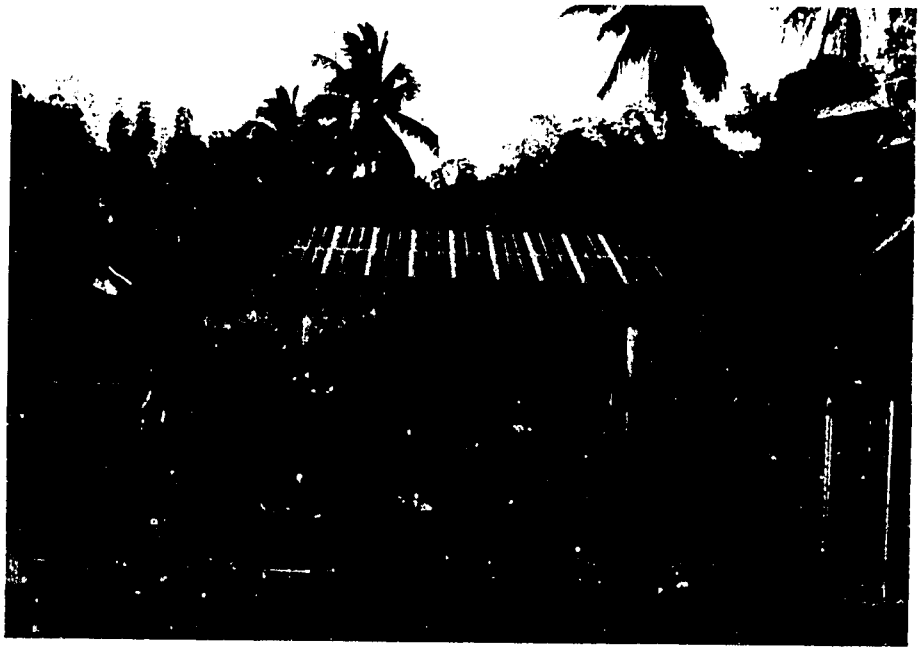

PHOTO 4.8 SOLAR PUMP AT BAN THA YIAM

PHOTO 4.9 MAIN STORAGE TANK AT BAN THA YIAM

PHOTO 4.10 WATER UTILIZATION AT BAN THA YIAM

Wind Turbine Pumps at Ban Samoh

Three windmills were installed at Ban Samoh to pump water for irrigation. Two of them were a multi-blade type, the other was a VITA type. The experimental results of two windmills, the big multi-blade and the VITA ones, are reported.

The multi-blade windmill installed at Ban Samoh was a horizontal shaft type. Its blades were made of galvanized steel sheets with L-shaped steel frames. The diameter of the blades was 3.05 m. The blades were installed on a steel support with its center approximately 12 m above ground level. The pumping unit was a one-stroke displacement pump, with a piston diameter of 7.5 cm and a 7.5 cm displacement length. This windmill was installed to pump water from a drilled well with a 4.50 m lifting head.

The VITA windmill installed at Ban Samoh was a horizontal shaft type. It consisted of 20 bamboo blades, 6 m in diameter. The pumping unit was a PVC pope, 6 inches in diameter. The blades were installed on a steel support, 7.50 m above ground level. This windmill was installed to pump water from a storage pond. The lifting head was 0.60 m.

Photos 4.11-4.14 illustrate the windmills installed at Ban Samoh.

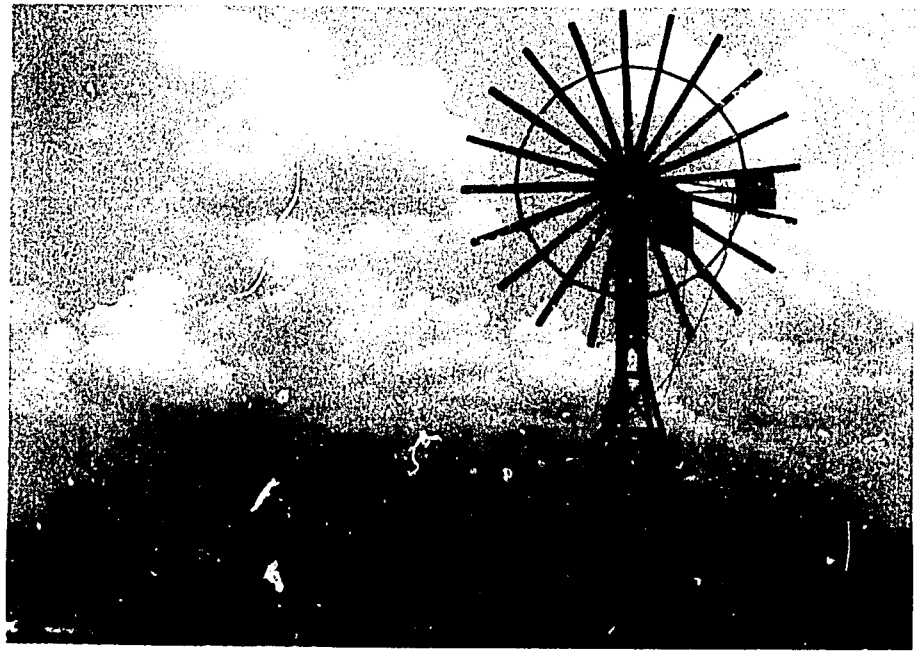

PHOTO 4.11 BAMBOO BLADE VITA WINDMILL AT BAN SAMOH

PHOTO 4.12 LARGE MULTIBLADE WINDMILL AT BAN SAMOH

PHOTO 4.13 SMALL MULTIBLADE WINDMILL AT BAN SAMOH

PHOTO 4.14 VILLAGER PARTICIPATION AT BAN SAMOH

F. INTERPRETATION OF RESULTS

In this section the results obtained from testing the performance of the installed solar and wind turbine water pumping systems are presented. The testing was conducted once the installation was completed. It took approximately 14 days to test each installed unit.

Solar Water Pumping System

Only the test data on the solar pumping system for domestic use at Ban Tha Yiam are available. This pumping system has been operational since January 1984. There were some conflicts over land ownership in Ban Sukorn. Therefore, the construction of the irrigation canal has been delayed, and hence the installed solar pumping system for irrigation purpose at Ban Sukorn is not yet operational.

In testing, the following measurements were made :

- Measurements of solar flux by using a solarimeter;
- Measurements of pumping discharge by using an orifice meter; and
- Measurements of ambient temperature and solar cell surface temperature by using a thermometer.

A typical curve of solar flux measured in the testing is shown in Fig. 4.1 whereas the corresponding pumping discharge curve is shown in Fig. 4.2. It should be noted that the highest pumping rate did not occur in conjunction with the highest solar flux intensity. The pumping rate was found to decrease gradually as the pump continued operating. This might have been caused by the increase in drawdown level which resulted in a higher lifting head and thus a lower discharge rate. Solar cell temperature was also a major factor that governed the performance of the solar array.

The cumulative energy on the solar array measured in kWh/m^2 is shown in Fig. 4.3, in which the daily value of 4.0 kWh/m^2 was recorded as total solar energy on the solar array.

Fig. 4.4 illustrates the daily cumulative pumping discharge of the solar pumping system at Ban Tha Yiam. Approximately 6.0 m^3 a day was obtained during the testing period.

The overall efficiency of this solar pumping system as a function of solar flux is plotted in Fig. 4.5. The overall efficiency was found to vary within the range of 0.9-1.6%. Its value decreased as the solar flux intensity increased.

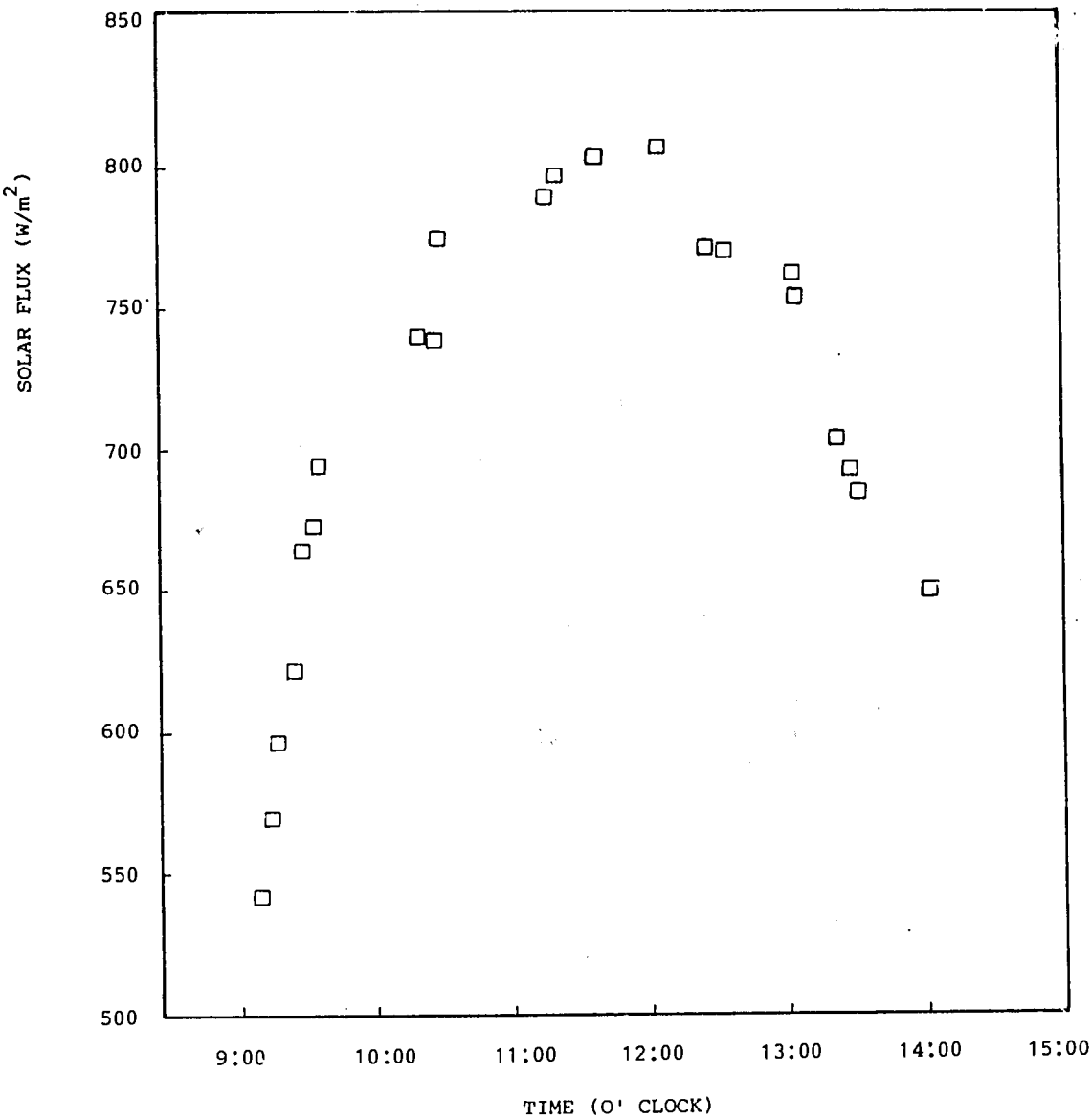

FIGURE 4.1 TYPICAL CURVE OF SOLAR FLUX AGAINST TIME AT BAN THA YIAM

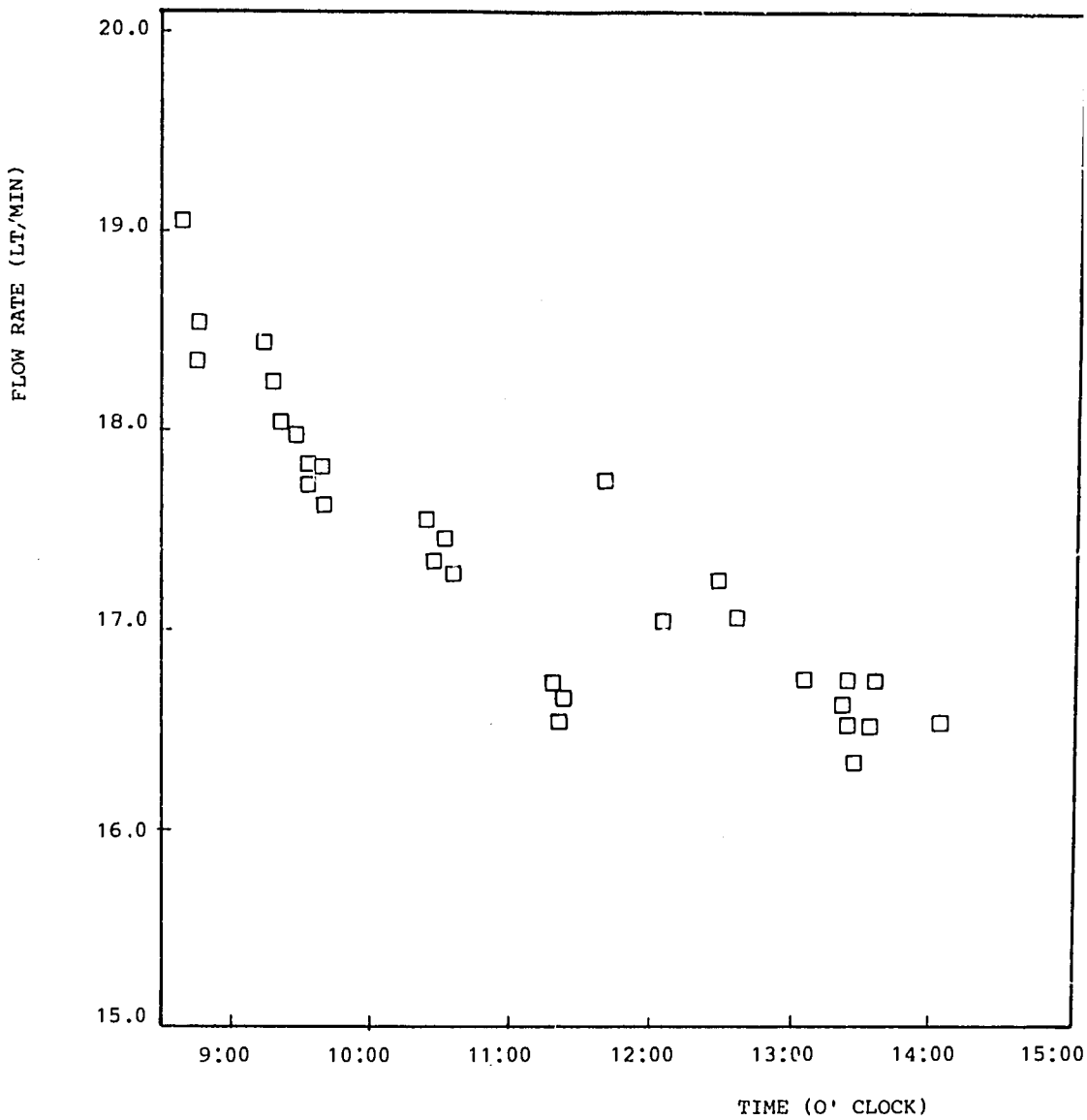

FIGURE 4.2 PUMPING FLOW RATE VS. TIME AT BAN THA YIAM

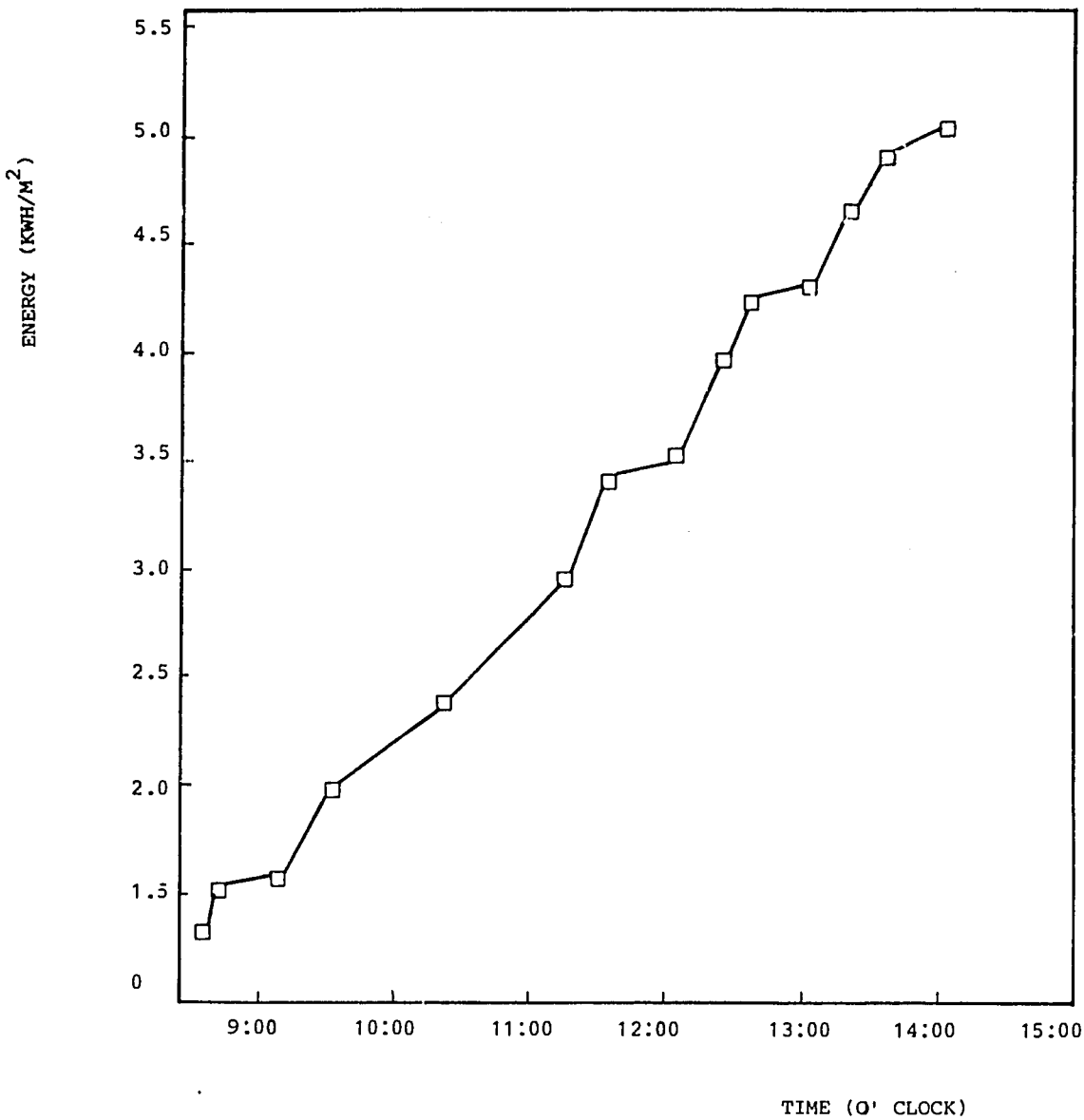

FIGURE 4.3 CUMULATIVE ENERGY ON SOLAR ARRAY AT BAN THA YIAM

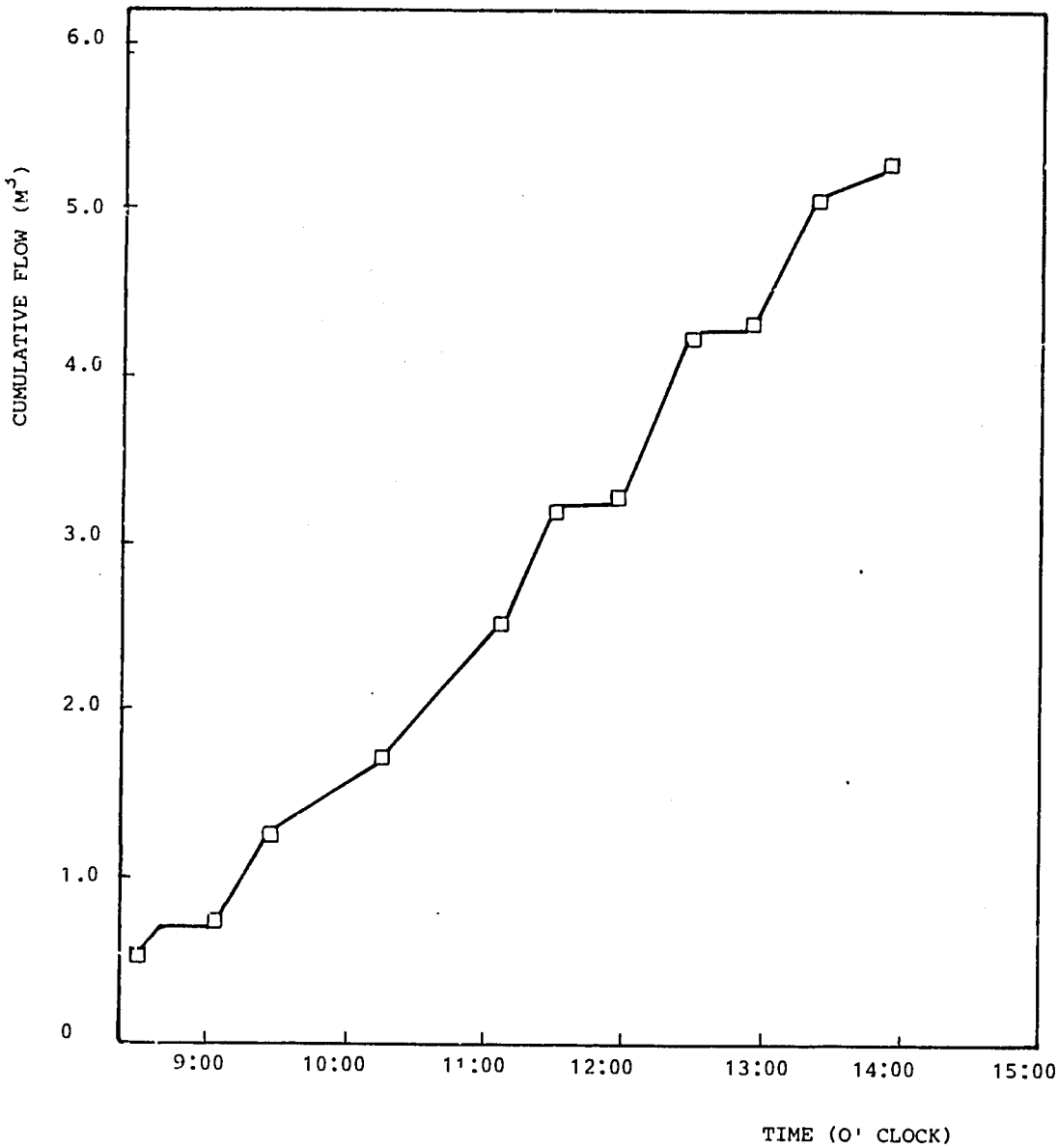

FIGURE 4.4 CUMULATIVE PUMP DISCHARGE AT BAN THA YIAM

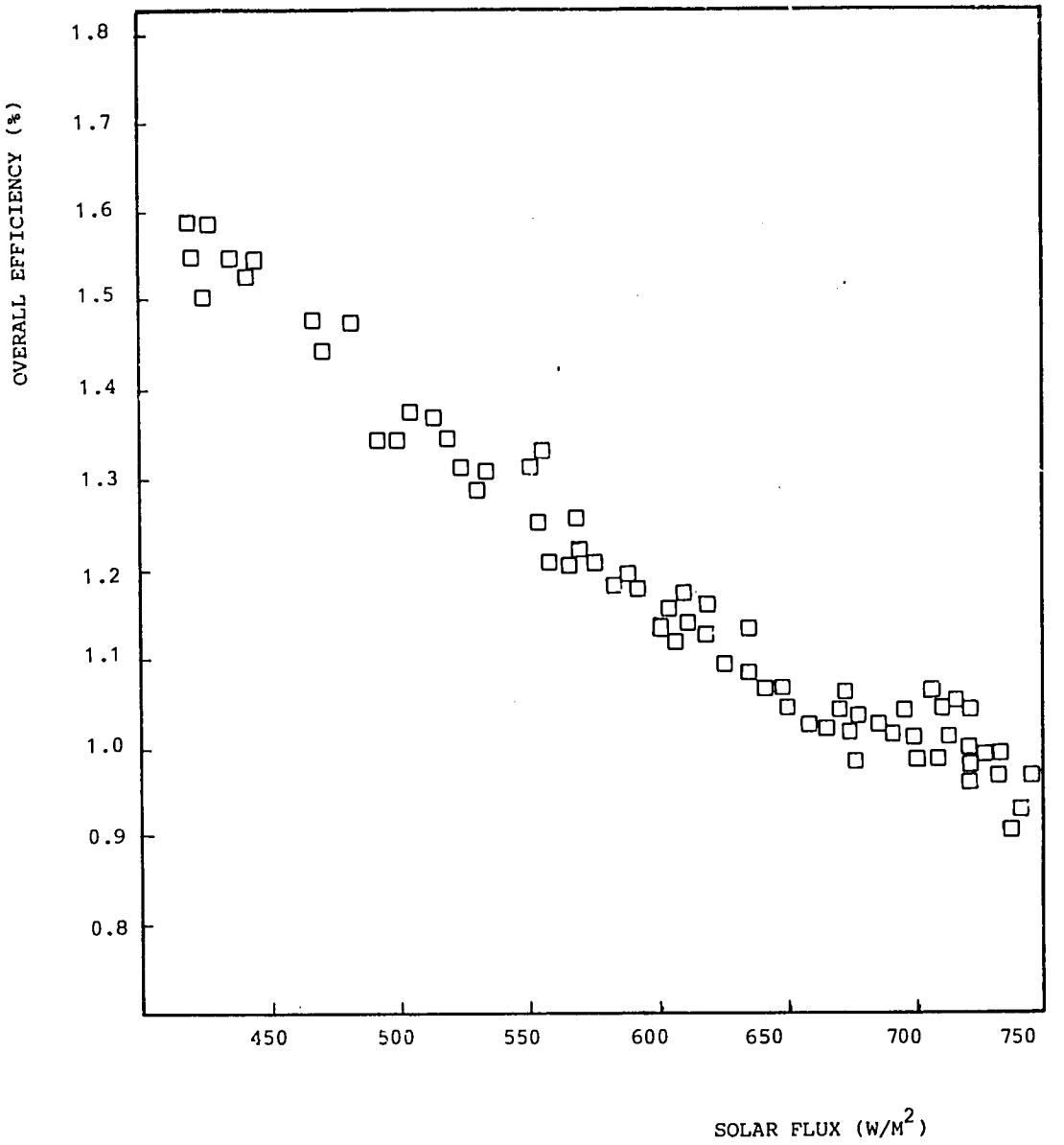

FIGURE 4.5 OVERALL PERFORMANCE EFFICIENCY VS. SOLAR FLUX

Wind Turbine Pumping System

There were three windmills installed at Ban Samoh, Yala Province. However, only test data from two windmills, one multi-blade and one VITA type, are available.

Multi-blade windmill

The results obtained from the testing can be summarized as follows :

1. Cut-in Speed The average speed at which the windmill started rotating was 2 m/s;

2. Pumping Discharge From the test data (Table 4.26) and Fig. 4.6 it was found that the pump discharge was linearly related to the mean wind speed. Using simple linear regression, the relationship $Q = 3.84 + 2.26\ V$, where Q is the pump discharge (lt/min.) and V is the mean wind speed (m/s), is obtained. This relationship is useful in estimating the pump discharge at the wind speeds higher than those in the test data. From Fig. 4.6 the pump discharge at the mean wind speed of 2 m/s is approximately 8 lt/min, and the pump discharge at the mean wind speed of 10 m/s is expected to be as high as 26 lt/min;

3. Windmill Speed From Table 4.26 and Fig. 4.7 the windmill will rotate at 25 rpm when the mean wind speed is 2 m/s and 78 rpm when the wind speed is 10 m/s;

4. Monthly Pump Discharge Fig. 4.8 shows the relationship between the monthly pump discharge and the mean wind speed. At a mean wind speed of 2 m/s, a monthly pump discharge of 274 m^3 is obtained and the monthly volume will increase to approximately 667 m^3 at a mean wind speed of 6 m/s.

5. Overall Efficiency ($C_p.\eta$) The overall efficiency is defined as the ratio of water power to wind power received by the windmill.

$$\text{Water power} = \rho_w g \frac{HQ \times 10^{-3}}{60}$$

$$\text{Wind power} = \frac{1}{2} \rho_a V^3 \pi R^2$$

where ρ_w is the density of water = 1,000 kg/m^3

g is the gravitational acceleration = 9.8 m/s^2

ρ_a is the density of air = 1.17 kg/m³

H is the lifting head, m

Q is the pumping flow rate, lt/min.

V is the wind velocity, m/s

R is the radius of the windmill blade

π (Pi) = 3.14127

The overall efficiency is therefore determined from

$$\text{Overall efficiency } (C_p.\eta) = \frac{\rho_w \, g \, HQ \times 10^{-3}}{\frac{1}{2} \rho_a \, V^3 \pi R^2 \times 60}$$

Table 4.27 and Fig. 4.9 show the relationship between the overall efficiency and wind speed. It was found that the overall efficiency of this windmill was highest (14%) at a wind speed of 2 m/s and the value would decrease as the wind speed increased.

6. Volumetric Efficiency (Q/Q_{th}) The volumetric efficiency is defined as the ratio of the actual pumping discharge (Q) and the theoretical pumping discharge (Q/Q_{th}).

The theoretical pumping discharge is computed from

$$Q_{th} = \frac{\pi}{4} D_p^2 \, SN$$

where Q_{th} is the theoretical pumping discharge,

D_p is the diameter of the piston,

S is the stroke length,

N is the windmill revolution

Table 4.27 and Fig. 4.10 show the relationship between the volumetric efficiency and wind speed. It was found that the volumetric efficiency was almost constant (98-99%).

TABLE 4.26 TEST DATA OF MULTI-BLADE WINDMILL

Bin No.	Bin Interval (m/s)	Number of Data set	Bin Average		
			Wind Speed (m/s)	Windmill speed (rpm)	Flow Rate (lt/min)
1	2.0-2.5	75	2.18	24.88	8.45
2	2.5-3.0	67	2.60	27.67	9.37
3	3.0-3.5	160	3.08	33.49	11.34
4	3.5-4.0	73	3.55	36.74	12.49
5	4.0-4.5	135	4.06	38.22	12.81
6	4.5-5.0	63	4.53	41.62	13.99
7	5.0-5.5	75	5.06	44.48	15.06

TABLE 4.27 TEST RESULTS AND FORECAST FOR MULTI-BLADE WINDMILL

Wind Speed (m/s)	Flow Rate (lt/min)	Windmill (rpm)	Overall Efficiency (%)	Q/Q_{th}
2.18	8.45	24.88	14.04	0.99
2.60	9.37	27.67	9.18	0.99
3.08	11.34	33.49	6.68	0.99
3.55	12.49	36.74	4.80	0.99
4.06	12.81	38.22	3.29	0.98
4.53	13.98	41.62	2.59	0.98
5.06	15.06	44.48	2.00	0.99
5.5	16.27	48.27	1.68	0.99
6.0	17.40	51.65	1.39	0.98
6.5	18.53	55.03	1.16	0.98
7.0	19.66	58.41	0.99	0.98
7.5	20.79	61.79	0.85	0.98
8.0	21.92	65.17	0.74	0.98
8.5	23.05	68.55	0.65	0.98
9.0	24.18	71.93	0.59	0.98
9.5	25.31	75.31	0.51	0.98
10.0	26.44	78.69	0.46	0.98
10.5	27.57	82.07	0.41	0.98
11.0	28.70	85.45	0.37	0.98

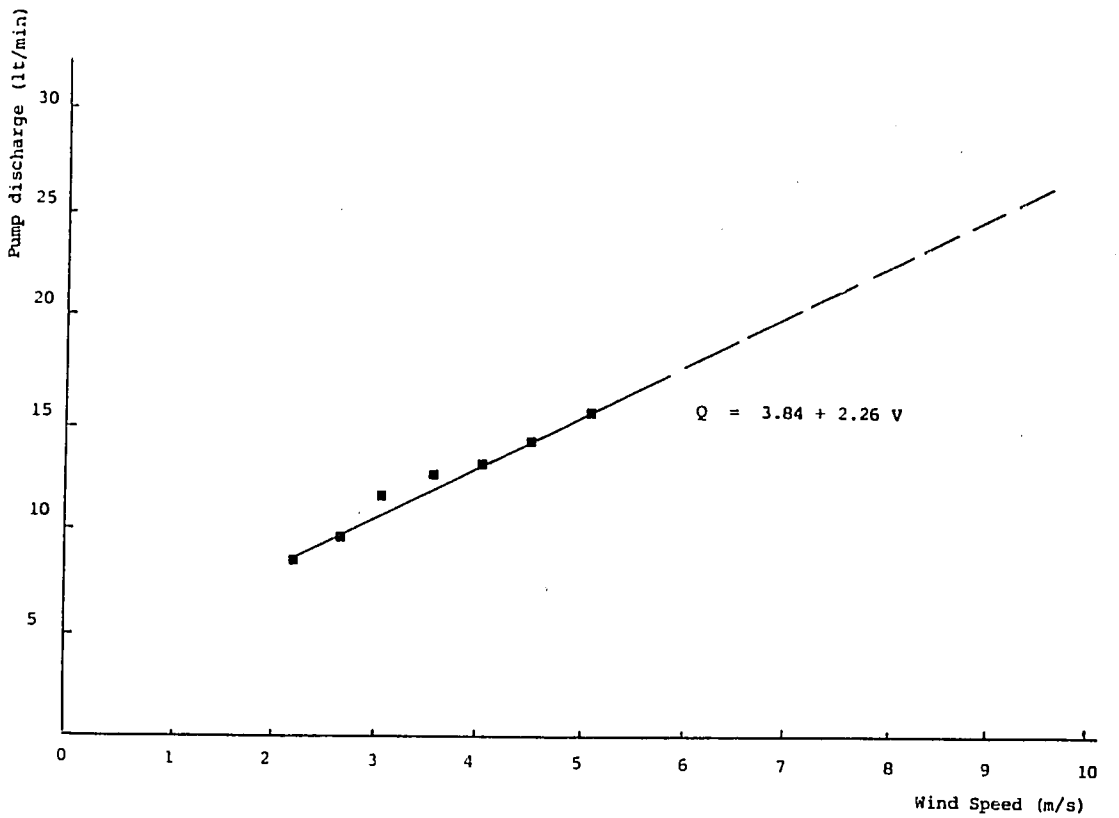

FIGURE 4.6 RELATIONSHIP BETWEEN PUMP DISCHARGE AND WIND SPEED (MULTI-BLADE)

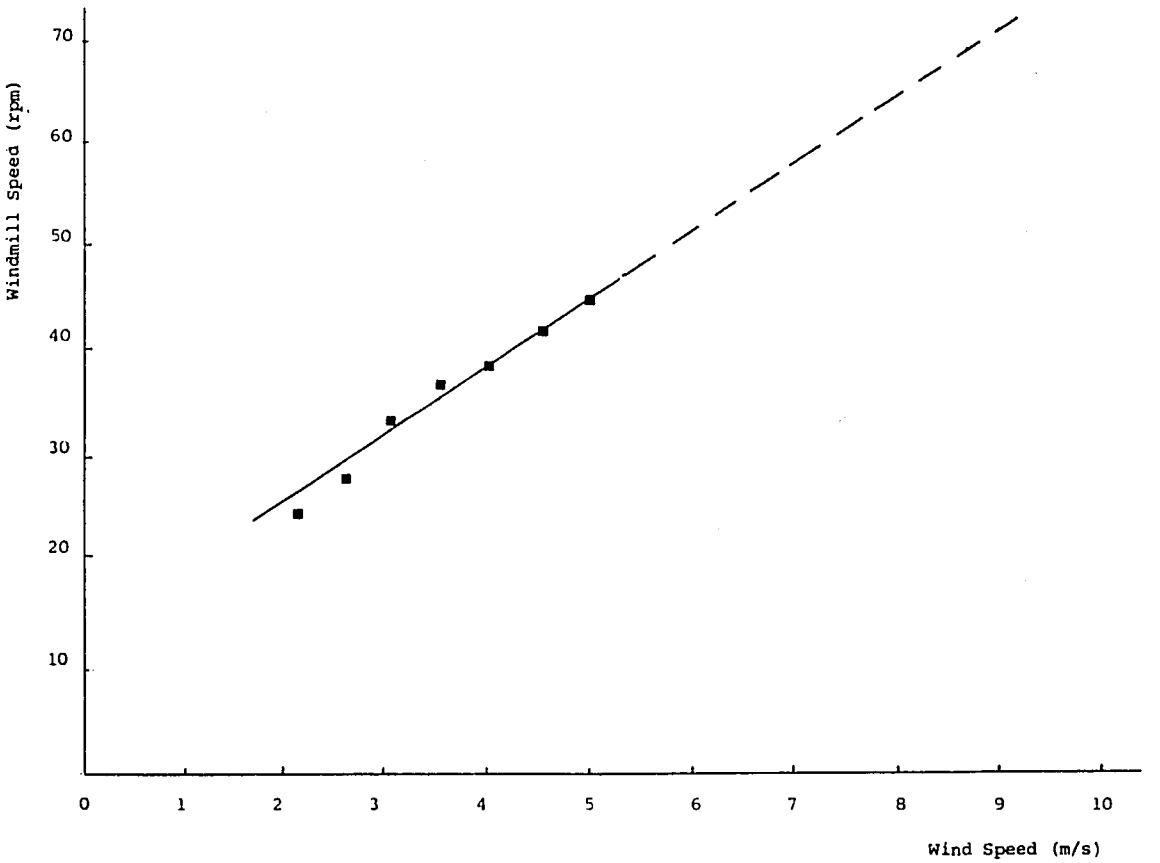

FIGURE 4.7 RELATIONSHIP BETWEEN WINDMILL SPEED AND WIND SPEED (MULTI-BLADE)

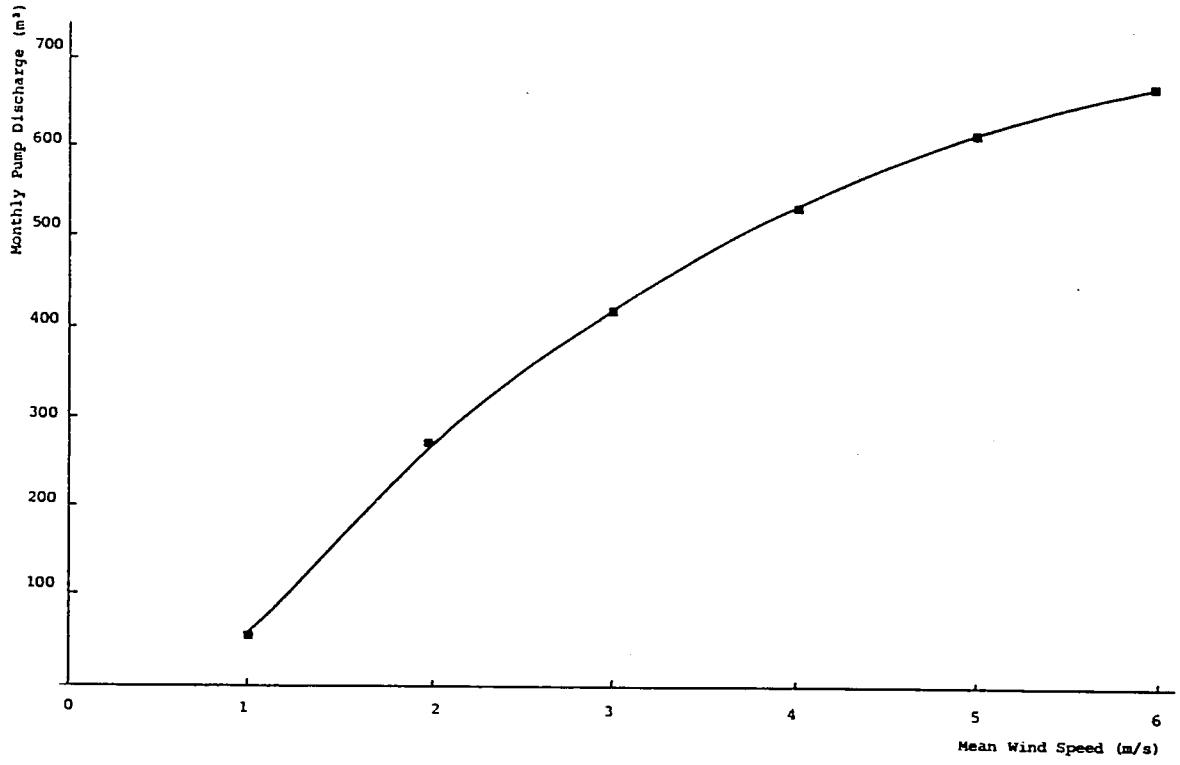

FIGURE 4.8 RELATIONSHIP BETWEEN MONTHLY PUMP DISCHARGE AND MEAN WIND SPEED (MULTI-BLADE)

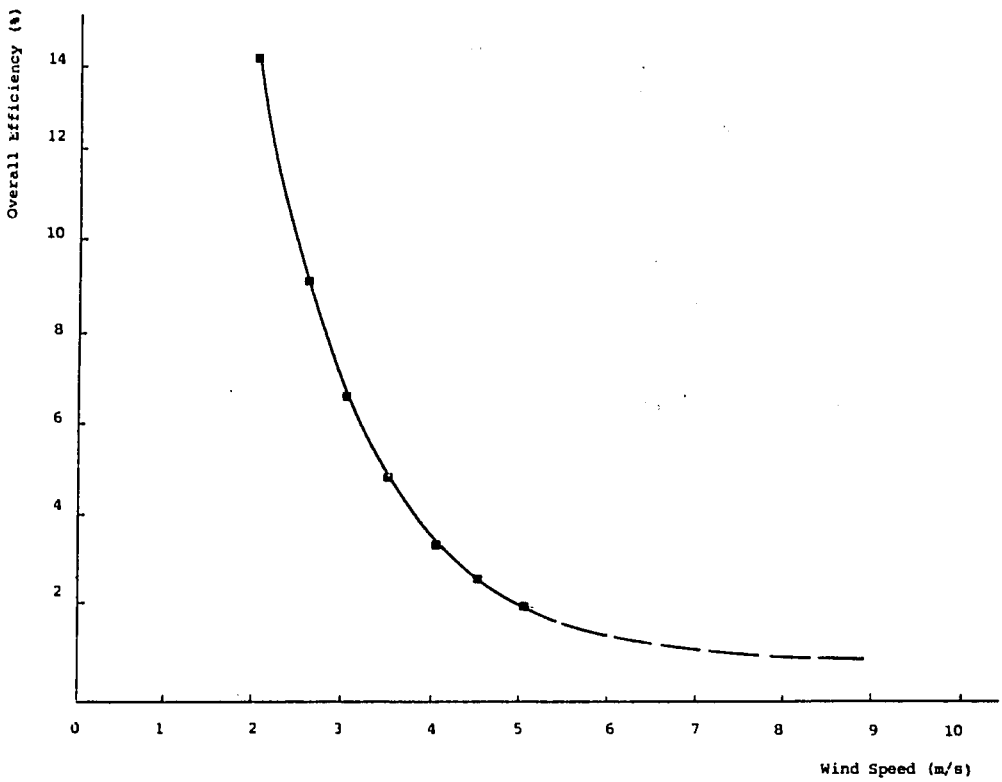

FIGURE 4.9 RELATIONSHIP BETWEEN OVERALL EFFICIENCY AND WIND SPEED (MULTI-BLADE)

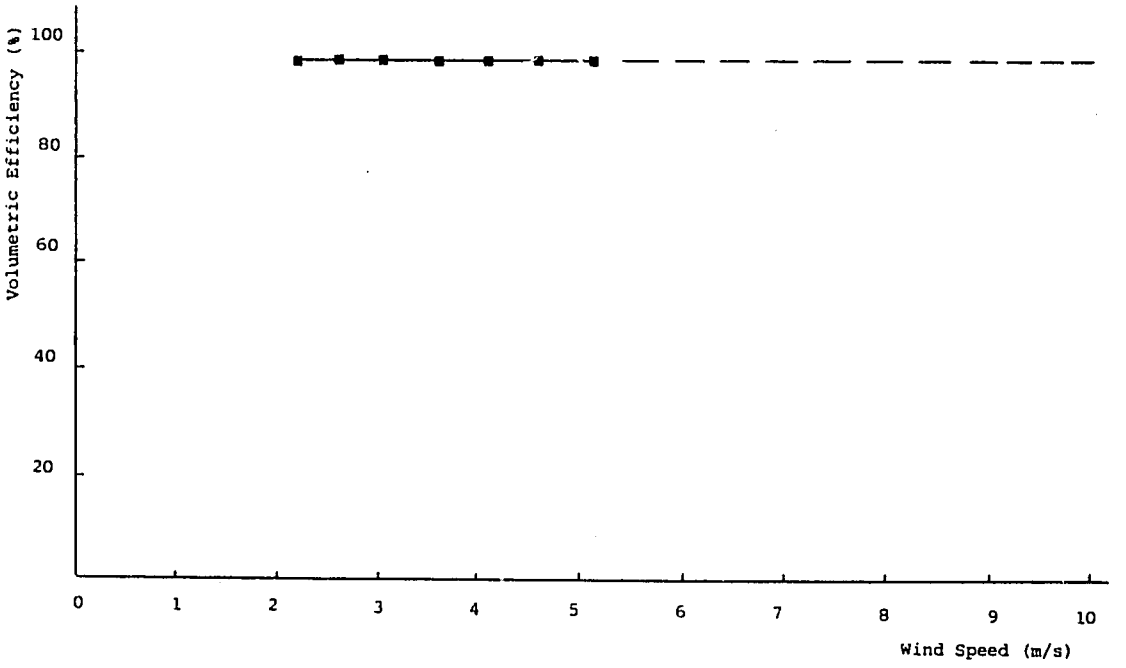

FIGURE 4.10 RELATIONSHIP BETWEEN VOLUMETRIC EFFICIENCY AND WIND SPEED (MULTI-BLADE)

VITA windmill

The results from the testing of the VITA windmill at Ban Samoh can be summarized as follows :

1. Cut-on Speed It was found that this windmill would start rotating at a wind speed of approximately 4 m/s. Once it is rotating it will pump water even though the wind speed decreases to 2 m/s;

2. Pump Discharge Table 4.28 and Fig. 4.11 show the relationship between the pump discharge and the wind speed. The pump discharge is linearly dependent on the wind speed. From the linear regression, the relationship $Q = 4.54 + 0.36\ V$ is obtained, where Q is the pump discharge in lt/s and V is the wind speed in m/s. At a wind speed of 4 m/s a discharge of approximately 5 lt/s was obtained. This relationship is useful in estimating the pump discharge at wind speeds higher than the test values;

3. Windmill Speed The relationship between the windmill speed and the wind speed is shown in Table 4.28 and illustrated in Fig.4.12. From linear regression, the relationship $R = 12.9 + 1.84\ V$ is obtained where R is the windmill revolutions in rpm and V is the wind speed in m/s;

4. Monthly Pump Discharge Fig.4.14 shows the relationship between the monthly pump discharge and the mean wind speed. At a mean wind speed of 3 m/s the monthly pump discharge of approximately 5,500 m^3 was obtained. The monthly discharge increased to 12,500 m^3 when the mean wind speed increased to 6 m/s;

5. Overall Efficiency The relationship between the overall efficiency and the wind speed is shown in Table 4.29 and Fig. 4.14. An overall efficiency of 3.3% was computed at a wind speed of 4 m/s. The overall efficiency decreased as the wind speed increased;

6. Volumetric Efficiency The volumetric efficiency of this PVC-ladder pump is shown in Table 4.29 and illustrated in Fig.4.15. The value gradually decreased as the wind speed increased. A value of 71 percent was computed at a wind speed of 2 m/s and it decreased to 63 percent at a wind speed of 6 m/s.

TABLE 4.28 TEST DATA OF VITA WINDMILL (TYPE V-20 B)

Bin No.	Bin Interval	Number of Data Set	Bin average		
			Wind Speed (m/s)	Windmill Speed (rpm)	Flow rate (lt/s)
5	2.0-2.5	17	2.0	16.59	5.55
6	2.5-3.0	24	2.5	16.75	5.20
7	3.0-3.5	42	3.0	16.86	5.49
8	3.5-4.0	44	3.5	21.2	6.15
9	4.0-4.5	26	4.0	20.96	5.37
10	4.5-5.0	32	4.5	22.22	6.26
11	5.0-5.5	39	5.0	22.85	6.38
12	5.5-6.0	6	5.5	21	6.63

TABLE 4.29 TEST RESULTS AND FORECAST FOR VITA WINDMILL

Wind Speed (m/s)	Flow Rate (lt/s)	Windmill (rpm)	Overall Efficiency (%)	Q/Q_{th}
2.0	5.25	16.58	23.4	0.71
2.5	5.45	17.5	12.4	0.70
3.0	5.6	18.42	7.3	0.68
3.5	5.8	19.34	4.8	0.67
4.0	5.98	20.26	3.3	0.66
4.5	6.15	21.18	2.4	0.65
5.0	6.35	22.1	1.8	0.64
5.5	6.5	23.02	1.3	0.63
6.0	6.7	23.94	1.1	0.63
6.5	6.9	24.86	0.9	0.62
7.0	7.05	25.78	0.78	0.61
7.5	7.25	26.7	0.6	0.61
8.0	7.40	27.62	0.5	0.60
8.5	7.60	28.54	0.44	0.60
9.0	7.76	29.46	0.40	0.60
9.5	7.95	30.38	0.33	0.59
10.0	8.14	31.3	0.3	0.58
10.5	8.3	32.22	0.25	0.58
11.0	8.5	33.14	0.22	0.58

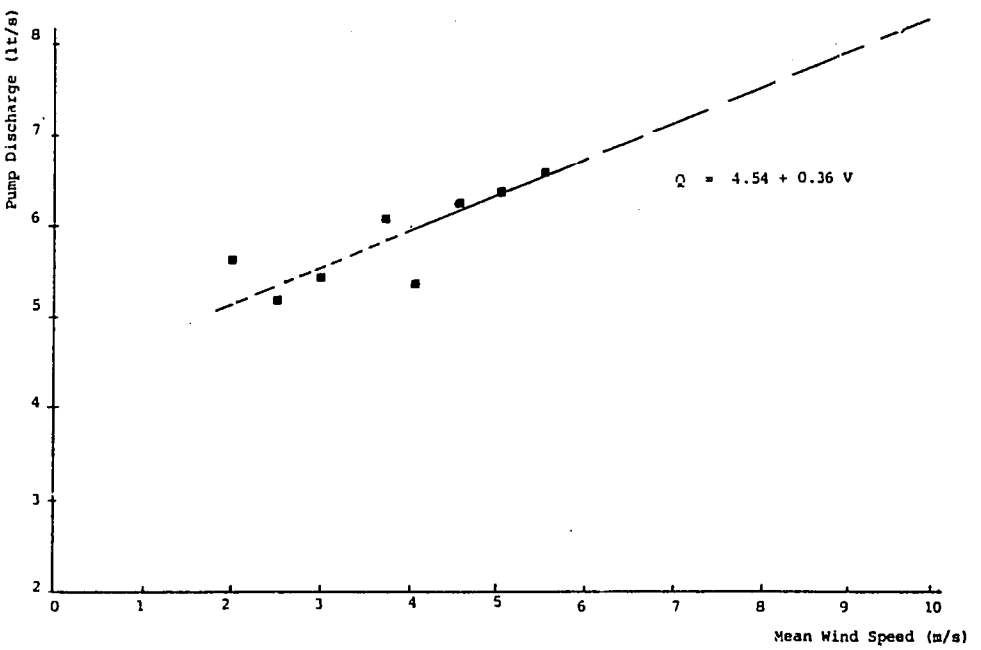

FIGURE 4.11 RELATIONSHIP BETWEEN PUMP DISCHARGE AND WIND SPEED (VITA)

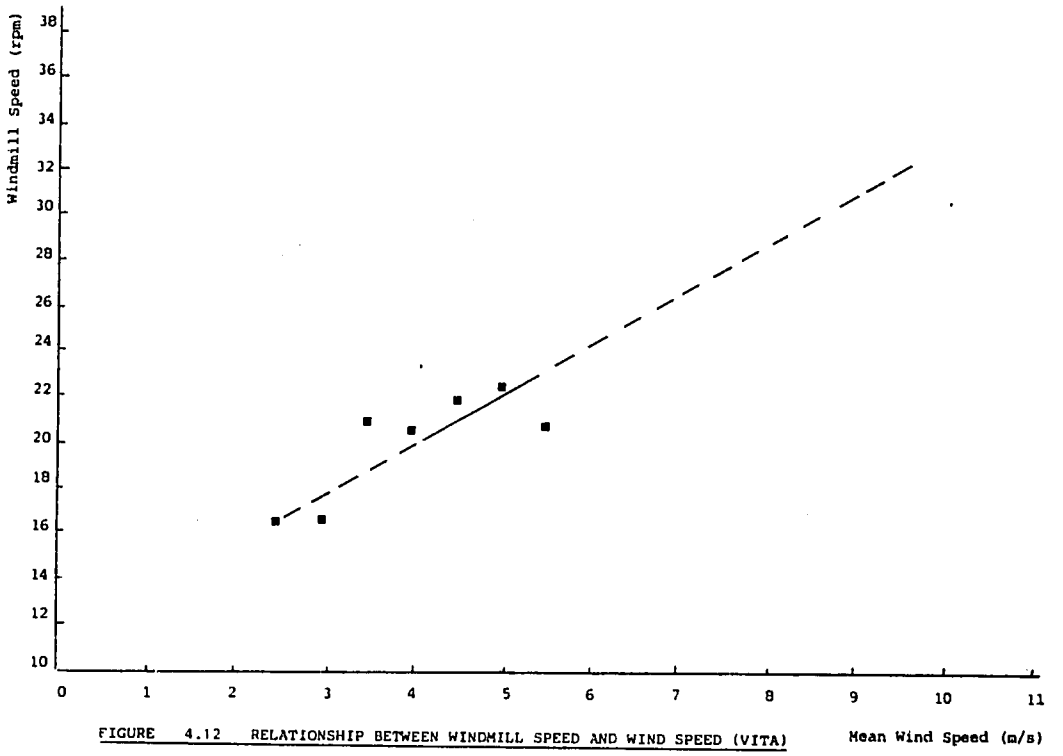

FIGURE 4.12 RELATIONSHIP BETWEEN WINDMILL SPEED AND WIND SPEED (VITA)

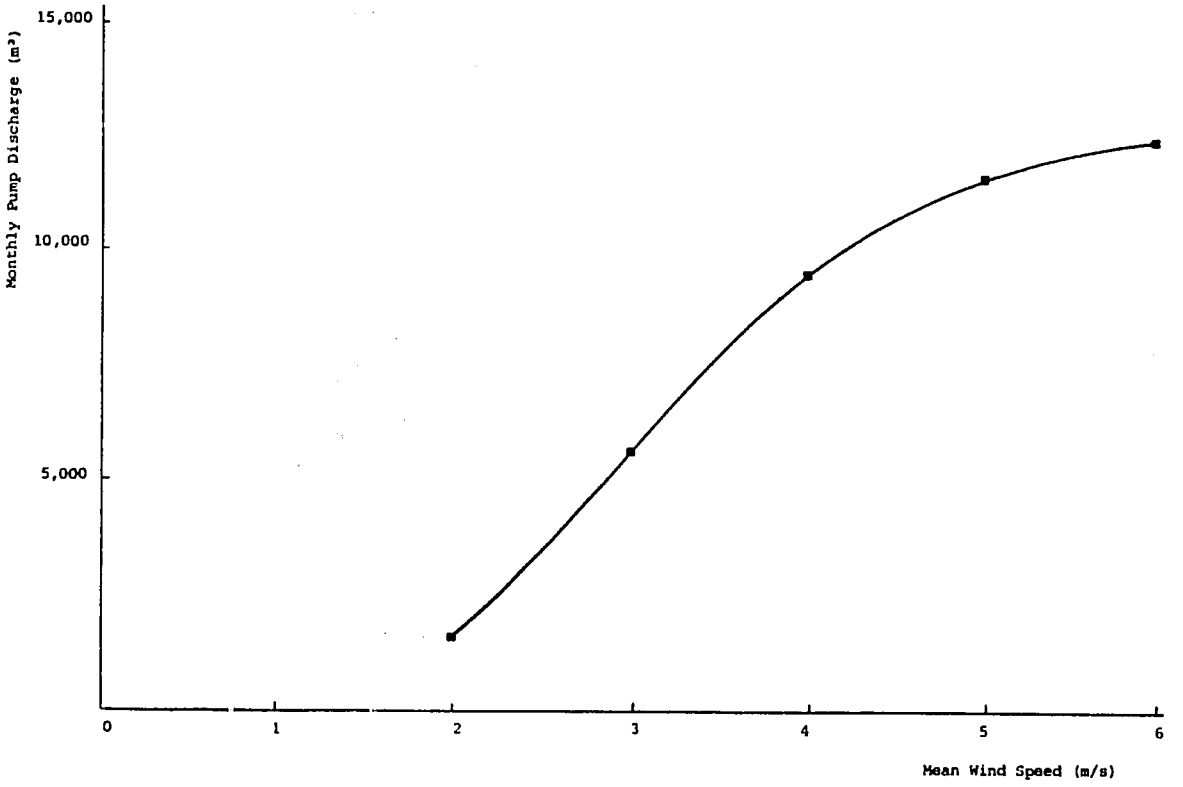

FIGURE 4.13 RELATIONSHIP BETWEEN MONTHLY PUMP DISCHARGE AND MEAN WIND SPEED (VITA)

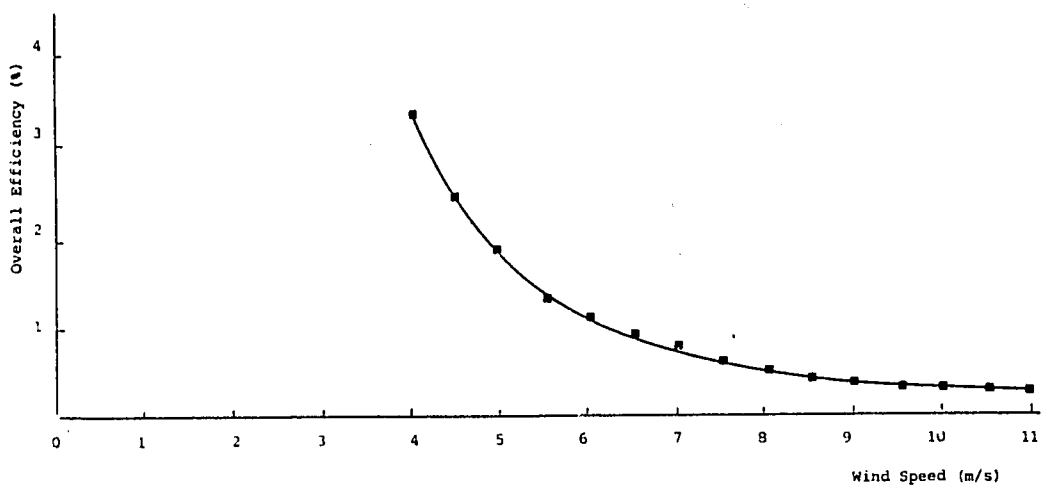

FIGURE 4.14 RELATIONSHIP BETWEEN OVERALL EFFICIENCY AND WIND SPEED (VITA)

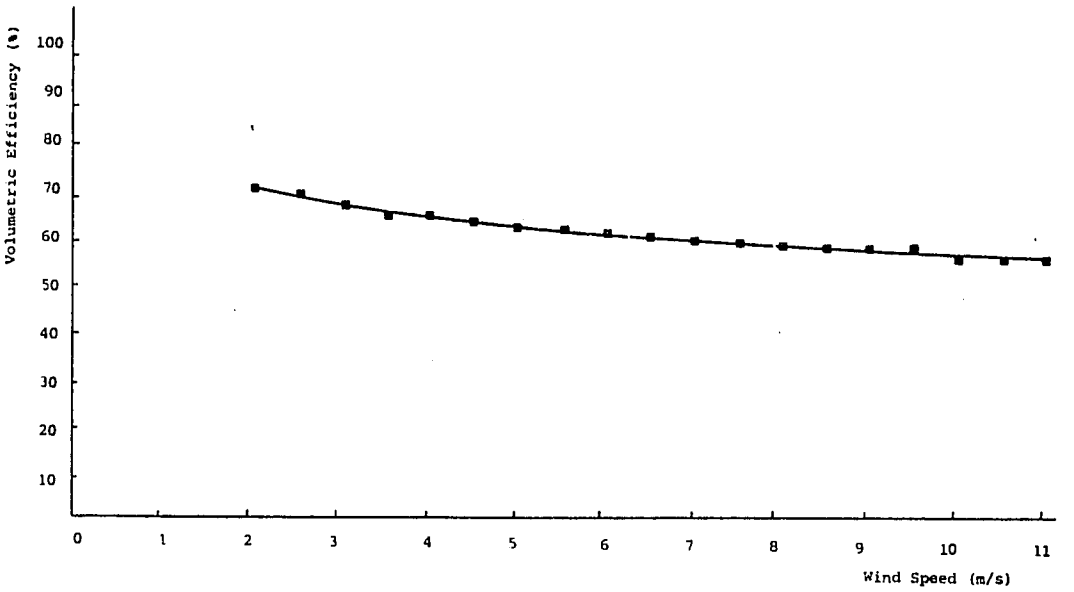

FIGURE 4.15 VOLUMETRIC EFFICIENCY OF PVC-LADDER PUMP

CHAPTER 5

DISCUSSION AND EVALUATION

OF RESULTS

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DISCUSSION AND EVALUATION OF RESULTS

In this chapter general comments on the project implementation and an economic evaluation of each installed project are made.

A. VILLAGERS' COOPERATION

The implementation of these renewable nonconventional energy projects has been accomplished with cooperation from the villagers in the project areas. Discussions between the NEA's staff and the village headmen were made before the final decisions for site selections were made. The cooperation of the villagers was the main factor taken into consideration in selecting the sites.

The villagers in the project areas have participated in the project's development, mostly in the form of a labor force. Some indirect benefits can be outlined from such a development, including :

- Initiating the role of cooperation in rural development;
- Fostering close cooperation between local people and government officials;
- Initiating the application of an appropriate technology to the rural people; and
- Improving the annual incomes and living standards of the local people.

B. PROBLEMS ENCOUNTERED IN THE IMPLEMENTATION

There existed some problems in the implementation of these renewable energy projects. These problems were different from site to site. However, problems in transportation seemed to be common to all projects, since all sites selected for implementation were located in the remote areas where there was no electricity and the access roads to these sites were in poor condition (especially during the rainy season).

The solar water pumping system installed at Ban Sukorn has not been operational yet since there existed some conflicts in land ownership and thus the construction of the irrigation canal was delayed.

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The wind turbine pumping system experienced some problems in maintenance, since most villagers in the project area were rather busy in their occupation activities and so less care was given to the installed windmills. some vegetation cover grew in the surrounding areas. One main problem in the windmill operation was the inadequacy of water in the ponds where the windmills were installed. A portion of the pumped water was wasted because there were no storage facilities.

The gasifier and biogas pumping systems have not been installed yet due to a delay in supplying the imported equipments.

C. ECONOMIC EVALUATION

The economic analysis of the installed water pumping systems was made by comparing the systems with a diesel pump of the same capacity. In other words, the investment, operation and maintenance costs of the diesel pump were considered the benefit of the solar and wind turbine water pumping systems.

Project Cost

The project cost (consisting of investment, operation and maintenance costs) was considered as a percentage of the investment cost of the concerned item. The following values were used in this study.

- The operation and maintenance cost of the solar array was 0.2 percent of its installation cost;

- The operation and maintenance costs of the motor and pump as well as the electrical systems were 5 percent of the installation costs;

- The operation and maintenance costs of all civil structures, water storage and distribution systems were negligible; and

- The operation and maintenance costs of the windmills were 1-2 percent of the installation cost.

Project Benefit

As mentioned above, the investment, operation and maintenance costs of an equivalent diesel were considered as the benefit of the installed solar and wind turbine pumping systems in economic analysis. The operation and maintenance cost of the diesel pump can be divided into 2 main items, i.e. fuel cost and maintenance cost.

The fuel cost is considered proportional to the energy produced by the diesel engine. It was estimated that 0.4 liter of diesel oil was used for each kWh of energy output with the diesel engine. In estimating the total amount of diesel oil to be used annually the following calculations were made :

The useful energy produced by the installed solar or wind turbine pumping system was computed from the equation

$$E_w = \frac{1000\ Q\ H}{102} \times t$$

where E_w is the useful energy produced each day (kWh)

Q is the pumping flow rate (m^3/s)

H is the total head (m)

t is the total number of hours in a day when the solar pump or wind turbine pump is operated.

The value of the useful energy E_w was then considered as the output of the equivalent diesel pump. The efficiency of the diesel pump was considered to be 25 percent. Thus, the required energy output of the diesel engine, E_d, was computed from :

$$E_d = \frac{E_w}{0.25}$$

where E_d is the energy output of the diesel engine each day (kWh)

the required amount of diesel oil was then computed from :

$$O_d = 0.4\ E_d \times 365$$

where O_d is the amount of diesel oil used annually (liter)

It was estimated that the annual maintenance cost was equal to 10 percent of the diesel pump cost.

Economic Analysis

The economic analysis of the solar and wind turbine pumping systems was made based on the following assumptions :

- The service life of all civil works is 30 years;
- The service life of the electrical works is 20 years;
- The service life of the solar array is 20 years;
- The service life of the motor and pump is 10 years;
- The service life of the water storage and distribution system is 20 years;
- The service life of the windmill is 10-15 years;
- The service life of the diesel pump is 10,000 hours of operation, but not more than 10 years;
- The interest rate is 12 percent; and
- The operation and maintenance costs are as mentioned in the preceding sections.

Based on the above assumptions, the investment, operation and maintenance costs of each water pumping system, the annual equivalent cost of the system is computed. The benefit-cost ratio of the installed water pumping system is then obtained by dividing the annual equivalent cost of the installed unit by the annual equivalent cost of the equivalent diesel pump.

Economic Analysis of the Solar Water Pump at Ban Sukorn

At present the solar pumping system installed at Ban Sukorn has not yet been in operation due to a delay in the construction of an irrigation canal. The economic analysis presented in this section is based on the data mentioned in the specifications of the solar arrays, motors and pumps. The project cost will exclude the cost of the irrigation canal.

Project cost

The project cost of the solar pumping system at Ban Sukorn mainly consists of the costs of the solar arrays, pumps and motors, electrical works and administration. In addition, annual operation and maintenance costs for the solar array, electrical works, motors and pumps will have to be paid during the operational period. The investment cost of this project, excluding the cost of the irrigation canal, is 1,094,555 Baht (US$ 47,589), of which 944,127 Baht (US$ 41,049) was contributed by USAID (Table 5.1).

TABLE 5.1 COST OF SOLAR WATER PUMPING SYSTEM AT BAN SUKORN

Cost Item	Amount (Baht)
1. Civil works	55,200
2. Solar array	884,879
3. Electrical works	19,228
4. Motor and pump	59,248
5. administration	76,000
6. O & M for solar array	1,770 per year [1]
7. O & M for electrical works	961 per year [2]
8. O & M for motor and pump	2,962 per year [3]

Note : [1] considered 0.2 percent of the solar array cost
[2] considered 5 percent of the electrical works
[3] considered 5 percent of the motor and pump cost

The annual equivalent cost of this solar pumping system can be determined using the service life values as mentioned in the preceding section. The total annual equivalent of 154,246 Baht (US$ 4,706) was calculated (Table 5.2).

TABLE 5.2 ANNUAL EQUIVALENT COST OF THE SOLAR PUMPING SYSTEM AT BAN SUKORN

Item	Investment Cost (Baht)	Service Life (years)	Annual Equivalent Cost (Baht)[1]
1. Civil works	55,200	30	6,852
2. Solar array, electrical works and administration	980,107	20	131,215
3. Motor and pump	59,248	10	10,486
4. O & M for solar array	-	annual	1,770
5. O & M for electrical works	-	annual	961
6. O & M for motor and pump	-	annual	2,962
Total	-	-	154,246

Remark : [1] considered a discount rate of 12 percent per annun.

Cost of equivalent diesel pump

From the specifications of the purchased solar pumping system at Ban Sukorn, the volume of water to be pumped is 480 m^3/day with a lifting head of 5.0 m. Considering the operating time as 6 hours a day the average pumping rate of the solar pump should be approximately 2.2×10^{-2} m^3/s. If the pump unit of the diesel system has 25 percent efficiency, the required energy output from the diesel pump equivalent to this solar pumping system is 26 kWh, and the diesel oil consumption is estimated to be 3,800 liters per annum. The fuel cost will be 28,500 Baht (US$ 1,240) per annum. It is estimated that the investment in this diesel pump would cost approximately 100,000 Baht (US$ 4,348), and the administration cost would be 10,000 Baht (US$ 435). With the same value of civil work cost, the total investment cost of this equivalent diesel pump would be 155,200 Baht (US$ 6,748). The operation and maintenance cost is estimated to be 10,000 Baht (US$ 435) per annum. Table 5.3 summarizes various cost items of this equivalent diesel pump.

TABLE 5.3 COST OF EQUIVALENT DIESEL PUMP

Cost Item	Amount (Baht)
1. Civil works	55,200
2. Diesel pump	100,000
3. Administration	10,500
4. O & M for diesel pump	10,000 (per year)
5. Fuel cost	28,500 (per year)

Similarly, the annual equivalent cost of this equivalent diesel pump can be determined. The value of 64,819 Baht (US$ 2,818) was computed (Table 5.4).

TABLE 5.4 ANNUAL EQUIVALENT COST OF THE EQUIVALENT DIESEL PUMP

Item	Investment Cost (Baht)	Service Life (Years)	Annual Equivalent Cost (Baht)[1]
1. Civil Works	55,200	30	6,852
2. Diesel pump & administration	110,000	10	19,467
3. O & M for diesel pump	-	annual	10,000
4. Fuel cost	-	annual	28,500
Total	-	-	64,819

Remark : [1] considered a discount rate of 12 percent per annum.

Economic justification

By dividing the annual equivalent cost of the diesel pump with the annual equivalent cost of the installed solar pump the benefit-cost ratio (B/C) is obtained. A value of 0.42 : 1 is calculated for the solar pumping system at Ban Sukorn. In other words, this solar pumping is not feasible from an economic point of view. It is further estimated that if the cost of the solar array can be reduced to 312,000 Baht (US$ 13,565), the benefit-cost ratio would be equal to 1:1.

Economic Analysis of the Solar Water Pump at Ban Tha Yiam

In this section an economic analysis of the solar water pump installed at Ban Tha Yiam is made. This pumping system has been in operation since December 30, 1983.

Project cost

As previously mentioned, the project cost of the solar pump is classified as the installation cost and operation & maintenance cost. The installation cost includes the costs for civil works, water storage and distribution systems, solar array, electrical works, motor and pump, as well as the administration works. The operation & maintenance (O & M) cost consists of the O & M costs for the solar array, the electrical works, the motor and pump. Table 5.5 shows a breakdown of various cost items of the solar water pumping system at Ban Tha Yiam. The total investment cost was 357,550 Baht (US$ 15,546), of which 235,980 Baht (US$ 10,260) was contributed by USAID.

TABLE 5.5 COST OF SOLAR WATER PUMPING SYSTEM AT BAN THA YIAM

Cost Item	Amount (Baht)
1. Civil works	16,000
2. Water Storage and distribution system	69,900
3. Solar array	179,055
4. Electrical works	7,670
5. Motor and pump	56,925
6. Administration	28,000
7. O & M for solar array	358 per year[1]
8. O & M for electrical works	383 per year[2]
9. O & M for motor and pump	2,846 per year[3]

Note : [1] considered 0.2 percent of the solar array cost
[2] considered 5 percent of the electrical works
[3] considered 5 percent of the motor and pump cost

By considering the service lives of various items as mentioned previously, the annual equivalent cost of the solar pumping system at Ban Tha Yiam can be determined as shown in Table 5.6. A value of 53,753 Baht (US$ 2,337) was obtained.

TABLE 5.6 ANNUAL EQUIVALENT COST OF THE SOLAR PUMPING SYSTEM AT BAN THA YIAM

Item	Investment Cost (Baht)	Service Life (Years)	Annual Equivalent Cost (Baht)[1]
1. Civil works	16,000	30	1,986
2. Water storage and distribution system	69,900	20	9,358
3. Solar array, electrical works and administration	214,725	20	28,747
4. Motor and pump	56,925	10	10,075
5. O & M for solar array	-	annual	358
6. O & M for electrical works	-	annual	383
7. O & M for motor and pump	-	annual	2,846
Total	-	-	53,753

Remark [1] considered a discount rate of 12 percent per annum.

Cost of equivalent diesel pump

The results obtained from the performance testing of the solar water pumping system at Ban Tha Yiam shows that the solar pump at Ban Tha Yiam will work about 6 hours a day, from 9:00 a.m. to 3:00 p.m. The cumulative discharge was approximately 6.0 m^3/day. In other words the average flow rate when this solar pump was operating was 2.78×10^{-4} m^3/s. The total head was 21.5 m. Thus the useful energy obtained from the solar pump

was estimated to be 0.35 kWh a day. The required energy output from the equivalent diesel engine would be 1.4 kWh, considering the efficiency of the equivalent diesel pump would be 25 percent. If 0.4 liter of diesel oil is used for each kWh of energy output from the diesel engine, the annual amount of diesel oil required would be 204 liters. Considering the unit price of 7.50 Baht (US$ 0.33) per liter for diesel oil, the fuel cost of the equivalent diesel pump is 1,530 Baht (US$ 66.5) per annum. It is estimated that an installation cost of 45,000 Baht (US$ 1,957) is required for a diesel pump of this capacity. The maintenance cost of the diesel pump is considered to be 10 percent of the investment cost annually. Table 5.7 shows the breakdown of various cost items for the diesel pump equivalent to the solar pumping system at Ban Tha Yiam.

TABLE 5.7 COST OF EQUIVALENT DIESEL PUMP

Cost Item	Amount (Baht)
1. Civil works	16,000
2. Water storage and distribution system	69,900
3. Diesel pump	45,000
4. Administration	5,000
5. O & M for diesel pump	4,500 per year [1]
6. Fuel cost	1,530 per year

Remark [1] considered 10 percent of the diesel pump cost

The annual equivalent cost of this diesel pump can be determined in a similar manner as that of the solar pumping system. A value of 26,223 Baht (US$ 1,140) was obtained (Table 5.8).

Economic justification

The benefit-cost ratio (B/C) of the solar pumping system is calculated by dividing the value of the annual equivalent cost of the equivalent diesel pump by the annual equivalent cost of the installed solar pumping system. A value of 0.49:1 was obtained. In other words, the solar water pumping system is not feasible from an economic point of view. This is due to the very high prices for the solar array, as well as the motor and pump used in this installation. In order that this solar pumping

TABLE 5.8 ANNUAL EQUIVALENT COST OF THE EQUIVALENT DIESEL PUMP

Item	Investment Cost (Baht)	Service Life (years)	Annual Equivalent Cost (Baht)[1]
1. Civil works	16,000	30	1,986
2. Water storage and distribution system	69,900	20	9,358
3. Diesel pump & administration	50,000	10	8,849
4. O & M for diesel pump	-	annual	4,500
5. Fuel cost	-	annual	1,530
Total	-	-	

Remark [1] considered a discount rate of 12 percent per annum.

system be economic feasible (B/C $\geqslant$1.0), the investment cost of the solar array, motor and pump at this installation should not exceed 66,000 Baht (US$ 2,870).

Economic Analysis of the Wind Turbine Water Pumps

In this section an economic analysis of the two windmills at Ban Samoh is made using the same procedures as were used for the solar pump. In this analysis, an annual average wind speed of 2.0 m/s is considered.

Project cost

The project cost of the wind turbine water pumping system includes the investment cost of the windmill and the operation & maintenance cost. The investment cost of the multi-blade windmill was 80,000 Baht (US$ 3,478) whereas that of the bamboo blade (VITA) windmill was 45,830 Baht (US$ 1,993) which was contributed by USAID.

The operation and maintenance cost was considered to be 1.0-2.0 percent of the installation cost. Thus, the amounts of 800 Baht (US$ 35) and 917 Baht (US$ 40) are estimated for the multi-blade and VITA windmills, respectively.

By considering the service life to be 10-15 years and a discount rate of 12 percent per year, the annual equivalent costs of these two windmills are determined as shown in Table 5.9. The values of 12,546 Baht (US$ 546) and 9,028 Baht (US$ 393 were estimated for the multi-blade and VITA windmills, respectively.

Costs of equivalent diesel pumps

The testing data of the multi-blade windmill showed that at a wind speed of 3.0 m/s, the mean volume flow rate was approximately 11 liters/min (1.8×10^{-4} m^3/s) with a lifing head of 4.5 m. Considering that the windmill was useful only in the dry season (180 days), the value of useful energy to be derived each year is 34 kWh. If this windmill were to be replaced by a diesel water pump with a 25 percent pumping efficiency, the energy generated from the diesel engine would be approximately 136 kWh. A diesel oil consumption of 54 liters of oil would be required annually. This would cost approximately 405 Baht (US$ 17.6).

TABLE 5.9 ANNUAL EQUIVALENT COST OF INSTALLED WINDMILLS

Item	Investment Cost (baht)	Service Life (years)	Annual Equivalent Cost (Baht)
Multi-blade windmill			
Installation	80,000	15	11,746
O & M	-	annual	800
Total	-	-	12,546
Bamboo blade windmill			
Installation	45,830	10	8,111
O & M	-	annual	917
Total	-	-	9,028

It was estimated that the installation of a diesel pump of this capacity would cost approximately 20,000 Baht (US$ 870), and about 2,000 Baht (US$ 870) would be needed for the maintenance annually. By considering 15-years of service life and a 12 percent discount rate, the annual equivalent cost of 5,945 Baht (US$ 258) was calculated (Table 5.10).

TABLE 5.10 ANNUAL EQUIVALENT COST OF THE DIESEL PUMP EQUIVALENT TO THE INSTALLED MULTI-BLADE WINDMILL

Item	Investment Cost (Baht)	Service Life (years)	Annual Equivalent Cost (Baht)
1. Diesel pump	20,000	10	3,540
2. O & M	-	annual	2,000
3. Fuel cost	-	annual	405
Total	-	-	5,945

For VITA windmill, the testing data showed that at a mean wind speed of 3.0 m/s, the mean volume flow rate was 5.65 liters/sec with a lifting head of 0.6 m. With this windmill, the useful energy obtained was estimated to be 146 kWh annually. If this windmill were to be replaced by a diesel pump with a 25 percent pumping efficiency, the required energy generated from the diesel engine would be 586 kWh annually. About 234 liters of diesel oil would be used which would cost about 1,757 Baht (US$ 76) annually.

It is roughly estimated that the installation cost of such a diesel pump would be 20,000 Baht (US$ 870) and about 2,000 Baht (US$ 87) would be required annually for the maintenance. The annual equivalent cost of this diesel pump, considering a 10-year service life and a 12-percent discount rate, would be 7,297 Baht (Table 5.11)

Economic justification

By dividing the annual equivalent cost of the equivalent diesel pump with the annual equivalent cost of the windmill, the benefit-cost ratio (B/C) is obtained. The B/C value of the multi-blade windmill is 0.47:1 and the B/C value of the bamboo blade windmill is 0.81:1. In other words, neither windmill is economically feasible. This is due to the high investment cost.

TABLE 5.11 ANNUAL EQUIVALENT COST OF A DIESEL PUMP EQUIVALENT TO THE INSTALLED VITA WINDMILL

Item	Investment Cost (Baht)	Service Life (years)	Annual Equivalent Cost (Baht)
1. Diesel pump	20,000	10	3,540
2. O & M	-	annual	2,000
3. Fuel cost	-	annual	1,757
Total	-	-	7,297

CHAPTER 6

CONCLUSIONS

CONCLUSIONS

The study on the development of these renewable evergy projects leads to the following conclusions :

A. THE SOLAR PUMPING SYSTEM AT BAN SUKORN

This solar pumping system has been planned to pump water from the Pradok Reservoir for irrigating the agricultural lands in Ban Sukorn, Nakhon Ratchasima Province. There are a total of 112 households with 646 residents in this village. Most of the villagers are farmers. Rice is the dominant crop. The system is designed so that the nominal maximum power at the standard condition of solar array (100 mW/cm^2 at 25°C) is not less than 4,300 Watts. Four sets of solar arrays, DC motors and self-priming centrifugal pumps were installed. Each solar array consists of 32 modules of solar cells. The designed pumping discharge is 480 m^3/day at 5.0-m lifting head.

The total cost of this system, excluding the cost of the irrigation canal, was 1,094,555 Baht (US$ 47,589) of which 944,127 Baht (US$ 41,049) was contributed by USAID. An economic analysis shows that the benefit-cost ratio of this solar pumping system is 0.42:1, and that the installed system is not economically feasible.

Due to a delay in constructing the irrigation canal, this solar pump has not yet been operational.

B. THE SOLAR PUMPING SYSTEM AT BAN THA YIAM

This system was installed to pump water from a ground water well to serve the villagers in Ban Tha Yiam, Sakon Nakhon Province. There are 57 households with 347 residents in this village. Agriculture is the main occupation of the villagers. Rice is the dominant crop grown in this area. The installed system has been designed so that the nominal maximum power at the standard condition of solar array is not less than 700 Watts. A solar array with 18 modules of solar cells was installed together with a DC motor and a screw-type pump. The designed flow rate was 10 m^3/day at a 21.5 m head. However, due to an increase in the draw-down level in the ground water well, the daily pumping discharge was approximately 6 m^3/day. The results obtained from the test-run show that the overall efficiency of this system varies between 0.9-1.6%. Its value decreases as the solar panel temperature increases.

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The total investment cost for this solar pumping system was 357,550 Baht (US$ 15,546) of which 235,980 Baht (US$ 10,260) was contributed by USAID. An economic analysis reveals that the benefit-cost ratio of this solar system was 0.49:1 and that the system is not economically feasible.

C. THE WIND TURBINE PUMPING SYSTEM AT BAN SAMOH

Two multi-blade and one VITA windmill were installed at Ban Samoh, Yala Province, to pump water from storage ponds for irrigating the village agricultural area. There are 204 households with 868 residents in this village. Most of them are farmers. Rice and rubber are the main crops grown in this area.

The test run of these windmills showed that the windmill speeds and the pump discharges increased linearly with the wind speed. For the large multi-blade windmill, the monthly pump discharge was 274 m^3 at a mean wind speed of 2 m/s and the value increased to 667 m^3 with a mean wind speed of 6 m/s. The overall efficiency decreased as the wind speed increased. A value of 14% was computed for a wind speed of 2 m/s. The volumetric efficiency of the pump unit was as high as 98-99%.

For the VITA windmill, the measured monthly discharge was 5,500 m^3 at a mean wind speed of 3 m/s and the value increased to 12,500 m^3 at a mean wind speed of 6 m/s. The overall efficiency also decreased as the wind speed increased. A value of 3.3% was computed for a wind speed of 4 m/s. The PVC ladder pump was used with this windmill. The volumetric efficiency was 71% at a wind speed of 2 m/s and the value decreased to 63% as the wind speed increased to 6 m/s.

The investment costs of these three windmills were 80,000 Baht (US$ 3,478), 50,000 Baht (US$ 2,435) and 45,830 Baht (US$ 1,993), for the two multi-blade windmills and the VITA windmill, respectively. These windmill costs were contributed by USAID. An economic analysis reveals that the benefit-cost ratio of these windmills varied from 0.47:1 to 0.81:1, and this showed that the wind turbine pumping system is not economically feasible.

CHAPTER 7

RECOMMENDATIONS

RECOMMENDATIONS

The study on the implementation of these pumping systems can lead to the following recommendations:

- Since the solar pumping systems are not financially feasible (compared to diesel engine-pumping systems) at the present time, the promotion of this energy technology should be limited until the cost of the solar array is decreased to a certain value or benefit from having water for irrigation shows that it is suitable for rural development.

- More research should be conducted to investigate the performance of various components of the system, to obtain data necessary for future project designs and to study the problems which might be encountered in the operation and maintenance of such a system.

- The investment costs of the installed windmills are rather high at this time, which makes the project not financially feasible. However, the benefit-cost ratios show that the utilization of windmills are near-term feasible. Therefore, more development of the windmill should be made with an aim of reducing the construction costs and increasing the overall efficiency.

- Since there are some indirect benefits resulting from the participation of the villagers, the system should be maintained and improved so that the utilization of the water lifting technology would be self-sustaining.

- The project would be more successful if some villagers were trained during the installation of the systems and during the testing runs.

- Monitoring activities should be continued to obtain further information concerning benefits on income resulting from providing water for irrigation since the water lifting project needs considerable time to obtain information after installation.

- Efficient utilization of pumped water should be emphasized and villagers should be educated along these lines.

- Villagers' needs and willingness to participate in the project should be carefully studied during the site selection phase in order to assure a more successful outcome during implementation.

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