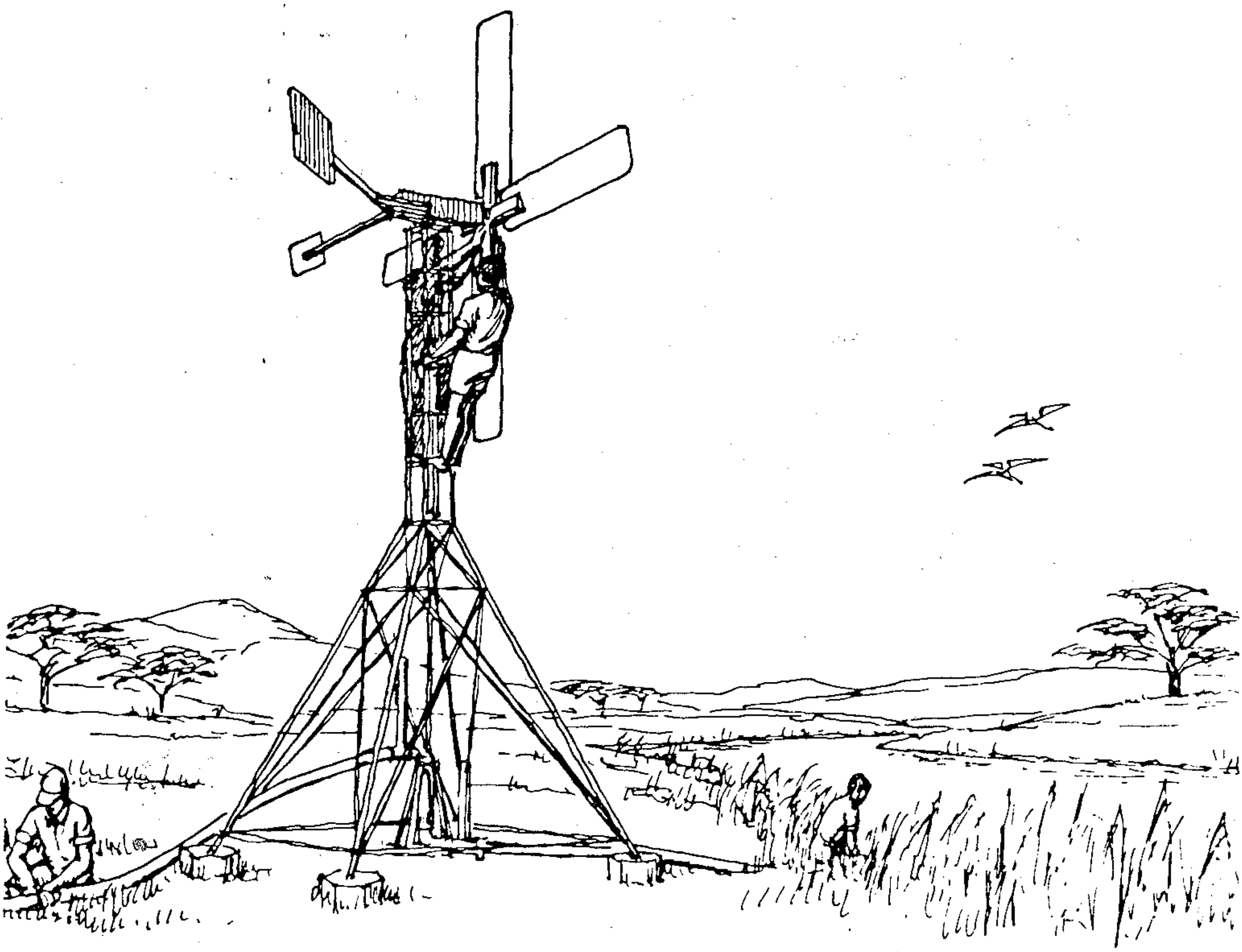
THE FC-WINDPUMP PROJECT



FC

THE DANISH CENTRE FOR RENEWABLE ENERGY

CONTENTS

INTRODUCTION

FC - the Danish Centre for Renewable Energy - develops renewable energy systems for local production.

The following report on the FC-windpump project presents the background, technical concept and perspectives for water-pumping and electricity production with small-scale windmills, aiming especially at the needs of many 3rd world countries.

FC-technologies provide possibilities for the promotion of local industries and trade through the development of renewable energy systems which are presented in the form of "builders handbooks" comprising full technical drawings and a text to assist in planning and production.

Co-operation with development agencies, non-governmental organisations, etc. is invited. We will be happy to send detailed information on our activities and to receive information from others working in the field of renewable energy.

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FC - THE DANISH CENTRE FOR RENEWABLE ENERGY

BACKGROUND

Since the oil crises of the 1970´s Denmark has achieved an internationally recognised reputation in the field of electricity producing wind energy conversion systems (WECS).
Export orders to the USA alone have marked the industry as the fastest growing sector in Danish industry with orders for 1982, 1983, and 1984 being respectively 30, 300 and 1500 units. In 1985 an export of 2500 units is expected.

This explosive growth builds on past traditions of windmill use refined during the 1970´s by the activities of among others the founders of FC.

10 years work with development projects on windmills, biogas and solar heating led in 1983 to the formation of the Centre, a non-profit organization, with government and local council funding. The role of FC is to undertake research and development for small and medium scale industry in the field of Renewable Energy Technology. No patents are taken on the technologies developed at the centre which are thus open to all through detailed builders manuals.

AIMS

Research and development for producers who have not the capacity to maintain their own innovative departments has given FC a background of experience in adaptation of technology, technology transfer and development of local production which is in many ways unique, even in an international context.

Apart from technical development, FC´s experience includes erection and supervision of demonstration systems, and the educational and informational activities allied to them.

Location of FC in the North-West of Denmark

REVIEW OF RENEWABLE ENERGY DEVELOPMENT AT FC

WINDMILLS

The Blacksmith series of grid-connected electricity producing windmills in various size classes are designed for single homesteads, institutions, industries and inclusion in windmill farms:

13 kW, 22 kW, 55/75 kW,
99 kW, 150 kW.

Special areas of development include: laminated wooden wings, steel wings, generator suitability, windmill farms.
Windmills for water pumping and autonomous electricity production: wing diameter 4-6 m, simple and robust; suitable for manufacture overseas or in Denmark.

SOLAR ENERGY

A variety of solar panels for water heating, ranging from do-it-your-self to more sophisticated installations.
Solar water pumping systems.
Solar cooling.

BIO-ENERGY

Energy forestry.

BIOGAS

Steel and concrete tank systems of 50-150 m^3 operating as mesophilic or thermophilic.
Information on biogas systems for developing countries.

COURSES AND TOURS

For producers, self-builders, schools, societies etc.

3RD WORLD PROJECTS

The close connection FC makes between technical development, technology transfer and education makes the centre especially suited for participation in projects in the developing countries.

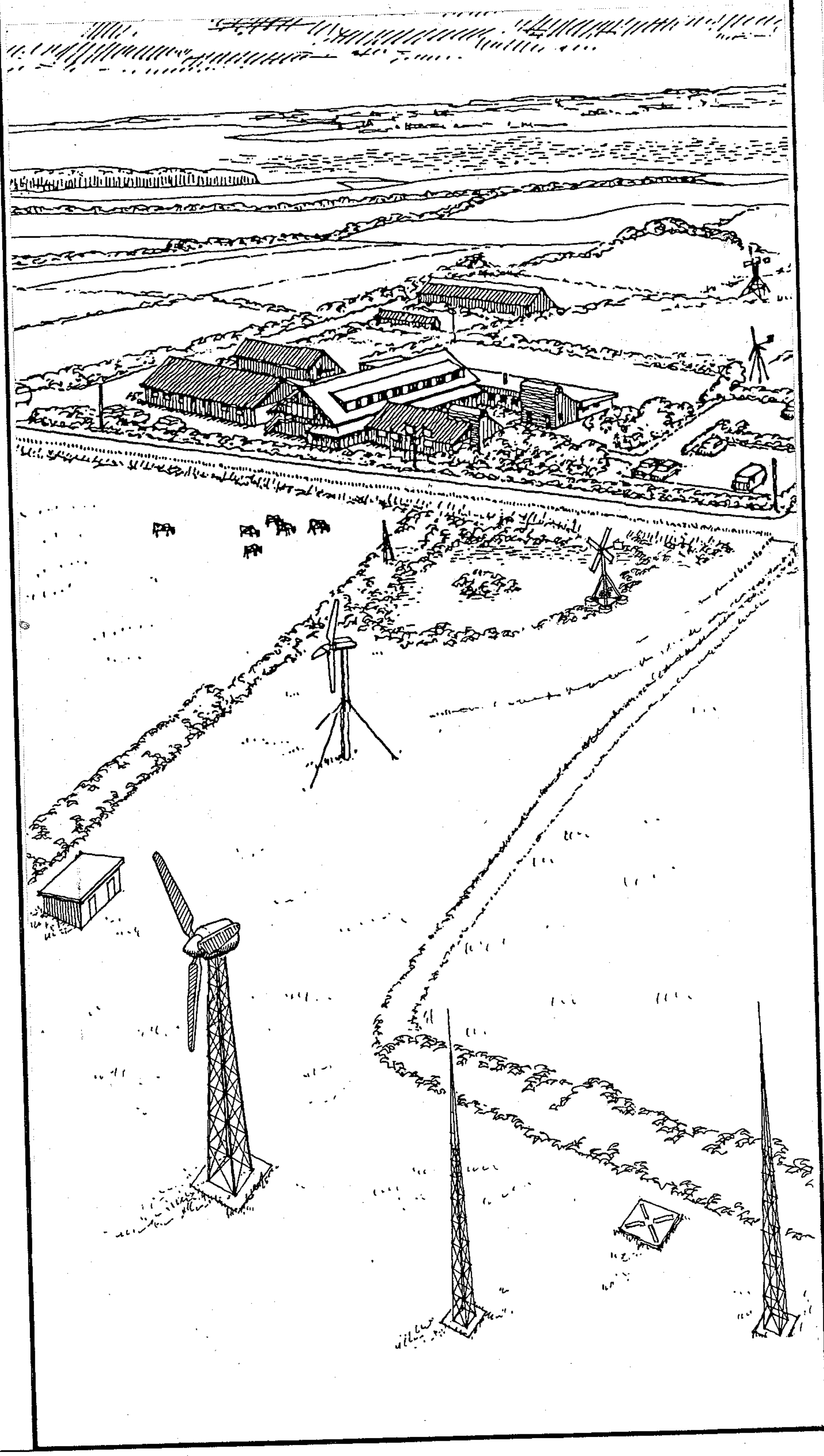
FC will thus be able to participate in projects with development organizations, missionary bodies, official institutions, non-governmental organizations etc. Competence is offered in the following areas:

1. Adaptation of technology to local conditions.

2. Implementation of local production

   a) education
   b) work-shop lay-out
   c) start-up assistance and supervision of production.

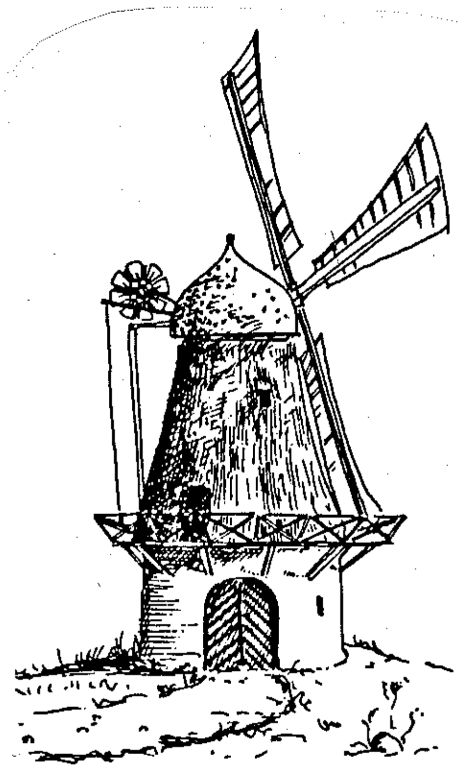
3. Consultancy in small- and medium-scale renewable energy systems.



SMALL SCALE WIND ENERGY APPLICATIONS

Wind energy is one of the few renewable energy sources with a past history of utilisation and profitability. Different forms of wind energy technology have existed for over a thousand years. In the 6th century windmills were used in Persia, and as far back as the 13th century 4-winged horizontal-axle Dutch windmills came into use in several European countries.

By the 1930's there were more than 30,000 windmills in Denmark, and a similar number in the Netherlands used for threshing, grinding, water pumping and electricity production.

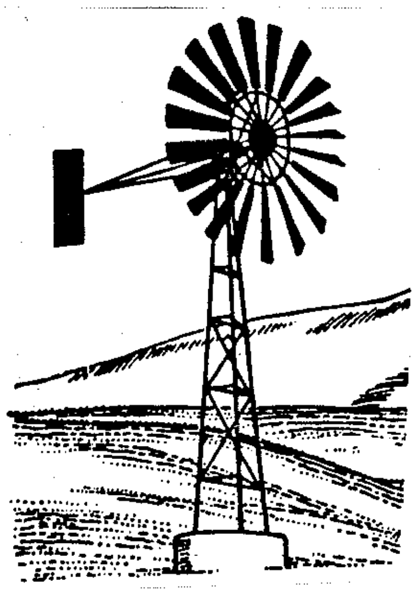


MECHANICAL WATER PUMPING

In the second half of the 19th century small wooden-bladed windroses were developed for waterpumping. From 1850 - 1940 6 million examples of this type were produced in the USA alone, and even to-day windrose windmills are produced in large numbers, especially in Argentina, Australia, and South Africa, but also in France, Holland and other countries.

Approximately 1 million of these windroses are in operation to-day (1980) and the potential global market for small mechanical windpumps is large, running to several million units. <u>By the middle of the next century it is estimated that several hundred million people throughout the world will use wind energy to power small-scale pump systems.</u>

Apart from the windrose types, other windmills have been and are still produced for pumping water. Examples are the Danish produced Sparco, Gjellerup and Unimax, developed in the 1930's and and more or less unchanged to-day. Apart from these, other types of windmills such as the Cretan sailwings are still to be found pumping water.

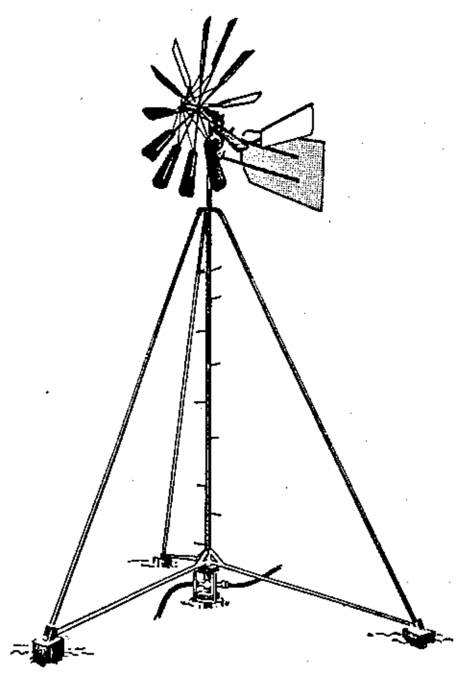


Common to the smaller windpump systems is a low wing tip velocity and relatively large wing area. The windmills thus operate at low wind velocities which make them particularly well suited to conditions in the 3rd world.

Existing windpumps can operate in wind speeds of 2-3 metres per second (ms^{-1}) so that in theory they could be used throughout half of the world's land-areas.

Windpumps should be regarded as of particular interest in drier areas, eg. East Africa, Indian subcontinent, Northern Argentina, N.E. Brazil, Mexico and Peru, where the ability to pump water can be a condition for life.

In tropical areas where trade winds do not exist, utilisation potential is lower, but local conditions vary so greatly that even here wind energy will be viable if attention is paid to site selection.



WINDPUMP DEVELOPMENT

In recent years metal has become the preferred material for the windrose and other multiblade designs which are thus lighter, simpler and slightly more effective than the traditional wooden multiblade rotors.

These developments have been spear-headed by ITDG (Intermediate Technology Development Group) in London, and CWD (Wind Energy Steering Development Committee) and WOT (Volunteers in Technology) in Holland.

Sailwing windmills (Cretan type) have also been improved, with progress made particularly in Colombia, Ethiopia, India and Holland. The constructions can be locally produced in small workshops in developing countries and have been demonstrated to be significantly cheaper than imported systems.

These advances have however not achieved a significant spread of the technology, possibly on account of insufficient marketing and distribution effort. Neverthelesss, CWD (Holland) are at the present time involved in projects or project preparation in a wide range of countries, and the break through appears close at hand.

ELECTRICITY PRODUCTION

Electricity producing windmills for charging of batteries have been in use since the beginning of this century and were commonly used for electricity supply on isolated farms, weather stations, navigation marks, and similarly remote sites. Expense in battery storage normally limits such systems to 3 kW.

Such power supplying windmills have the potential of being many peoples first exposure to electricity, and so long as they can operate down to windspeeds of 3 ms^{-1}, have a similar growth potential to water pumping systems. The electricity supply from such windmills might typically be used for refrigerators, lighting, communication (radio, TV, etc.), small hand tools and motors (including electrically driven water pumps).

Larger "stand alone" (grid independent) windmills can be combined with for example diesel back up, possibly supplied with battery storage, or with water reservoirs which can store and later release excess electrical generation. Particularly within this field of integrated generation is there a requirement for research and development.

The economic incentive for solving these problems is large; particularly if such wind generating systems can be combined with existing small diesel power units, and thus reduce fossil fuel import and consumption.

ECONOMIC VIABILITY OF WINDPUMPS

On economic comparison, windpumps are competitive in many parts of the 3rd world with diesel pumping systems. Indian and Kenyan experiences, which take into account both wind variations and fluctuating water demand, demonstrate that even in areas graded as "marginal" (from the point of view of wind speed), use of windpumps is cheaper than either draught animals or diesel pumps.

Economic comparisons based on Dutch experience are further described in the study project "Vindkraft og vandpumpning i u-lande", (p. 27 ff.).

IRRIGATION COSTS

Comparison of diesel pumps with combined windmill and diesel systems for 30 ha. irrigated throughout the year and with adjusted cropping pattern. Kenyan example.

	30 ha. throughout the year			Adjusted cropping
	4 diesel pumps (8 HP)	2 diesel pumps (27 HP)	3 diesel 8 HP 4 windmills (Kijito)	1 diesel 8 HP 4 windmills (Kijito)
Total costs/m³ water (K.Sh)	0.189	0.168	0.172	0.186

The similarity in price levels allows for other than economic considerations. For example, continuity of supply is best assured by the combined windmill and diesel option. In addition rising fuel prices make the windmill options increasingly economically favourable.

VARIATION IN WINDPUMP WATER PRICE (K.Sh/m³) at two locations in Kenya when compared with diesel pumps.

	Windrose windmill	5.25 HP Diesel Pump: Low utilisation	5.25 HP Diesel Pump: High utilisation	2.5 HP Petrol pump
Total costs/m³ water (K.Sh)				
Example 1	0.54	0.70	0.38	0.91
Example 2	0.125	0.210	0.160	

1 US $ = 10.5 K.Sh.
The extreme difference in price levels between examples 1 and 2 is explained by windspeed, pumping head and storage alternatives.

WINDREGIMES IN THE 3RD WORLD

It can generally be said that the average wind speed is low in comparison with other climatic zones.

However, one should be aware that a low average wind speed often hides a daily variation where the light winds predominate for a period of the day while for the rest of the day windspeeds are well above average.

The daily variation at Dodoma in Tanzania can be taken as an example. The avearage wind-speed is here 3.9 ms^{-1} while the pattern for an average day is as shown below. As may be seen the wind-speed is greater than 5 ms^{-1} for about 6 hours per day.

Seasonal variations can be a limiting factor. Wind free periods of long duration, eg. 6-8 weeks, can hinder a windpump project even if average annual windspeed appears favourable. In such cases back-up power sources should be considered.

WIND MEASUREMENTS

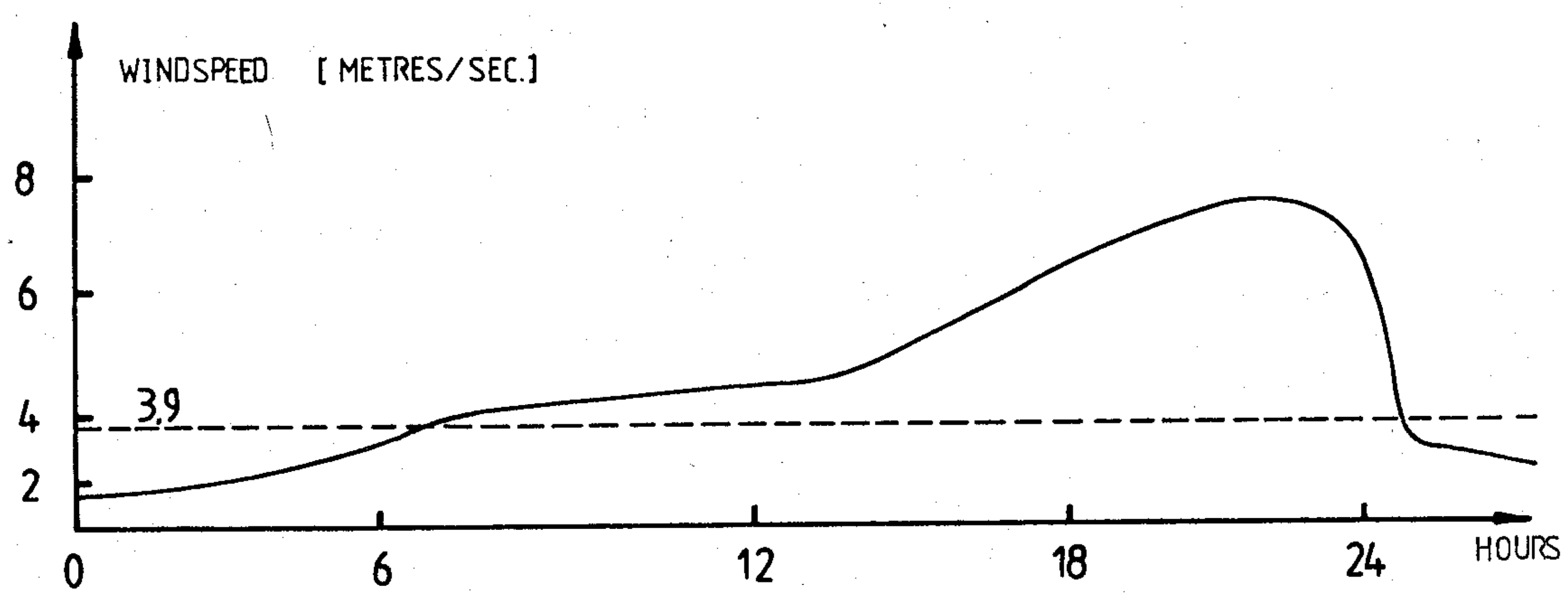
Good wind data is of primary importance for an evaluation of wind energy potential. A wind measuring programme is often the first stage of a project due to the general lack of available data.

Local information on wind regimes, backed up by a short period of wind measuring may be sufficient if one will avoid long term wind-measuring.

Further wind data is given in the study project "Vindkraft og vandpumpning i u-lande".

Wind Distribution

Dodoma, local estimate for an average day in the dry season.



THE FC-WINDPUMP PROJECT

The starting point in the project for development of windpumps for use in the 3rd world was the wish to combine Danish windmill design and experience with requirements for the developing countries.

The project started with collection of material and experiences from technical institutions already working within the field (presented in the study project "Vindkraft og vandpumpning i u-lande"). Contact was made with relevant persons in Kenya, Tanzania, and Nicaragua and the experiences of FC members who have worked abroad was drawn on.

The Danish Technology Council, who funded the project, established a steering committee consisting of Danish windmill technicians, former volunteers from developing countries and others with knowledge of the use of wind energy in developing countries.

Agreement was reached with a local co-operative of 4 blacksmiths to undertake home production and assist in the development.

THE GENERAL CONCEPT

Although the windmill for developing countries (the windpump series) is a new technological development, it is not an experimental windmill in the normal sense of the word since it is built up on generally known and tried principles.

The new element is that technology from electricity producing windmills is now transferred to small-scale water pumping systems.

Most windmills produced for water pumping are built on a technology and design that is about 100 years old. In other words, despite modifications to the windrose type of rotor, there has been little creative innovation for many years.

The result of the FC project is - as far as is known - a first time development of an aerodynamic "lift-type" windpump which has some of the slow-running windmills' best characteristics; i.e. can start and operate in light winds and at the same time is both robust and operationally effective in stronger winds.

The following characteristics can be **mentioned as differing from other waterpumping windmills:**

- No requirement for cement foundation.
- "Lift-type" windmill (higher effect per m^2 rotor area).

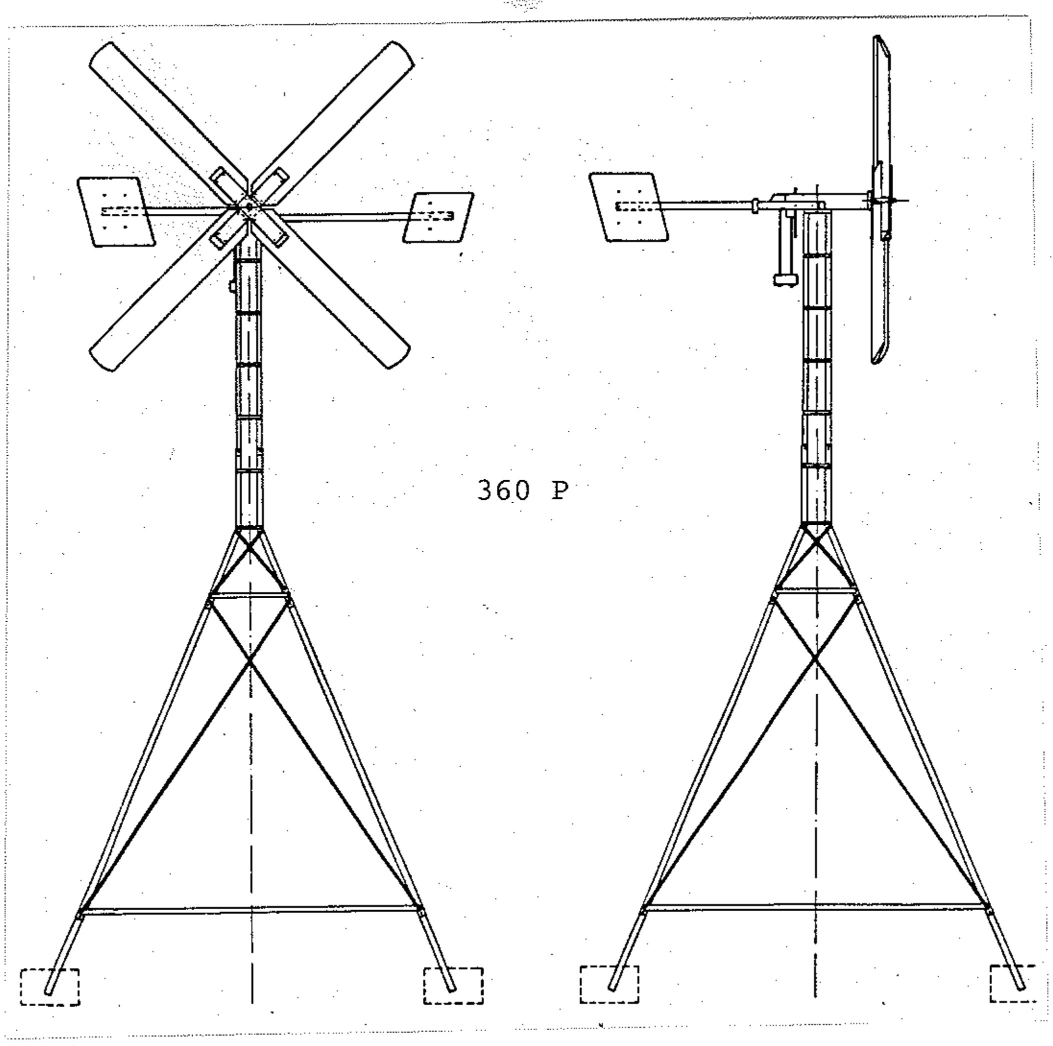
Other qualities that can be mentioned are:

- Long lifetime.
- Little maintenance.
- Robust; operates in winds up to 13 m^{-1}.
- Low wind speed characteristics.
- Transportable, no part longer than 3 m.

The windpump series are in addition developed with a view to local maintenance, and local production.

The windmill could be produced in small and medium-scale workshops, both at home and in developing countries.

Utilisation of standard materials and components selected for simplicity and durability ensures a long-lived uniform product; and is in addition a reflection of the requirements of appropriate technologies in the 3rd world.



ROTORDIAMETERS 6.0 AND 3.6 M

In the course of 1984 2 prototypes were built, one with a 6 m rotor diameter and the other with 3.6 m rotor diameter. Both mills use 4 laminated wooden wings, roller bearings and lattice tower with a broad base. Two piston pumps have been developed for shallow and deep wells, and the larger windpump has the possibility of operating as a combined water pumping and electricity producing windmill through the erection of a 1.5 kW electricity generator on top of the nacelle. Electricity is stored in a battery storage system.

PRODUCTION MODEL

The 360 windpump has been chosen as the initial production model on account of its capacity to be erected without the use of cranes or winches. All parts can be lifted by a single man and erection of the full windmill can be achieved by 2 men in the course of a day.

The windpump is in the first stages of production by a blacksmith co-operative. Negotiations are also underway with other interested producers.

ASSOCIATED PROJECTS

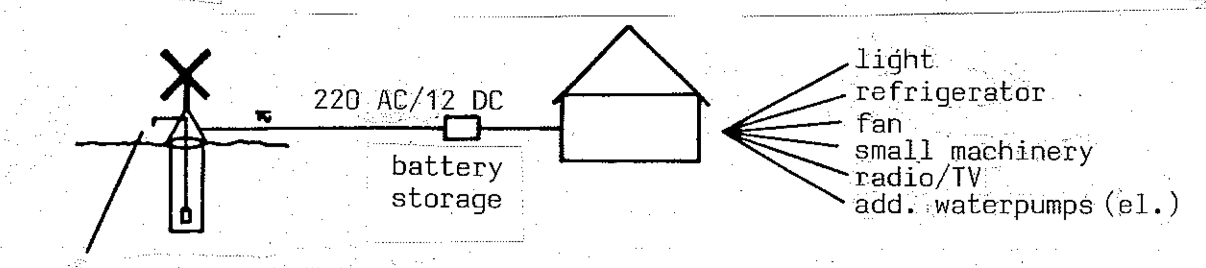
Running concurrently with FC´s project is a project at the Technical University of Denmark for development of a piston pump with a variable stroke which can better utilise low and high wind velocities; similarly a down-wind fibreglass high solidity rotor (windflower) is under development, and both pump and rotor will be tested at FC.

Wind pump main data

	600 P	360 P
Rotor diameter	6 m	3,6 m
Maximum effect	5.5 kW	2.5 kW
Total height	12.5 m	8.5 m
Maximum operative windspeed	13 ms^{-1}	13 ms^{-1}
Revolutions (rpm)	120 rpm	180 rpm
Start windspeed	3 ms^{-1}	3 ms^{-1}
Total weight	1400 kg	300 kg
Pumped volumes at windspeed 13 ms^{-1}/total head	4.8 m^3hr^{-1}/12 m	10 m^3hr^{-1}/3 m
Maximum head	60 m	20 m

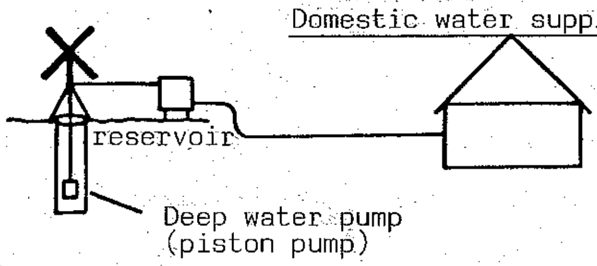
Windpump applications

Mechanical water lifting/autonomous prod. (1,5 kW)

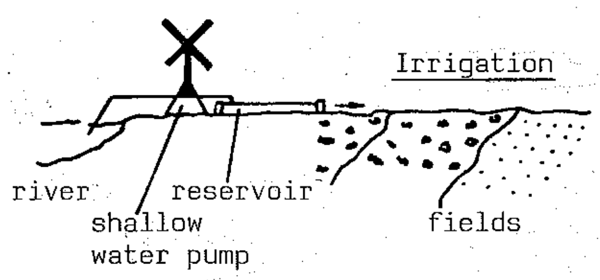


Domestic water, irrigation

Domestic water supply



Irrigation



REVIEW OF THE COMPONENT SYSTEMS OF THE FC-WINDPUMPS USING THE 600 CM ROTOR DIAMETER MODEL AS AN EXAMPLE

The 600 windpump has been chosen to illustrate the component systems of the FC windpumps on account of containing features such as air brakes and electricity generator not used on the smaller windpump.
The 360 which has been chosen as the initial production model otherwise cotains the same principal components on a smaller scale.

THE 600 WINDPUMP

ROTOR

A low-solidity 4-bladed rotor has been chosen for combination of power and torque. Blades are aerodynamically profiled (Clark Y 12 1/2%) with a pitch angle of 20^{o} to increase the slow running characteristic.

The rotor develops 40-80 rpm according to wind speed and develops a maximum effect of 5.5 kW.

In addition to FC´s low-solidity rotor a parallel trial is being made with a high-solidity rotor which endeavours to combine the windrose´s characteristics with the higher efficiency of the fast-running rotor types.

The rotor, known as 'Windflower consists of 24 flexible fibreglass blades which "close" when the wind pressure becomes too high. The design is of necessity a "downwind" rotor.

TOWER

The lattice tower of galvanised angle-iron is found in two versions:

1) Stand-alone (requiring no concrete foundation). Breadth at the ground 5.6 m. Bolted together from 3 m sections.

2) Narrow tower requiring conventional concrete foundation. Welded and bolted.

In addition towers constructed of standard water pipes are available for areas where angle iron is unobtainable.

NACELLE

The main axle has a diameter of 60 mm and is supported by 2 sealed spherical roller bearings of almost unlimited lifetime.

The hub is shrink fitted to the main axle, and the blades bolted directly on.

An eccentric is direct-driven by the shaft and gives the possibility of adjusting the piston stroke-length.

SAFETY SYSTEM

The safety system is composed of a side vane with air-brakes on the blades as a secondary mechanism.

The side vane is automatically activated by critically high wind speeds and yaws the rotor out of the wind.

Loss of control is further reduced by the presence of air-brakes on two of the blades. These are activated by wind pressure at high revolutions and automatically close, by the action of a spring, once the revolutions fall.

FOUNDATION

For the wide based tower the only foundation necessary is a heap of stones (300 kg) piled on a wooden platform at each corner of the tower. The tower is then sufficiently stable for the windpump to withstand wind speeds up to 25 ms^{-1}.

PUMP

A simple piston pump of internal diameter 70 mm has been modified for windpump use.

The maximum water output at 60 rpm is 4.85 m^3/hour from a depth of 12 m.

The pump can lie up to 60 m underground and has the capacity to pump a further 30-50 m up from the wellhead.

As mentioned the pump stroke length can be varied by positioning on the eccentric.

In addition a special mechanism is under development at the Technical University in Copenhagen whereby the piston stroke length is varied according to the wind speed. This can increase pumping efficiency by 30-60%.

ELECTRICITY PRODUCTION

The windpump can be assembled as a combination water pump and electricity production unit.

A 1.5 kW generator is chain driven from the eccentric and the electricity stored in conventional lead acid batteries.

Alternatively the WECS could be used for electricity production alone.

THE 360 CM ROTOR DIAMETER WINDPUMP

This is a reduced version of the 600 and varies considerably in weight.

The windpump can be erected by 2 persons and requires no aids such as cranes or pulleys.

With a rotor diameter of 360 cm the maximum effect is approx. 2,5 kW.

The tower design however allows for a rotor diameter of up to 500 cm so that the WECS becomes even more suitable for low wind regime areas.

The foundation is of 4 concrete blocks, each 100 kg, bolted to the corners of the tower.

No air brakes are required as the rotor has built in stall characteristics over 200 rpm.

The windmill can also be equipped for electricity production alone.

OPTIONAL SYSTEMS

There are various options for each of the WECS depending on location, availability of materials, etc.

BLADES

Rotor type: 4-bladed; fibreglass windflower, (24 blades).
Blade length: variable 0-3 m.
Blade material: laminated wood; fibreglass (windflower).

BEARINGS

Main axle: steel roller bearings; wooden bearings.
Yawing mechanism: iron rollers; wooden bearings.

ECCENTRIC

Variation of piston stroke length 150-350 mm.

TOWER

Type: broad base (no foundation); narrow base (underground concrete foundation).
Height: towers are fabricated from 3 m modules and can be extended to any required height.
Material: angle iron, water pipes.

POWER CONVERSION

1. Mechanical piston pump (deep water pump) with or without variable piston stroke mechanism.
2. Mechanical piston pump (shallow wells etc.).
3. Mechanical piston pump, combined with 1,5 kW electrical generator.
4. Electricity production.

LOCAL APPLICATION - SOME CONSIDERATIONS

THE TECHNICAL SYSTEM

As mentioned earlier in this report the potential for wind power in developing countries is large and at the present time largely unrealized.

It is important that the windmill is seen as part of a complete system. Thus that windmill, pump/generator, reservoir/battery storage and consumption points are regarded and launched as a complete unit, so that the various components are related to each other according to energy production and consumption patterns.

As wind regimes, water resources, consumption patterns etc., can vary from area to area, local conditions must be mapped and the system adjusted accordingly (eg. tower height, rotor diameter, pump capacity etc.). This process should be complete before starting any programme for expansion of the technology and in this context it will be decisive to have results from trial sites in different areas before a wider launching takes place.

There will often be a requirement from the donor agency or receiving country for either the complete system or components thereof to be locally produced by small-scale industries or similar. Such a requirement can be expected, where a donor agency (such as DANIDA, Danchurchaid, World Bank, UNDP, etc.) is the client, due to the policy of promotion of trades and industry in rural areas.

It was therefore considered important in the design stage that the windpump system be developed with a view to fulfilling varying requirements for mode of production (workshop capacity etc.) and material choice (eg. use of locally available materials).

Despite the above mentioned requirement for flexibility in the system the following technical characteristics are fundamental to the design:

1. It must start and operate in light winds.
2. It should be easy to repair and maintain, be reliable and have a long lifetime.
3. It should be unaffected by heavy rain, high temperatures, dust, temites etc.
4. It should withstand variation in water-resources (eg. that wells dry out during certain periods) and wind resources (eg. no wind periods, be they seasonal or daily).

TRIAL SITES

As different local areas involve different negative factors which must be overcome, the importance of preliminary research and trial sites is emphasised, so that adaptations of the system and experience of local requirements achieve a sufficient stage of expertise for the windmill to become accepted as a functional, viable and preferred alternative to existing power conversion systems.

THE SOCIAL AND CULTURAL SYSTEM

The windmill as an introduced new technology must find its place in an extensive and complicated web of social, cultural and economic relationships.

It is seldom that the technical and production side of the technology is the limiting factor to the spread of windpower. It has been demonstrated many times in the past, that if the windmill cannot find its place in this wider sphere of relationships it is doomed to become yet another example of misdirected aid politics.
To illustrate the nature of the problem the following, primarily economic limitations, may be mentioned:

1. Small-scale subsistence farmers, with a primarily barter economy, do not have the capital to invest in windmills.
2. As opposed to diesel and electrical pumps, there are no credit institutions with a tradition for financing windmills.
3. There are no technical information or service centres to assist with installation and maintenance.
4. There has been a lack of understanding, both at home and abroad, for the potential of windpower.

It is clear therefore that for an increase in the use of small-scale windmill systems (and other renewable energy technologies), that hand in hand with the technological advances must come a development of financial, service, education, and information facilities.

LOCAL PRODUCTION

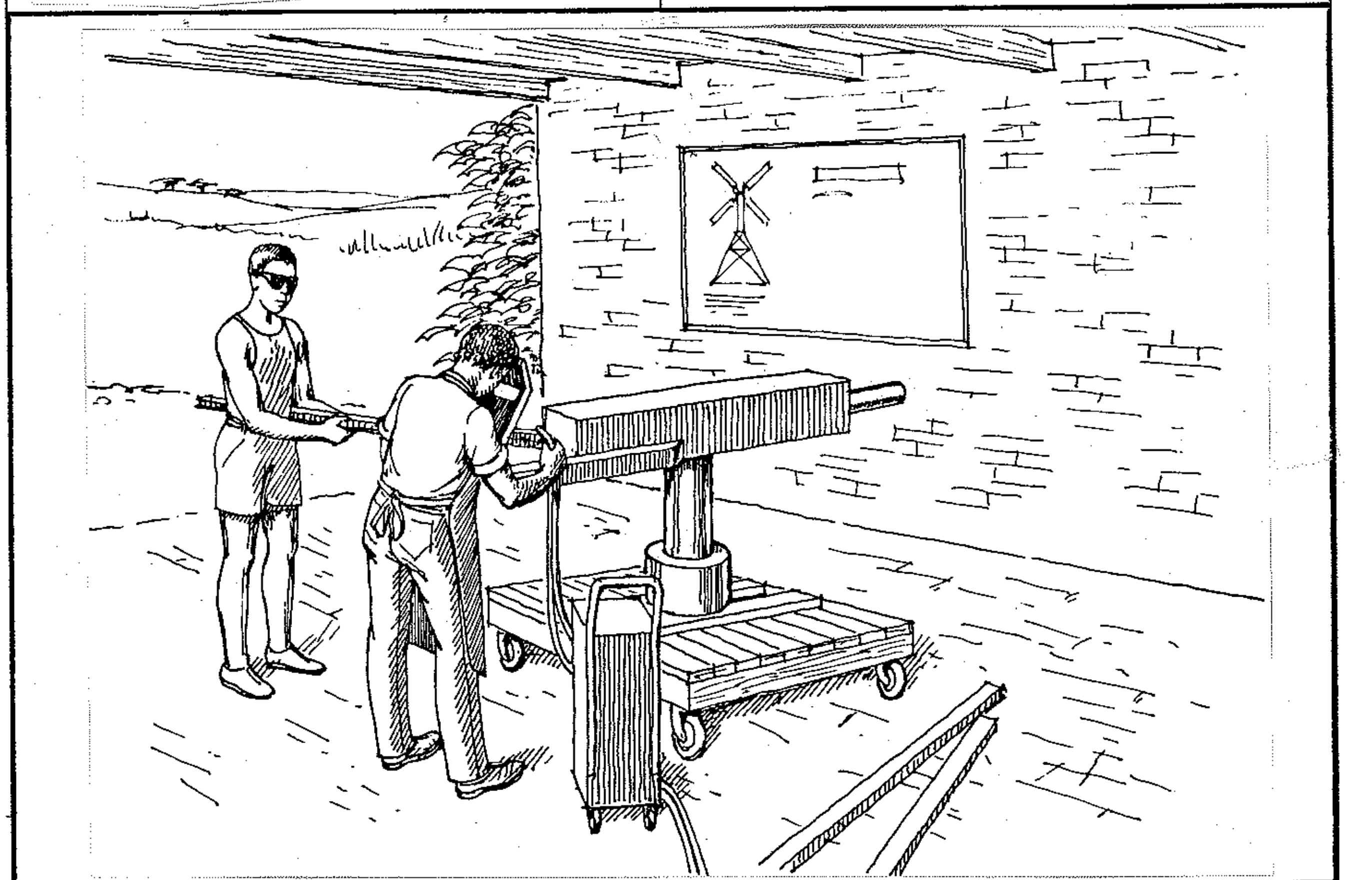
The FC windpumps can be manufactured in small and medium-scale workshops with ordinary welding and drilling equipment, hand tools for metal and wood etc.

As mentioned, the FC will be able to adapt (within limits) the construction to local conditions (windspeeds, materials available, etc.). However, a natural first step in such projects will be to import a Danish manufactured windpump for demonstration purposes.

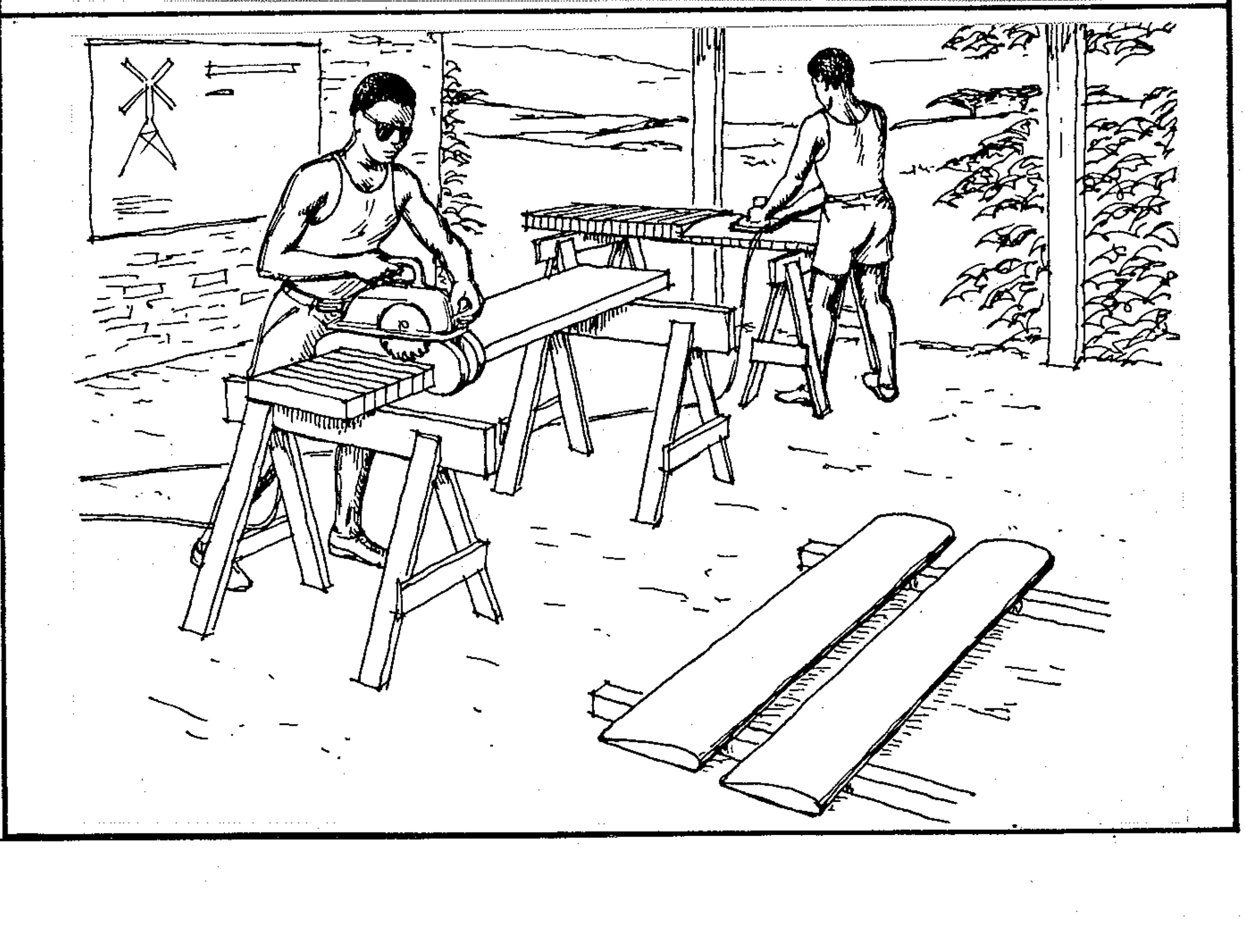
When the technology has proved its feasibility, local production, combined with education and information activities, can be initiated.

Step by step, this process could run as follows:

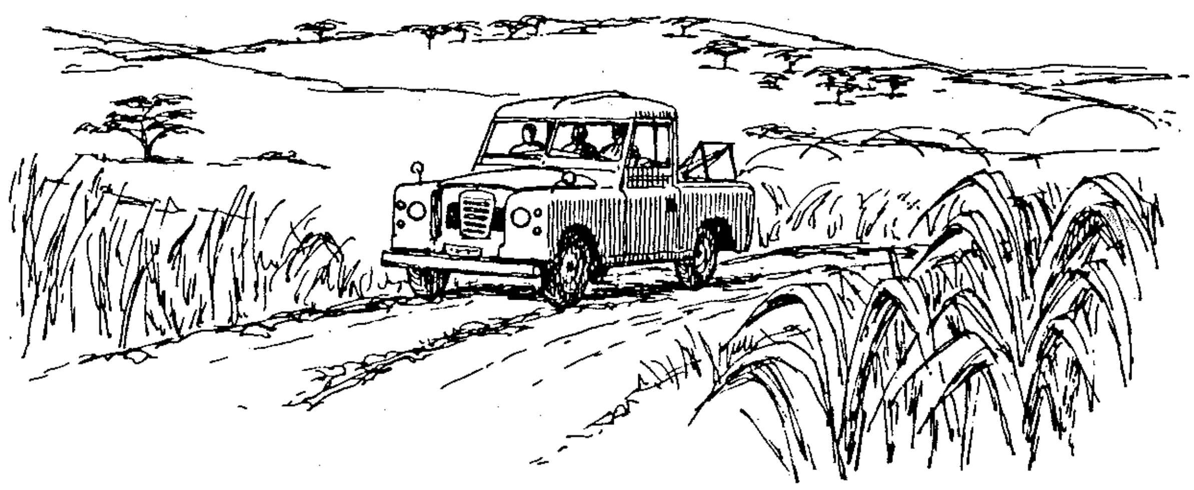
1. Preliminary investigations, e.g.:
   - Physical: wind resources, water resources, pumping levels, etc.
   - Technical: materials available, local skills, etc.
   - Social and economic considerations.
2. Import of windpump from Denmark.
3. Demonstration/information activities. Adaptation to local conditions etc.
4. An adapted version is built for training of workshop personel, optimising workshop layout etc.
5. The construction enters production.



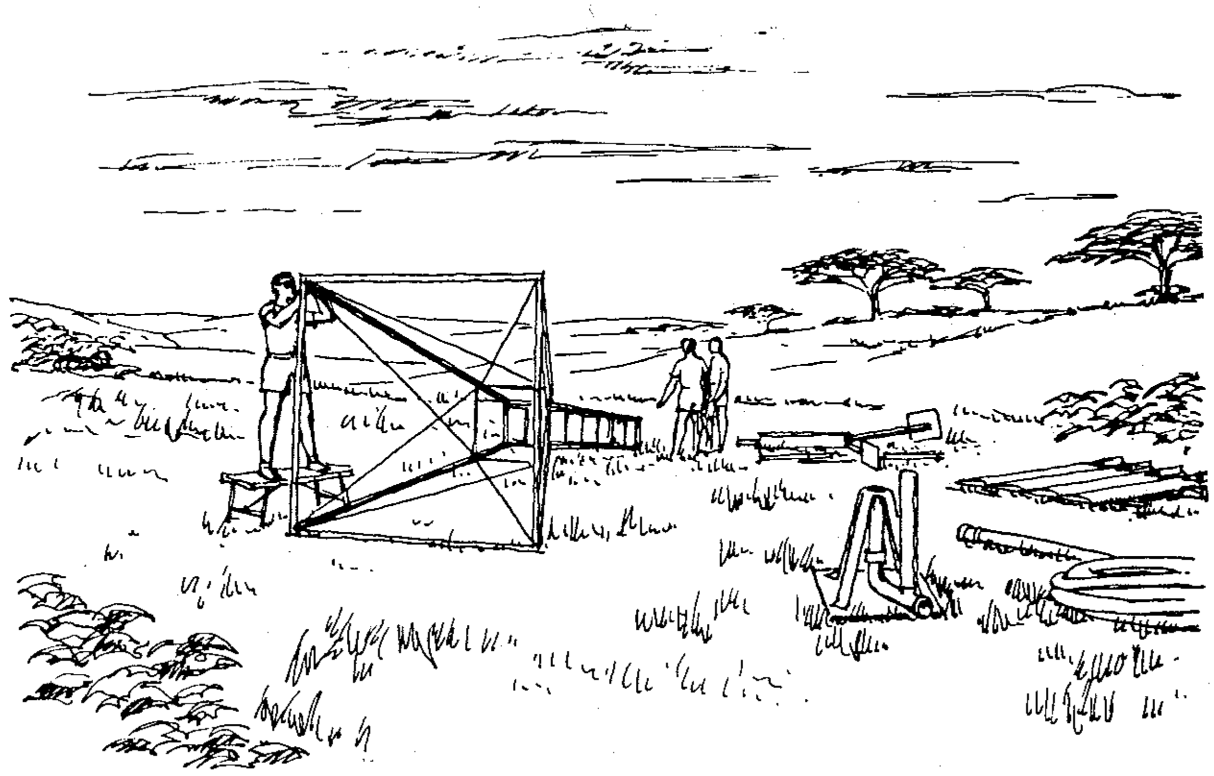
Welding, drilling, bolting etc. of nacelle and tower is done in the workshop.



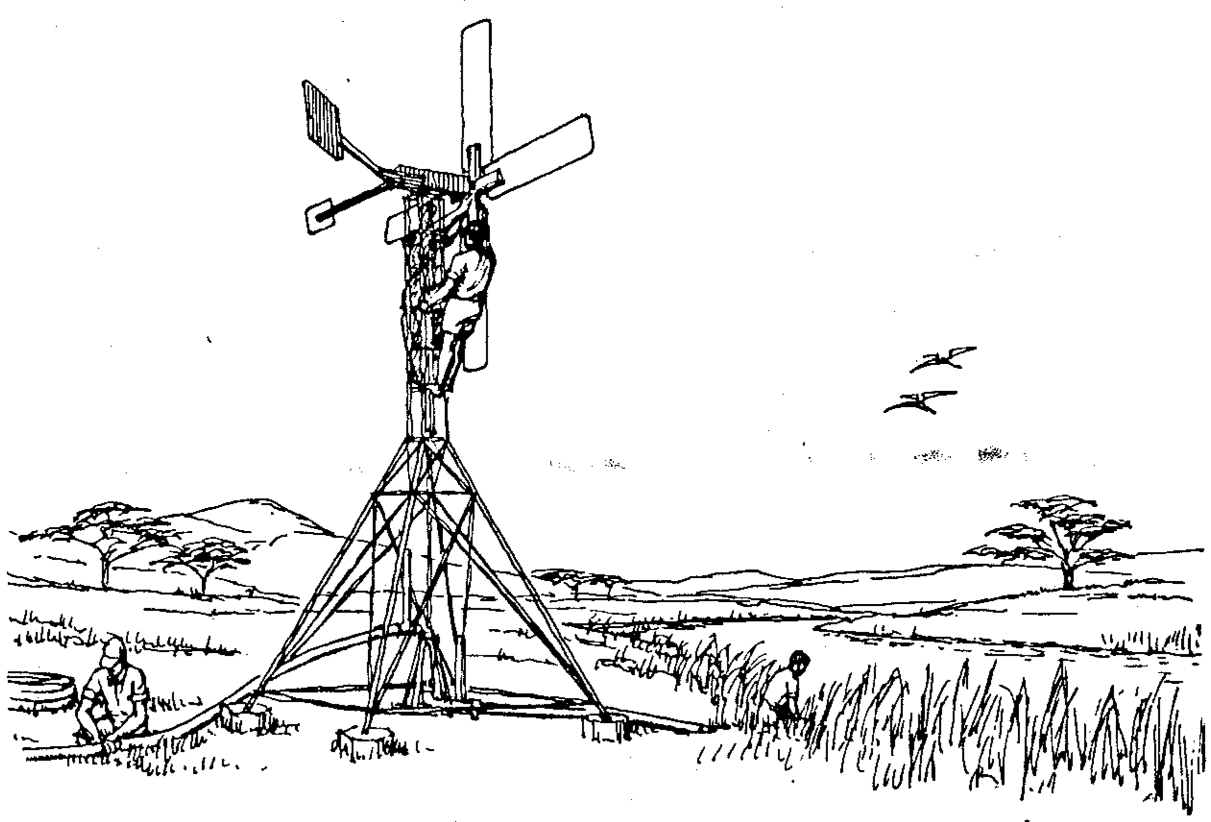
Rotorblades are manufactured from laminated wooden beams.



The windpump is transported in sections to the selected site.



The windpump is assembled with ordinary hand tools.



The windpump, erected by hand, is ready to pump water from the river.