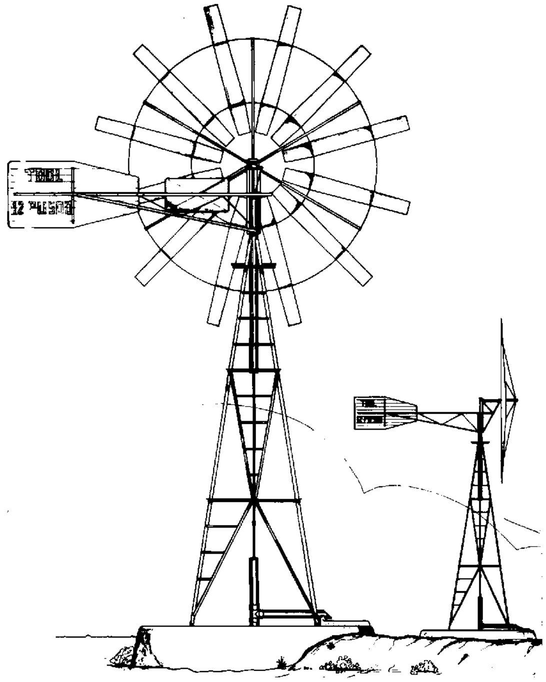

Energy: Wind

The wind has been a significant source of power for centuries. Early windmills in China and Southeast Asia lifted water into rice fields. In Europe the windmill developed into an enormous structure, nearly the size of a small sailing ship, developing power in the range of 25 hp and higher, for use in grain grinding, drainage and a multiple of small industrial tasks. The first windmills in North America and the Caribbean were of this type. In the late 19th century, water pumping windmills were manufactured by the thousands, and several million machines were operated by the end of this century. These were mostly lifting water for farm houses and livestock.

Wind generators for electricity spread by the hundreds of thousands across rural North America in the 1930s supplying the farm houses with small amounts of power for radios and a few lights. Both the water pumping windmills and the wind generators went into decline with the coming of rural electrification, which offered cheap electricity for running electric pumps and many more household uses. With the energy crisis, however, sales of water pumping wind mills and wind generators have greatly increased in the United States.

It is the water pumping windmill that appears to be the most immediately relevant for rural energy needs in the developing countries, both for high value community water supplies and for irrigation pumping. Irrigation is the biggest single factor in improving farm yields, and there are many places where low-lift irrigation on small plots could be accomplished with windmills. Thailand, Greece, Japan, Peru, and Portugal are among the nations where significant numbers of irrigation windmills have been used in recent times. In North America, farmers built thousands of scrap wood waterpumping windmills before the manufactured *steel machines appeared. In all of these national experiences, local windmill designs were developed to fit pumping needs, wind conditions, and materials available. These machines were built in small workshops; this kept prices low and repair skills nearby. In other countries where manufactured windmills have been directly introduced, the initial high cost and lack of repair skills have greatly reduced their attractiveness. (South Africa and Australia may be exceptions. In these industrialized countries, variations in the American fan-bladed windmill have been widely used to water livestock and isolated farmhouses. These are expensive high performance machines requiring infrequent but skilled maintenance and repair.)*

Thus the historical record suggests that successful windmill promotion programs in developing countries will need to focus on locally adapted designs and craftsperson based production using local materials, with a limited number of manufactured parts. Promotion programs might include credit mechanisms whereby the windmill itself is both loan and collateral. Also of interest is the Las Gaviotas approach in which the buyer assembles and installs a metal windmill from a kit (see **Un Molino de Viento Tropical***).*

Waterpumping windmills for irrigation purposes are most economically competitive in areas that do not already have electricity for powering irrigation pumps. In these circumstances the alternatives are generally small engine driven pumps that are expensive to fuel and maintain. Low-lift applications for high value vegetable farming may be economically competitive in many parts of the world. The economic appeal of locally built windmills is even greater when the savings of scarce foreign exchange from reduced foreign imports and village level economic multiplier effects are considered. Other advantages of locally built windmills include the creation of village capital using local labor and materials, much lower initial cost, and avoidance of maintenance problems associated with engine-driven pumps. Such windmills appear to have more frequent but simpler maintenance requirements than manufactured windmills.

A small number of people are working on water pumping windmill designs in developing countries. The interesting contemporary examples of locally evolved designs include the Cretan sail windmills, the bamboo and cloth sail windmills of Thailand's salt ponds, and the locally built windmills of the Cape Verde Islands. All of these were built and maintained by local craftspeople. New designs of fabricated steel windmills that attempt to reduce costs have been built and tested in India, Sri Lanka, and elsewhere, for both water supply and irrigation applications.

In the United States, isolated houses have become a major market for wind generators for electricity. **Wind Power for Farms, Homes and Small Industry** *and* **The Wind Power Book** *are recommended for readers considering such an installation. Technical advances now also allow a windmill to feed surplus power back into a conventional electric grid, a practice which makes wind-generated electricity in urban and suburban settings much more attractive than before, as the substantial expense of a battery system can be avoided.*

For any windmachine, the choice of site is very important. Trees and buildings can greatly reduce the useful winds reaching a windmill. A small difference in wind speed can mean a big difference in power available, because the power in the wind varies with the cube of the wind speed. Thus a 12-mph wind has 8 times as much power as a 6-mph wind. Wind generators operate at the highest possible wind speeds, and the user will usually want to find the windiest spot possible for such an installation. Waterpumping windmills, on the other hand, need greater protection from the extremes of high wilds, and are usually designed to operate in low and medium winds. We have included several publications on site *selection for wind machines, including vegetative indicators of high average windspeeds at particular locations.*

The Wind Power Book, MF 21-495, hardcover book, 255 pages, by Jack Park, 1981, $21.95 plus $2.00 postage (add $10.00 for airmail shipping) from Cheshire Books, 4532 Cherryvale Avenue, Soquel, California 95073, USA.

This book incorporates many developments in the field of windpower since the author wrote **Simplified Wind Power Systems for Experimenters and Wind Power for Farms, Homes and Small Industry** (see reviews). As with **Simplified**, Jack Park has made his presentation simple and understandable in order to allow innovative people to adapt the basic concepts to fit their own situation. For example, he explains the necessary formulas for calculating windpower available, and what to expect from different types of machines. This is the best book available for an overview of the topic Written for a North American audience, but useful for people in developing countries.

Wind Power for Farms, Homes, and Small Industry, MF 21-497, book, 229 pages, by Jack Park and Dick Schwind, 1978, Document Number RFP 284111270/7814, paper copies $31 domestic, $62 foreign; microfiche $8 domestic, $16 foreign; from NTIS.

This is a no-nonsense introduction to windpower and windmachines for the North American. It is not a design manual, but a book to help the reader understand how to decide whether to buy a windmachine, considering needs, wind conditions, and other power options. The author discusses the different kinds of wind measuring equipment, different electrical systems, possible legal problems, and the routine tasks that come with owning a wind system. Monthly wind data for most of the United States is included. If the reader decides to get a windmachine, the book will help him/her decide what kind, what size, and what kind of energy storage system to use. Windgenerators and waterpumpers are considered. Highly recommended for North Americans considering installing a wind system.

Windpumping Handbook, MF 21-510, book, 85 pages, by Sarah Lancashire with Jeff Kenna and Peter Fraenkel, 1987, £7.50 from ITDG.

An introduction to windpumping with primary emphasis on developing countries, this will help the reader understand many of the central factors that determine whether windpumping is a good choice of technology for a particular need. Other books contain more detailed coverage of wind measurement and site selection for wind machines, agriculture and windpumped irrigation, and windpump design and construction.

A Siting Handbook for Small Wind Energy Conversion Systems, MF 21-489, book, 120 pages, by H.L. Wegley et. al., 1978, acc. no. PNL-2521 (plus Rev.1 for 1980 ed.), paper copies (1978) $23 domestic, $46 foreign; paper copies (1980 revised ed.) $17 domestic, $34 foreign; microfiche (1980 ed.) $8 domestic, $16 foreign; from NTIS.

"The primary purpose of this handbook is to provide siting guidelines for laymen who are considering the use of small wind energy conversion systems." This kind of information is essential in promoting the effective use of windpower in the best locations.

The choice of a site for a wind machine is very important because: 1) the energy in the wind is proportional to the cube of the windspeed, and thus small differences in windspeed mean large differences in windpower available; 2) small obstacles on the ground in flat terrain can slow the wind considerably; and 3) wind patterns are greatly affected by hilly and mountainous terrain. This handbook will help identify the sites with the highest windpower potential. This is most important for windgenerators, which take advantage of the high range of winds at a site, for maximum electricity production. The manual will also be of value in choosing sites for waterpumping windmills, which need more protection from high winds and operate in the low range of windspeeds to allow more dependable water pumping.

Most of the information included can be used anywhere in the world. The core of this book is a well illustrated presentation on the effects of trees (including windbreaks), shrubs, and buildings in flat terrain, and the effects of ridges, passes, valleys and other features in mountainous or hilly terrain. Groups in other countries could substitute their own data for the section on special weather hazards of the United States (snow, hail, icing, tornadoes, thunderstorms, high winds and dust storms), with maps that identify affected areas. Most Developing countries do not have as firm a data base for these country maps, but some of the problems are avoided also.

"To understand and apply the siting principles discussed, the user needs no technical background in meteorology or engineering; he needs only a knowledge of basic arithmetic and the ability to understand simple graphs and tables."

"According to manufacturers ... the greatest cause of dissatisfaction among owners has been improper siting .... This handbook incorporates half a century of siting experience ... as well as recently developed siting techniques."

Wind Pumping: A Handbook, World Bank Technical Paper No. 101, MF 21509, book 273 pages, by Joop van Meel and Paul Smulders, 1989 $17.95 from World Bank Publications, Box 7247-8619, Philadelphia, Pennsylvania 19170-8619, USA.

"This handbook has been prepared to give an insight into the merits of using wind energy for small-scale water pumping and to enable a comparison between the use of wind pumps and use of ... solar pumps, engine driven pumps, animal traction and hand pumps." The book has been written for a broad audience, from policymakers to farmers and engineers. The authors have for the most part succeeded in making this information easily understood for the general reader, although there are many technical details that will prove challenging.

"Where other forms of energy are difficult or expensive to obtain ... windpumping in many instances represents the most effective and economic alternative."

The book begins with a discussion of typical water pumping applications, and follows with coverage of wind pump technology, sizing of wind pumps and other small pumps, the economic and financial assessment of pumping technologies, and field testing of windpumps. An additional chapter on logistics and supporting activities has been written for managers of large-scale projects.

This is a good starting point for readers who wish to consider windpumps. Many of the topics are covered in greater depth elsewhere.

Report on the Practical Application of Wind-Powered Pumps, MF 21-507,26 pages, by Marcus Sherman, 1977, Natural Resources Division, United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), out of print; also reproduced in

"Proceedings of the workshop on biogas and other rural energy resources held at Suva, and the roving seminar on rural energy development, held at Bangkok, Manila, Tehran and Jakarta," Energy Development Series No. 19, ESCAPE, 1979, out of print.

This short paper contains a unique and very useful set of tables comparing the operating characteristics, design features, and costs of a wide variety of waterpumping windmills. The author's intent is to "assist in the design and evaluation of future wind-powered water pumps projects for a wide range of environments. Water source, water use, local wind conditions, and availability of labor, capital, and materials are the major determinants of design selection."

Most windmill types are covered. These include Greek (Cretan) sail, multi-vane, Savonius, Chinese vertical axis, Thai cloth, Thai bamboo, medium speed cloth, medium speed metal, and high speed windmills. Categories for comparison include rotor diameter, blade material, pumping rates, starting and rated wind velocity, initial capital cost, expected lifetime, maintenance costs and cost per cubic meter of water lifted a standard distance. The format allows quick comparisons of different windmill types, though for some (e. g. Chinese vertical axis windmills) little performance information is available.

"It appears that local design and construction of wind-powered water pumps is generally feasible .... The selection of low capital cost, low technology, high labor input designs is usually preferred for agricultural applications unless farmer credit schemes can be used. Higher cost is tolerable for public drinking water supply because the initial cost can be amortized through a long term community budget."

A Survey of the Possible Use of Windpower in Thailand and the Philippines, Publication No. PNAAB481, MF 21-490, book, 74 pages plus appendix, by W. Heronemus, 1974, on request from AID Document and Information Handling Facility, 7222 47th Street, Suite 102, Chevy Chase, Maryland 20815, USA; also from NTIS (quote accession number PB-245 609).

This report answers favorably the question "could windpower be used by the peasant farmer in Thailand or the Philippines to improve the quality of his life?"

"Numbers of six-sail wind machines are currently in use in the salt works around the northern shore of the Gulf of Thailand. The machines are of about 6 meters diameter and use bamboo spars, rope and wire to form a wheel which carries 6 triangular sails, each woven from rush or split bamboo." These machines drive the paddles of the traditional water ladder low-lift pumps. The author recognizes that while efficiency could be greatly improved, the current machines are "admirably sized to the task they are to perform" and the primary limiting factor is not in the machines but in the land available for salt evaporation.

For use in irrigation, the author makes some stimulating suggestions for improvements in the sail windmill design and for local adaptation of a wooden, 16-bladed fan mill. "The blades would be of molded plywood, made between matched concrete molds in the existing Bangkok plywood factories .... Each laminated blade would be inserted into a wood spoke and the spokes would in turn be brought to an iron banded wood hub. The entire wheel would be a timber (plus glue) product, producible by native artisans possessing the same skills and tools required to build the water ladders."

Most of the report is focused on Thailand, but the contents are of general interest to people in any area where there is a need for low-lift pumps for irrigation.

Photos of the sail windmill and water ladder are included.

Wind pumps for Irrigation, MF 21-508, book, 96 pages, by H.J. van Dijk and P.D. Goedhart, 1990, CWD, Dfl. 35.00 from TOOL.

This recent release from CWD is the latest word on the use of windpumps to provide irrigation water, incorporating recent experience and describing the record of indigenous windpumps used in Crete and in Sao Vicente, Cape Verde Islands. The intention is to provide the reader with sufficient information about windpumps and irrigation to judge whether it makes sense to consider windpumps for a specific task.

The rapid spread in the 1970s and 1980s of indigenous wind pump technology in Sao Vicente is particularly interesting. The command area per windpump is about 0.120.16 ha. The farmers grow vegetables and drought resistant crops, and use storage tanks of about 1.5 days capacity. Many farmers use motorized pumps to back up their wind pumps, but, as one farmer put it: "The supply of wind for the wind pump is more secure at Sao Vicente than the supply of spare parts for a motor pump."

"Chapter 1 introduces the key factors to be studied in connection to the viability of windpumps in different farming systems .... Chapter 2 introduces the technical aspects of windpumps .... Chapter 3 provides information on collecting and analyzing climatic data with special reference to the wind regime .... Only after reliable wind data has been analyzed can it be determined whether or not there is potential for the use of windpumps in the region .... In Chapters 4 and 5, the relationships between the output of a windpump and the use of the water output for irrigation is discussed. Estimating the area that can be cultivated (command area) and the factors influencing this command area are the subjects of Chapter 4 .... Windpump irrigation has specific problems related to the fact that the windpump output is not constant all the time. The effects of this phenomenon on farm water management are discussed in Chapter 5. Several measures such as storage tanks are suggested .... A method of estimating the required storage tank capacity is included .... In Chapter 6, the economics of wind pump irrigation are analyzed, taking into account the national economics and farm economics .... Chapter 7 summarizes the book with an example set up for a wind pump project."

Construction Manual for 12PU350 and 12PU500 Windmills and related books (see below), TOOL, all out of print.

These waterpumping windmills are the product of a three-and-a-half year collaboration between Dutch engineers and some local organizations in India. The windmills were designed for irrigation pumping, and are manufactured in local metalworking shops. They still represent a relatively expensive investment, and the economic viability is not certain.

Four reports exist on the windmills themselves. **Technical Report 1982 (TOOL Windmill Projects)** (MF 21-504, book, 110 pages, by Niek Van de Ven, 1982) describes the problems and design changes made, and testing equipment used, during the program. **Construction Manual for 12PU350 and 12PU500 Windmills** (MF 21-501, book, 80 pages, by Niek Van de Ven, 1982) contains the necessary drawings, photos, and instructions to build these windmills. **Set of Construction Drawings for 12PU300 and 12PU500 Windmills** (MF 21-502, 14 large sheets, 1979) contains many of the same technical drawings, but of a larger size for use in the workshop during fabrication. **Syllabus for Irrigation with Windmills: Technical Aspects** (MF 21-503, book, 75 pages, by Willem Nijhoff, 1982) is, despite the title, mostly concerned with the design calculations for this windmill, plus how to measure the windmill output.

A fifth report, **Aspects of Irrigation with Windmills** (MF 21-500, book, 100 pages by A. van Vilsteren, 1981) is a review of the agricultural and economic factors that affect the viability of windpowered irrigation. This material is certainly applicable to other windmill designs as well.

Un Molino de Viento Tropical Gaviotas, MF 21-479, booklet, 45 pages, in Spanish, by Centro Las Gaviotas, Colombia, 1980, out of print.

Presented in a popularized "foto-novela" (picture novel) format, this manual introduces a small waterpumping windmill designed by the Colombian appropriate technology center Las Gaviotas. The large number of photos and drawings are intended to allow the buyer of a windmill kit to assemble and install it him/herself.

The windmill described is the production version of the latest in a series of 56 prototypes built by Las Gaviotas in their attempt to develop a low-cost windmill that would operate in low wind speeds. This one is l.9 meters in diameter, with a double-acting piston pump, able to pump to a depth of 25 meters. From a 10-meter depth, this windmill will pump 2 cubic meters of water per day in a light and sporadic wind, and 45 cubic meters of water per day in a moderate continuous wind. These windmills are made in a well-equipped large workshop.

Selecting Water Pumping Windmills, MF 21-487, booklet, 14 pages, 1978, by the Energy Institute, New Mexico State University, out of print.

This booklet is an introduction to the multi-blade windmill commonly seen on North American farms. It describes the parts of a windmill, tank sizes, and the pumping scheme for American farm windmill lifting capacity of windmills of different sizes. "Selecting" in the title refers to the size (diameter), not the type of windmill.

Considerations for the Use of Wind Power for Borehole Pumping, MF 21-464, leaflet, 15 pages, by the Appropriate Technology Unit of the Christian Relief and Development Association, Ethiopia (out of print in June 1978).

An introduction to the basic considerations for the use of multi-bladed windmills for water pumping. Explains the importance of site selection, rotor design, and the other major components along with the criteria that affect these choices. No plans or detailed information given.

The Homemade Windmills of Nebraska, MF 21-472, book, 78 pages, by E. Barbour, 1898 (reprinted 1976), Farallones Institute, California, out of print.

Sketches are provided of more than 60 different windmills. They appear roughly in order of efficiency, and the text explains the advantages and disadvantages of each. The book was written with the express purpose of providing good models to copy, so that builders would benefit from the experiences of others.

This is a great idea book: many of these designs could be adapted to use bamboo poles and woven bamboo mats for the blades or sails, along with wooden bearings and power transmission arms. In fact, if combined with simple low-lift pumps, a waterpumping windmill could be put together for an extraordinarily small cash outlay in many developing countries. The designs are so simple that any carpenter could put one together just by looking at an existing machine. This is exactly how they spread all over the state of Nebraska in the United States.

The majority of the machines do not have the capability of turning to accept wind from any direction; they were designed for areas with a prevailing wind from a dependable direction. However, some of the machines do rotate to face the wind and others are vertical-axis machines for which wind direction is not important.

"Labor, it is found, is contributed freely to such work, at times when more important work is practically at a standstill." Many of the farmers "put them to work in various ways to save hand labor, such as running the grindstone, the churn, the feed grinder, the corn sheller, the wood saw, and other farm machinery." It is also interesting to note that many of the farmers were wealthy and didn't purchase a shop-made mill (which was more efficient) because they could build a heavier duty, cheaper mill themselves.

The text is full of "case studies" of the farmers and their mills.

Vertical Axis Sail Windmill Plans, MF 21-493, 16 pages, 1976, reprinted 1979, $4.00 from Low Energy Systems, 63 Greenlawns, Skerries Co., Dublin, Ireland.

This design combines some of the principles of sail and sailwing rotors. "The rotor consists of two or more sailwings mounted vertically at equal distance from a vertical axis .... Each sailwing is formed from a rigid spar ... at the leading edge of the sail .... The surface of the sailwing is made from a cloth envelope .... When the wind impinges on the sailwing it takes up an airfoil shape with a concave surface facing into the wind .... During one complete revolution of the rotor the sailwing switches the concave surface from one side to the other automatically .... It is self starting, unlike the Darrieus rotor, to which it is similar in some other respects."

This small lightweight windmill is used by its designers to grind grain. It develops a maximum power of about 1/4 hp in a 20 mph wind.

(This design should not be confused with the traditional Cretan sail windmill which has a horizontal axis, and is used for irrigation water pumping in Crete.)

Sahores Windmill Pump, MF 21-485, booklet, 80 pages, by J. Sahores, 1975, in French only, Commission on the Churches' Participation in Development, World Council of Churches, out of print.

French language edition only; however, the step-by-step construction plans are so detailed that the unit has been built without a translation of the text.

A group of French engineers has developed a light, simple windmill, mainly using bamboo sticks, cloth and string, which sets in motion a standard water pump (design not included). Only the welded transmission mechanism needs some sophistication for manufacture.

There are three innovations of particular note: 1) The 3-meter diameter wheel is made of bamboo (or wood) with cloth sails in the shape of the American multi-blade design; its light weight and automatic feathering mechanism mean that the tower can consist only of a pole with 4 cord or steel guy wires rather than a large, expensive (usually steel) structure. 2) The automatic feathering system consists of pieces of inner tube attached so that the blades open more as the wind becomes stronger, thus protecting the windmill from damage while also allowing it to make use of light winds. 3) A counterweight system is employed which enables the pumping action to be adjusted by the owner, for operation at windspeeds from 2 m/sec up to strong winds.

The cost of materials in France was approximately US $85 (this included a purchased pump). The first prototypes worked for at least 3 years. Twenty of these machines were built in 1974 and tested in Africa.

Low-Cost Windmill for Developing Nations, MF 21-477, booklet with dimensional drawings, 40 pages, by H. Bossel, $7.25 (overseas orders add $3.00 for surface mail, $5.00 for airmail), from VITA.

Despite the title, the need for a car axle and differential make this a design better suited to do-it-yourself construction in industrialized countries.

"Construction details for a low-cost windmill are presented. The windmill produces one horsepower in a wind of 6.4 m/sec (14.3 mph), or two horsepower in a wind of 8.1 m/sec (18.0 mph). No precision work or machining is required, and the design can be adapted to fit different materials or construction skills. The rotor blades feather automatically in high winds to prevent damage. A full-scale prototype has been built and tested successfully."

Performance data is included. The windmill is best used to transmit mechanical energy, but also can be connected to a generator.

Windpower in Eastern Crete, MF 21-499, booklet, 9 pages, by N. Calvert, 1971 Newcomen Society, 70 pence (in sterling) including postage from The Society for the Protection of Ancient Buildings, 37 Spital Square, London E1 6DY, England.

This booklet provides a good description of the techniques and materials used to build the Cretan sail windmill. It is not a construction manual, and it does not provide precise dimensions.

These machines, thousands of which still operate in the plain of Lassithi, were evidently mostly built during the period 1900 to 1950. Many of them were constructed partially from military debris from the two world wars. There seem to be three basic types: 1) those which could have been made by a blacksmith-wheelwright using wood and metal and fastened with wedges and rivets; 2) those which could have been built by mechanics, using mostly metal parts welded or bolted together; and 3) those which have a stone tower instead of a steel one.

"Observations were made on a number of machines in the fully rigged state and in rotation, at wind speeds commencing at 2.2 m/sec (5 mph). A useful output of water appeared at a wind speed of 2.75 m/sec (6 mph). When the wind rose to 3.5 m/sec (8 mph), a four meter diameter machine would run at a speed of up to 25 revolutions per minute (the highest observed)." The author later built a similar waterpumping windmill for testing in Britain, and notes that a four meter machine under full sail would develop power of 220 watts in a wind of 3.5 m/sec (8 mph).

"There is no doubt that the Cretan Mill excels in its ability to utilize low windspeeds. This is consistent with the maximum number of operating hours per year and, in an irrigation context, is probably a criterion of excellence .... The efficiency of 30% noted in the author's tests compares satisfactorily with that recorded for any other type of windmill."

The Cretan Mill "can hardly be improved for the efficient use of material. Aerodynamically, the low speed efficiency is high and it has an inherent stability against accidental overspeed."

Food from Windmills, MF 21-468, book, 75 pages, by Peter Fraenckel, ITDG, 1975, out of print.

Fraenckel describes adaptation of the Cretan sail windmill to fit the circumstances of an isolated area in Ethiopia. (For design improvements that double the efficiency of these machines, see review of **How to Build a Cretan Sail Windpump for Use in Low Speed Wind Conditions**.)

The report contains drawings and photos of the necessary components. Much of the text discusses the design, problems, and resulting modifications. By "racing" one design against another (rather than getting involved with expensive monitoring devices), the Presbyterian Mission was able to come up with a windmill that would pump at almost twice the rate of a commercial American Dempster multi-blade windmill. (This was partly because the sail windmill, due to its relatively light weight, was constructed so as to sweep a larger cross-sectional area.) The sail windmill also performed better than three Savonius rotor windmills. The most impressive design was a 16-foot diameter rotor, which when rigged with four sails and operating at a static head of 9 feet, was able to pump 1300 gallons of water per hour in a 14.5 mph wind. Water was pumped from a river that had a water level variation of 6 feet; a float was used on the intake system.

The experiments resulted in a design which has 8 arms. The number of sails actually used depends on the wind at the time. The owner/operators put up the sails in the morning and adjust them while the mill is in use; when work is finished in the fields, the sails are removed for safe keeping (which also protects the mill from damage in case of a sudden storm and high winds). Thus these windmills are not taking full advantage of the 24-hour availability of wind, though in these circumstances the windmills are in operation during the peak wind velocity period.

The sails were made of donated Dacron sail cloth, which was both strong and resistant to the deterioration that comes from continuous exposure to strong sunlight. Cotton is claimed to be not generally strong and long lasting enough; the kind of cloth sail used in Crete is not identified .... Some experimentation was done with detachable aluminum sails, made from surplus roof cappings; these were claimed to be "readily available and cheaper than Dacron in most areas ... more durable than locally-available textile."

By August 1975, 19 windmills of various types were being used by villagers, and another 5 were operating on the mission grounds. The 11-foot design has a cost estimate of US $250-350, almost all of which goes for the steel, the pvc pipe, and the commercially-produced pump. Costs might be significantly reduced in areas with a supply of strong bamboo and wood materials.

How to Build a "Cretan Sail" Windpump for Use in Low-Speed Wind Conditions, MF 21-474, construction manual, 56 pages, by R.D. Mann, 1979, £6.95 Mom ITDG.

This waterpumping windmill design was based on the low-lift windmills which had been built on the Omo River in Ethiopia (see review of Food from Windmills), which had themselves evolved from the sail windmills of Crete. The author adapted the design for the lighter winds of the Gambia, and succeeded in nearly doubling the efficiency of the Omo River design. He reports on field testing done in 1978, and provides complete drawings and text for the construction of the windmill.

This machine was developed for irrigation use on small farms. In this region of the Gambia, there is no wind 31% of the time, wind of more than 12 mph only 6% of the time, and moderate winds to 12 mph 63% of the time. Needed is a windmill that will operate in winds of 5-10 mph. "The wind speed required to start the windpump from rest was calculated to be between 5.2 and 5.6 mph, and once started the windwheel continued to run in a steady wind down to 4.5 mph." During a series of 9-hour pumping trials spread over four months, the windmill lifted 1700 to 3400 gallons of water a height of 13'4"; windspeed averaged 5.1 mph at the low end and 6.75 mph at the high end of this range.

The windmill has 6 sails, three full-sized and three smaller sails that help in starting. There is a 23-foot tower. Estimated cost of the windmill is £750 ($1650). As of this report, the windmill had only been used to operate a lift pump, with a 14 foot lift. Future tests will involve a force-pump and 45 foot head (lift).

The drawings are separated from the text, making the book a bit awkward to use. However, the drawings can be clipped from the book and spread out separately, and with study they become clear to the reader. There are also 12 photos.

Construction Manual for a Cretan Windmill, MF 21-465, book, 59 pages, by Niek Van de Ven, WOT/CWD, October 1977, serial no. CWD77-4, in English and Dutch, out of print.

This is a construction manual for a waterpumping sail windmill similar to the ones found in Crete. This version was built at the Twente University of Technology in The Netherlands.

The low-cost design shown here could be built almost anywhere in the world with mostly local materials. It is best suited for low-lift pumping. The rotor diameter is 6 m, but could be made smaller. Sail windmills are especially interesting in areas where the winds are occasionally very high—the sails can be removed and the windmill protected under conditions that would destroy a commercial windmill.

Plans are also included for a pedal-powered woodworking lathe, which can be built with hand tools using wood and a few bicycle parts. The lathe is used in making some of the windmill parts. A shallow borehole, hand-drilling method using locally-made drill bits and augers is shown. A piston pump design is also provided. The manual is well-illustrated, with over 100 photos and drawings.

The Gaudgaon Village Sailwing Windmill, VITA Renewable Energy Series, MF 21-506, booklet, 94 pages, by William W. Smith III, 1982, $10.95 from VITA; blueprints also available for $29.00.

Aspects of erecting low-cost, labor-intensive windmills in rural India are covered in a thorough, if somewhat disjointed, manner. Includes checklists, appendices, scale plans, fabrication techniques, and construction tips that have proven relevant in the author's experience and should be useful for others engaged in similar work with local craftspeople in developing countries.

How to Construct a Cheap Wind Machine for Pumping Water, MF 21-475, leaflet, 13 pages, Brace Research Institute, 1965 (revised 1973), $1.75 from BRACE.

This device is a Savonius rotor, adapted to water pumping for irrigation where windspeeds are 8-12 mph or more, and water level is not more than 10-15 feet below ground.

Brace has tested the unit to find out its potential for low-cost water pumping. "From the tests the following conclusions can be drawn: the Savonius Rotor, although not as efficient as a windmill of comparable size, lends itself to waterpumping for irrigation due to its low initial cost, simplicity of materials and construction, and low maintenance cost .... The only important points to be observed in erecting such a machine is the proper choice of the site and careful assessment of the average wind speeds. From this information, the proper pump size and stroke can be chosen from the graphs at the back of this pamphlet." Another graph is included which gives the output at various windspeeds. One pump designed to operate at 10 mph and lift water 15 feet will have an output of 181 Imperial gallons per hour at that windspeed.

The rotor has been designed in this form for moderate windspeeds and waterlifting up to 30 feet. Brace reports that a fair amount of "experimentation was needed to determine the best location of the pump relative to both the source and the discharge." Design of a simple diaphragm pump is also included.

Performance Test of a Savonius Rotor, Technical Report T10, MF 21481, technical report with charts and graphs of the test results, 17 pages, by M. Simonds and A. Bodek for Brace Research Institute, 1964, $2.55 from BRACE.

Performance tests were carried out using an 18 sq. ft. rotor on an open site. "It is concluded that a Savonius Rotor pumping system operates quite satisfactorily and is indeed a practical design of windmill. It is, however, only about half as efficient as the conventional fan mill" which costs 4 or more times as much. Two rotors would thus have the same output as a conventional fan mill, but the total cost would be less than half that of the conventional machine.

"The system seems best suited for pumping in cases where the well-depth does not exceed 20 ft ... the windmill should be designed to look after itself safely in storms."

This is clearly an important report for anyone who plans to experiment with Savonius rotors. Torque, power coefficients, and tip speed ratios are examined.

Savonius Rotor Construction, Vertical Axis Machines from Oil Drums, MF 21-486, booklet, 53 pages, by Jozef Kozlowski, 1977, $7.25 (overseas orders add $3.00 for surface mail, $5.00 for airmail), from VITA; also available in French.

The author "has built two Savonius rotors—one in Wales and the other in rural Zambia. This manual details the construction of these machines ... puts the rotors in a perspective which allows potential builders to judge the applicability of such machines for meeting their needs and then provides effective guidelines for constructing each." One of the rotors is for pumping water, and one is for charging automobile batteries.

The rotors are not very effective compared to other low-cost windmills. For example, "The data from Bodek and Simonds' experimental S-rotor in the West Indies shows that the useful energy from a 12 mph wind ... means that one can pump 75 Imperial gallons/hour up to 30! above the water level (341 liters/hour up to 9.14 m). In an 8 mph wind ... only 25 Imperial gallons/hour (104 liters/hour) can be pumped to the same height." (This compares unfavorably to the 5.4 m Cretan sail windmill, which is reported to pump as much as 15 times this volume of water in an 8 mph wind. Low-cost sail or bamboo mat windmills in Thailand also appear to be considerably more productive.)

The summary of performance data on Savonius rotors and the reviews of other S-rotor publications are useful. The construction details are good, although many of the drawings are poorly reproduced.

Electric Power from the Wind, MF 21-466, booklet, 40 pages, by Henry Clews, 1974, Enertech, out of print.

In readable non-technical language, this booklet contains the basics about producing electricity from the wind. Examples are given from Clews' own wind generator (a commercial unit). A good place to start.

Matching of Wind Rotors to Low Power Electrical Generators, MF 21-478 book, 85 pages, by H.J. Hengehold, E.H. Lysen, and L.M.M. Paulissen, December 1978, CWD, serial no. CWD 78-3, out of print.

Here is a much-needed, good presentation of the design choices for the most likely application of windgenerators in the South: isolated, rural, low voltage, small capacity systems with battery storage. The text explains a number of design "rules of thumb" for this kind of application, to maximize daily electricity output while minimizing cost. A good set of charts shows the important relationships between windspeed, power output, rotor diameter, and generator size. Readers will require some knowledge of basic physics, though an appendix explains the operation of a generator.

The authors begin by showing how to use information on the local wind conditions, and the computed energy demand, to calculate the necessary rotor diameter and rated power of the generator. " The emphasis (of the book) lies on the electrical part of the system and its optimum matching to the rotor .... In the case of rural applications most windgenerators will be used to charge batteries for lighting purposes and to feed radio or TV equipment. Therefore we will limit ourselves here to DC loads, to avoid the complications of computing reactive loads" Particular attention is given to automobile generators and alternators. "These components are not the most suitable for our purpose, but since they are low priced and readily available they cannot be neglected."

Homemade 6-Volt Wind-Electric Plants, MF 21-471, booklet, l9 pages, by H. McColly (Ag. Eng.) and F. Buck (Elec. Eng.), North Dakota Agricultural College Extension Service, 1939 (reprinted 1975), out of print.

"This publication deals entirely with a homemade wind-driven 6-volt battery charger system which may be used to generate energy to keep batteries charged for radios, autos, and small lighting systems for farm houses and other farm buildings where the energy consumption is not large." The booklet was written for small farmers in the U.S. in 1939, and reprinted in 1975 due to the large current interest in windgenerators.

Dimensional drawings (English units) with text, step-by-step instructions, and many useful hints are given. The blades are hand fashioned out of wood. This low-cost system charges 2 6-volt batteries and powers several lights, radios, etc. It is designed to charge the storage batteries when the wind velocity is between 15 and 30 mph— probably too high for most situations. (Modification for charging during periods of lower windspeeds would involve either a gearing system, rewinding the generator, or using an alternator.)

The Homebuilt, Wind-Generated Electricity Handbook, MF21-470, book, 194 pages, by Michael Hackleman, 1975, Earthmind / Peace Press, out of print in 1986.

Much of this book is not on homebuilt systems at all, but on how to find and rebuild one of the hundreds of thousands of windgenerators that were manufactured in the United States between 1930 and 1950, before the completion of rural electrification. But there is a lot more to this book that is valuable to the person building his or her own windgenerator.

Potentially the most valuable are the 29 pages of simple explanations and drawings of the control box. "The point of this chapter is to detail the components of the wind-electric controls—how they work .... If you're building a wind-electric system, this chapter will tell you what you must account for and protect, and how you can do it." Covers relays, voltage regulator, current regulator, and other components (ammeters, voltmeters, fuses, etc.) in non-technical language. There is a very simple design for a control box system for units producing less than 400 watts (see below) and a complete wiring diagram and explanation of the owner-built control box for higher wattage systems.

"Let's trace the path of current in this unit. The generator current goes through the heavy coil on the relay but is blocked by the open switch, so it goes through the smaller winding of wire on the relay. When the voltage from the generator is sufficient to begin charging, the current in this part of the relay will be sufficient to pull in the relay and close the contacts. Now the current will flow into the batteries through the ammeter. When the windspeed drops, the windplant will slow; when it's at a lower voltage than the battery voltage, current will flow in a reverse direction through the heavy wire winding and this will neutralize the magnetic field of the small wire winding portion of the relay and the contacts will open. If the wind is not present, and you want to be sure that all is okay with the wind plant you can hit the PTT (push to test) switch and this will short the batteries out to the generator and motor the wind plant if it starts turning up there all is okay. If it doesn't, the batteries are dead or the windplant is frozen up or has a broken connection somewhere."

Also covered in this book is the art of tower-raising (57 pages). These are towers in the 40-foot and taller range, that are fully assembled on the ground. This is a rather delicate maneuver, and the text with photos and diagrams seems to cover the do-it-yourself methods nicely.

Simplified Wind Power Systems for Experimenters, MF 21-488, book, 80 pages, by Jack Park, 1975, out of print in 1985.

Most of the windpower information available "requires engineering training or is not complete enough .... It is hoped that (in this book) the reduction of complex mathematics into simple graphs and arithmetic problems will allow a greater segment of the innovative public to use the fundamentals an engineer has. To make this book as useful as possible, a page has been devoted to graph reading, and numerous examples are used to illustrate each step in the windmill design process."

Over 50 illustrations and photos of all kinds of windmachines and an equal number of simple graphs and minor drawings are included. This book comes close to reaching Park's goal of providing "the reader with the engineering tools necessary to accomplish a respectable job of designing and planning the construction of windmills"

Major topics are power required, wind energy available, windmill efficiency, airfoils, windmill augmentation, structural design, and mechanical design. Very little is actually said about pumping water, electrical systems or direct mechanical conversion; you'll have to go elsewhere for this essential information. This is a good book to have for the design of the wind rotor itself.

Rotor Design for Horizontal Axis Windmills, MF 21-484, book, 52 pages, by W. Jansen and P. Smulders, May 1977, Consultancy Services Wind Energy Developing Countries, serial no. CWD 77-1, out of print.

"This publication was written for those persons who are interested in the application of wind energy and who want to know how to design the blade shape of a windmill rotor ... a lot of attention is given to explaining lift, drag, rotor characteristics, etc. .... In the selection of a rotor type, in terms of design spread and radius, the load characteristics and wind availability must be taken into account .... The availability of certain materials and technologies can be taken into account in the earliest stages of design. We therefore hope that, with this book the reader will be able to design a rotor that can be manufactured with the means and technologies as are locally available."

The reader will need at least a good high school mathematics and physics background and familiarity with abstract technical presentations to be able to use this book.

Horizontal Axis Fast Running Wind Turbines for Developing Countries, MF 21-473, book, 91 pages, by W. Jansen, June 1976, CWD, serial no. CWD76-3
order code HAFR/24, Dfl. 13.00 from TOOL.

This is a highly technical report of some work on the design of rotors for high-speed windmachines. The authors argue that "in contrast with airplane propeller design, a maximum energy extraction is reached by enlarging the chords of the blades near the tips."

"A simple method for manufacture of twisted, arched steel plates is given. Six rotors were built of blades that were manufactured with this method."

This report will be of value to readers with an engineering background. "Final conclusion is that with simple materials high power coefficients are possible."

Optimization and Characteristics of a Sailwing Windmill Rotor, MF 21-480, report, 82 pages, by M. Maughmer of Princeton University, March 1976, accession no. PB-259898, paper copies $17.00 domestic, $34.00 foreign; microfiche $8.00 domestic, $16.00 foreign; from NTIS.

This is the final report of the Princeton sailwing windmill project. "Through many years of extensive research, the sailwing has been found to provide a simple, lightweight and low-cost alternative to the conventional rigid wing, while not suffering any performance penalties throughout most low-speed applications."

This unusual wind rotor design uses a sail cloth sleeve over a spar and tension cable, instead of a solid blade.

Rapid evaluation of comparative performance of 8 different rotor shapes was made possible by using a test tower mounted on a jeep, and a homemade cup anemometer, demonstrating that effective testing can be carried out at low cost.

Many technical terms are used.

Vegetation as an Indicator of High Wind Velocity, MF 21-492, and **Trees as an Indicator of Wind Power Potential**, MF 21-491, papers, 35 pages plus bibliography and 21 pages, by J. Wade, E. Hewson, and R. Baker, $2.00 and $1.50 respectively, from Dept. of Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97331, USA.

These papers describe the development of a technique for using trees as indicators of the long-term average winds in a particular place. "Plants provide a quick, at a glance, indication of strong winds and when calibrated by the degree of wind shaping provide a rough, first cut assessment of wind power potential .... This technique could appropriately be used as a first stage in a wind survey prior to instrumentation with anemometers."

A widespread obstacle to the use of windgenerators is that the energy available— and therefore the economic feasibility—varies dramatically from site to site. The approach described here is intended to aid in the selection of sites for wind generators, which require relatively high average windspeeds if they are to be economically feasible. The basic approach could also be used in identifying sites for waterpumping windmills, but they do not use—and in fact need protection from—the higher winds. New calibrators would be required for species of trees common to other areas, and a substantial amount of long-term windspeed data is needed in order to do such calibrations. Exposure and slope also affect the data.

Low Cost Wind Speed Indicator, Publication No. T-113, MF 21-476, single page of blueprints, 1979, $2.50 from Brace Research Institute, MacDonald College of McGill University, Ste. Anne de Bellevue, Quebec, Canada H9X lCO.

Plans for a simple tilting pointer windspeed indicator. Requires plastic tubing, aluminum sheet and aluminum rod, steel tubing, and a piece of wood.

Piston Water Pump, Publication No. T-114, MF 21-482, two pages of blueprints, 1977, $5.00 from Brace Research Institute, MacDonald College of McGill University, Ste. Anne de Bellevue, Quebec, Canada H9X lCO.

The fabrication and assembly of a piston water pump for use with waterpumping windmills is shown. Materials required include galvanized water pipe and steel rod. Some welding is required.

Energy from the Wind: Annotated Bibliography, MF 21-467, first edition plus three supplements up to 1982, compiled by Barbara Burke, write for price information to Publications, Engineering Research Center, Foothills Campus, Colorado State University, Fort Collins, Colorado 80523, USA.

The literature described in this bibliography ranges from "a popular review to a technical aerodynamic study, from do-it-yourself homebuilt projects for house or farm to large scale commercial production for power networks." Some 6300 references are covered. Very few of the documents listed contain any practical construction information, and the index does not identify them for the reader. No addresses are provided for documents. For people with special topic interests and access to a university library, this bibliography will, however, provide very helpful access to a wide literature on the economic, policy and theoretical design aspects of wind power. The center that produced this bibliography is now offering low-cost computer searches of wind energy references.

ADDITIONAL REFERENCES ON ENERGY: WIND

More Other Homes and Garbage, especially for small-scale generation of electricity; see GENERAL REFERENCE.

Traditional Crafts of Persia has a vertical-axis windmill used for grinding grain; see GENERAL REFERENCE.

LeJay Manual has information on homebuilt windgenerators and how to rewind an automobile generator so that when used with a windmachine it will begin charging at a lower rpm; see THE WORKSHOP.

Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy has very good coverage of work in the Third World has very good coverage of work in developing countries; see ENERGY: GENERAL.

Waterpumping windmills for India are discussed in articles in **Renewable Energy Resources and Rural Applications in the Developing World**; see ENERGY: GENERAL.

Commercially available windgenerators and windpumps are listed in **The Power Guide**; see ENERGY: GENERAL.

Gemini Synchronous Inverter Systems describes an electronic device that allows a windgenerator to be linked directly to the electric grid, thereby eliminating the need for batteries; see ENERGY: GENERAL.