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ACTIVITIES IN THE NETHERLANDS ON THE APPLICATION OF WIND ENERGY IN DEVELOPING COUNTRIES

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September 1980 R 445 D

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Steering Committee
Wind Energy
Developing Countries

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1. Introduction.

At present, two organizations in the Netherlands work in the field of wind energy for developing countries:

1) SWD (Steering Committee Wind Energy Developing Countries)
2) WOT (Working Group on Development Technology), member of TOOL foundation.

Although SWD and WOT are independent organizations, they work in close co-operation.

SWD-activities are presented in Chapter 2, those of WOT in Chapter 3.

Chapter 4 gives an indication of experience gained by SWD and WOT in the economic and agricultural aspects of irrigation by wind power.

Finally, in Chapter 5, additional remarks are made on availability of experts and on performance and reliability of waterpumping wind systems.

2. SWD.

2.1. General.

In July 1975 SWD was established by The Netherlands' Minister for Development Co-operation. SWD promotes the interest for wind energy in developing countries and aims at helping governments, institutions and private parties in the Third World in their efforts to utilize wind energy.

An agreement has been reached with The Netherlands' Government to continue the activities of SWD until 1985 at least. The parties currently co-operating within SWD are:

- Eindhoven University of Technology (Wind Energy Group)
- Twente University of Technology (Windmill Group)
- DHV Consulting Engineers.

About 20 persons (apart from students) are full-time involved in SWD-activities that cover:

- assistance to wind energy projects in developing countries
- wind energy research, mainly undertaken in The Netherlands
- transfer of knowledge on wind energy use.

At the moment the main emphasis within the programme is on applying wind energy for pumping water for irrigation, drainage, domestic purposes and cattle watering. A small part of SWD efforts is directed to small scale electricity generation. In the future the latter will be expanded; also it is planned to study other applications such as cooling, desalination, grinding, etc.

SWD aims at developing windmills that can be adapted to local conditions, available materials and skills, and that (for the greatest part) can be produced and maintained locally, at the same time leading to less foreign currency expenditure.
The above consideration has led SWD to restrict the rotor diameters of its designs to 10 m or less.

Although in the past some research activities have been devoted to vertical axis wind rotor systems, these activities have been temporarily stopped since the horizontal axis machines seem to show the best perspectives.

Experience in country projects in which SWD has been involved seems to indicate that, even in the restricted field of water pumping, a variety of prototypes is needed to cover the wide demand and range of applications: pumping heads varying from 1 - 100 m, average wind speeds from 2.5 up to 10 m/sec., daily amounts of water needed, water quality (salt, brackish to sweet), materials available. This is also apparent in the number of prototypes discussed under "research activities" (section 2.2): diameters from 2.7 to 8 m, rotors with blades using sails, curved plates and fiber reinforced polyester; tip speed ratios varying from 1 to 8; different pumps (piston, membrane, centrifugal); different transmissions (reciprocating, rotating and electrical).

Although a few of these prototypes will probably be abandoned or possibly blended into a new prototype, it is expected that other prototypes will spring up: e.g. wooden or other non-corrosive designs using Archimedes screws for salterns, and those using simple rotating displacement pumps.

The disversification sketched above, together with the idea of local production, implies that great attention must be paid to transfer of knowledge, treated in section 2.3. Building instructions of prototypes are - in themselves - insufficient. Adaptation of designs to local conditions demands a thorough understanding of the behaviour of the system as a whole as well as of its components.

The different aspects involved in the implementation of using wind energy become apparent in the execution of country projects discussed in section 2.4.

2.2 Research activities.

The research activities are undertaken with the following purposes:

- to develop windmill components as well as complete prototypes
- to support the country projects
- to train future experts for country projects.

Prototypes

As the price of a windmill is strongly related to its rotor size, the efficiency of all components (rotor, pump, transmission) influences the final cost of water pumped. Many of SWD's efforts are directed to designing simple, low-cost systems with high efficiency. A list of prototypes under development is given in Table 1. As examples, further details of some of the prototypes are given in Annex A.

Table 1:

Windmill prototypes

The following prototypes have been developed:

	diameter	number of blades	tip speed ratio	pump
THE-I/1	2.7 m	4	2.5	membrane
THE-I/2	2.74 m	6	2	piston or membrane
THT-I	4 m	16	2	piston
TNO-I	5 m	4	5	centrifugal
*WEU-I	3 m	8	2	piston
**Cretan	6 m	8	1	piston
***WEU-II/1	5 m	12	2	piston
WEU-II/2	5 m	8	2	piston
Under development are:				
THE-II	5 m	8	2	piston
THT-II	8 m	2	8	electrical centrifugal

* developed by WEU (Wind Energy Unit, Sri Lanka)

** developed by WOT with financial aid from SWD

*** developed by WOT and adapted by WEU

The most important and versatile system is the horizontal axis rotor driving a piston or membrane pump. By choosing a higher tip speed ratio ($\lambda = 2$) than has been traditionally favoured in the multiblade fanmill ($\lambda \approx 1$), an important reduction in weight (and price) is obtained, together with a slight increase in the power output efficiency of the rotor (C_p-values up to 0.4).

However, inherent to the choice of a higher tip speed ratio are the problems due to a lower starting torque and the dangerous increase of dynamic forces in the system. Also the mismatch of a wind rotor to a piston pump must be taken into account. By way of careful analysis - theoretical and experimental - and by using some simple devices to adapt the pump characteristic to that of the rotor, these problems can be partially solved. For example, the pump starting torque is reduced almost to nil by using an air-snifter on a membrane pump, and is reduced very substantially for a piston pump by having a controlled leakage between suction and pressure side of the piston.

The THE-II prototype is being specifically developed for the Cape Verdian Islands, where high windspeeds (6 to 10 m/sec.) allow some more expensive components to be used than would be economically justified in areas with lower windspeeds. Also the pumping heads (up to 80 m) make their own demands on the design.

The TNO-I prototype uses a rotating axis transmission to drive a centrifugal pump. Although the efficiency of a centrifugal pump is low compared to that of a piston pump, the prototype is well suited for application to moderate pumping heads (up to 10 m) and areas with average windspeeds from medium to high (> 4 m/sec.).

The THT-II prototype has an electrical transmission driving a centrifugal pump. The losses involved (generator, motor, pump) are very substantial. In situations such as exist on the Cape Verdian Islands, however, where average windspeeds are very favourable on the high plains, but wells are situated in the valleys with much lower windspeeds, the THT-II concept offers promising perspectives.

Components

Rotors.

A large number of rotors have been designed and tested, both at open air test stands and in a large windtunnel. Good results have been achieved with horizontal axis curved metal plate rotors, as predicted by theory. For low Reynolds numbers (< 100,000) curved plate profiles turn out to be better than the majority of more sophisticated airfoils.
(See, for example, Annexes A1 and A3)

Designing with higher tip speed ratios ($\lambda > 1$) results in lighter rotors and thus lighter and cheaper windmills.

Besides simple procedures to design optimal rotors, computer programmes have been developed to determine characteristics of rotors with different geometries.

Pumps.

As mentioned above, the optimum matching of a pump to the quadratic torque-speed characteristic of a wind rotor has been pursued by the development of variable torque pumps and by analysing the application of centrifugal pumps.
It is expected that in this way higher overall outputs will be obtained than with the traditional (constant torque) piston pumps.

Some of the most serious problems encountered in using piston pumps are due to delayed valve closure. Technically, the most simple valve design is obtained by using free moving valves without springs. This, however, can lead to delayed valve closure and generate dangerous peak forces in the transmission system. Valve behaviour is currently being analysed both experimentally and theoretically; the preliminary results of these studies are already providing essential data for valve design.

Safety systems.

A reliable safety system has been developed and tested for windspeeds up to 30 m/sec. The system operates by means of a small auxiliary vane that pushes the rotor out of the wind against the directional vane that is hinged on a leaning axis.

A simple model describing the steady behaviour of the system has been developed. A dynamical model is being studied.

Generators.

For deep wells, electrically driven pumps are considered as a serious alternative to direct mechanically driven pumps. Two types of generators are being tested to drive these pumps:

- a self excited induction generator
- a generator equipped with a permanent magnet rotor, using a stator and housing of an existing induction motor.

Also two control systems for alternators have been developed.

System analysis.

This comprises two main aspects:

- The analysis of the power output of wind driven waterpumping systems. Use has been made of the Weibull function to describe the windspeed distribution and this has shown to be a versatile tool in predicting power output and power availability. This course will be pursued further.
- As stated in section 2.1, SWD plans to study the application of wind energy for desalination, cooling, heating, etc.

Wind measurement

A very cheap electronic counter with an extremely low energy consumption has been developed for contact-anemometers.

A wind registration unit using a microprocessor is under development.

2.3 Transfer of knowledge.

Transfer of knowledge always is a two-way affair. On the one hand western technological knowledge is disseminated in Third World countries, on the other hand local knowledge of basic techniques and properties of local materials is transferred to Western "experts".

Knowledge in wind energy technology and related fields is transferred by SWD to developing countries by:

- publications (see Annex B)
- drawings and construction manuals of prototypes
- visits and consultancies
- education and training as a part of country projects
- courses.

Up to now a number of individuals have been trained by SWD in the design and construction of windmills. In 1977 SWD sent an expert for a six-month journey to lecture in a roving seminar on rural energy development, organized by the Economic and Social Commission for Asia and the Pacific (ESCAP), calling on the Fiji Islands, Thailand, the Phillipines, Iran and Indonesia. Also a member of SWD has given an introductory course on wind energy at the Asian Institute of Technology (AIT), Bangkok. It is planned that better and also more specialized courses will emanate from these activities; SWD intends to provide a handbook on waterpumping wind energy systems in the near future.

2.4 Country projects.

Sri Lanka.

In March 1977 the Wind Energy Utilization Project was started with financial support from the governments of Sri Lanka and The Netherlands. The execution is in the hands of the Wind Energy Unit (WEU) of the Water Resources Board of Sri Lanka. WEU is now staffed by 25 Sri Lankans (mechanical engineers, technicians, agricultural and irrigation engineers, etc.) and 2 SWD members as advisors to WEU (one mechanical engineer and one agricultural expert).

WEU designed one prototype (WEU-I) and adapted the design of the WOT (Ghazipur, India) prototype to become the WEU-II (see Table 1). The group acts as a national consultancy unit exploring and initiating the use of wind energy with special emphasis on small-scale irrigation. The WEU has workshops and test facilities. At present the WEU is involved in 10 pilot projects in which the feasibility of irrigation by windmills in Sri Lanka is being investigated.
A 100-windmill pilot programme will start in 1981.

Tunisia

A three-month feasibility study was carried out in 1978 by ASDEAR (Association pour le développement et l'animation rurale) and SWD. This study indicated that in the area of Hammamet where for a long time windmills had been used, the existing towers of out-of-service windmills could be recommissioned by producing new heads, transmission systems and pumps. Three prototypes (THT-I, see table 1) have been built by a local blacksmith, an ASDEAR and an SWD expert. A windmill workshop has been installed and extension of the project towards Central Tunisia is under consideration.

Republic of Cape Verde

In June 1976 a two-man-mission explored the application of wind energy on some of the islands. The present (Netherlands') Consultant to MDR (Ministry of rural development) a former SWD member, receives SWD's assistance on an informal basis.
Again, in the beginning of 1980, an SWD member paid a two-month visit to make a very detailed study on using wind energy for waterpumping on the Cape Verdian Islands. His report will be published in due course.
It is highly probable that SWD will be involved in future plans to exploit wind energy on the Cape Verdian Islands.

Tanzania

For the American missionary society of the Mary Knoll Fathers, the SWD has carried out a feasibility study on the use of wind energy along the shores of Lake Victoria in Tanzania. This study included a three-month field visit to the area at the end of 1977. A pilot project is in preparation.

The study indicates that climatic conditions are very favourable to utilize wind energy along the shores of Lake Victoria.

Pakistan.

Stimulating contacts with an entrepreneur in Karachi led to SWD's consultancy on deliberating series productions of windmills. As the first prototype, the WEU-I developed in Sri Lanka has been chosen and built. Late 1980 an SWD expert will pay a three-month visit for technical advising.

Peru.

Two agricultural projects, set up by the Netherlands' Ministry of Development Co-operation, and a university co-operation programme have shown interest in wind energy use. As a first result, a THE-I/2 prototype has been built. The possibility of a wind energy project here is being discussed at the moment.

Sahel.

A study was made (in French) on the possibilities of using wind energy for waterpumping in the Sahel. The study was based on data available in Europe.

Sudan.

In March 1980 an SWD expert carried out a prefeasibility study on wind energy use for waterpumping for domestic use. The conditions look very favourable. The report of this study will be published soon.

Maldives.

In July 1980 an SWD expert carried out a one-month pre-feasibility study on wind and solar energy use on the Maldives on the request of the Asian Development Bank.

Yemen.

In January 1980 an SWD expert made a one-month study on the possibilities of using wind energy for lifting water. This report will also be published soon.

3. WOT

3.1 General

The WOT is a non-profit, student volunteers organization with a small full-time staff at the Twente University of Technology which aims at assisting fieldworkers in developing countries by giving technical advice in the field of:

- wind energy for water pumping
- solar energy for heating
- water supply, in particular the construction of wells and hand pumps

WOT's broad objective is to improve the position of those groups which are economically or otherwise deprived of full opportunities for local, self-programmed and self-sustained development. WOT's strategy is to provide a link between appropriate technological knowledge, experience and basic needs in the rural and intermediate areas in the Third World.

Together with eight similar groups the WOT constitutes the TOOL-foundation (Technical Development Developing Countries). TOOL coordinates the distribution of the questions from development workers to the member groups.

3.2 Windmills developed by WOT

For water supply purposes, e.g. irrigation, the WOT has developed several prototype windmills. For multi purpose use one type is under development.

Table 2

type	rotor diameter	number of blades	tip speed ratio	pump
Cretan	6 m	8	1	piston
4PU250	2.5 m	4	4	piston
12PU350 1)	3.5 m	12	2	piston
12PU500 2)	5 m	12	2	piston
12PU700 1)	7 m	12	2	piston
4MP500 1)	5 m	4	4	multi purpose

1) Windmills under development

2) Adapted as WEU II (see table 1)

A construction manual of the Cretan windmill has been published in co-operation with SWD.
Drawings have been prepared of the 4PU250, the 12PU350 and the 12PU500.

3.3 Technical advisory function

Each year WOT receives about 50 questions related to energy from development workers and organizations. By means of correspondence, WOT tries to assist them with information on the use of wind energy. Some of these advices have resulted in the construction of Cretan windmills in Bangladesh, Bolivia and Sri Lanka. In Kenya, Sri Lanka and Indonesia windmills of the 12PU500 type have been erected, while some 4PU250 windmills have been constructed in Indonesia.

3.4 Windmill projects

Besides answering questions of development workers (by mail) the WOT organization is involved in three windmill projects in India, in which members of the WOT are working as windmill experts.

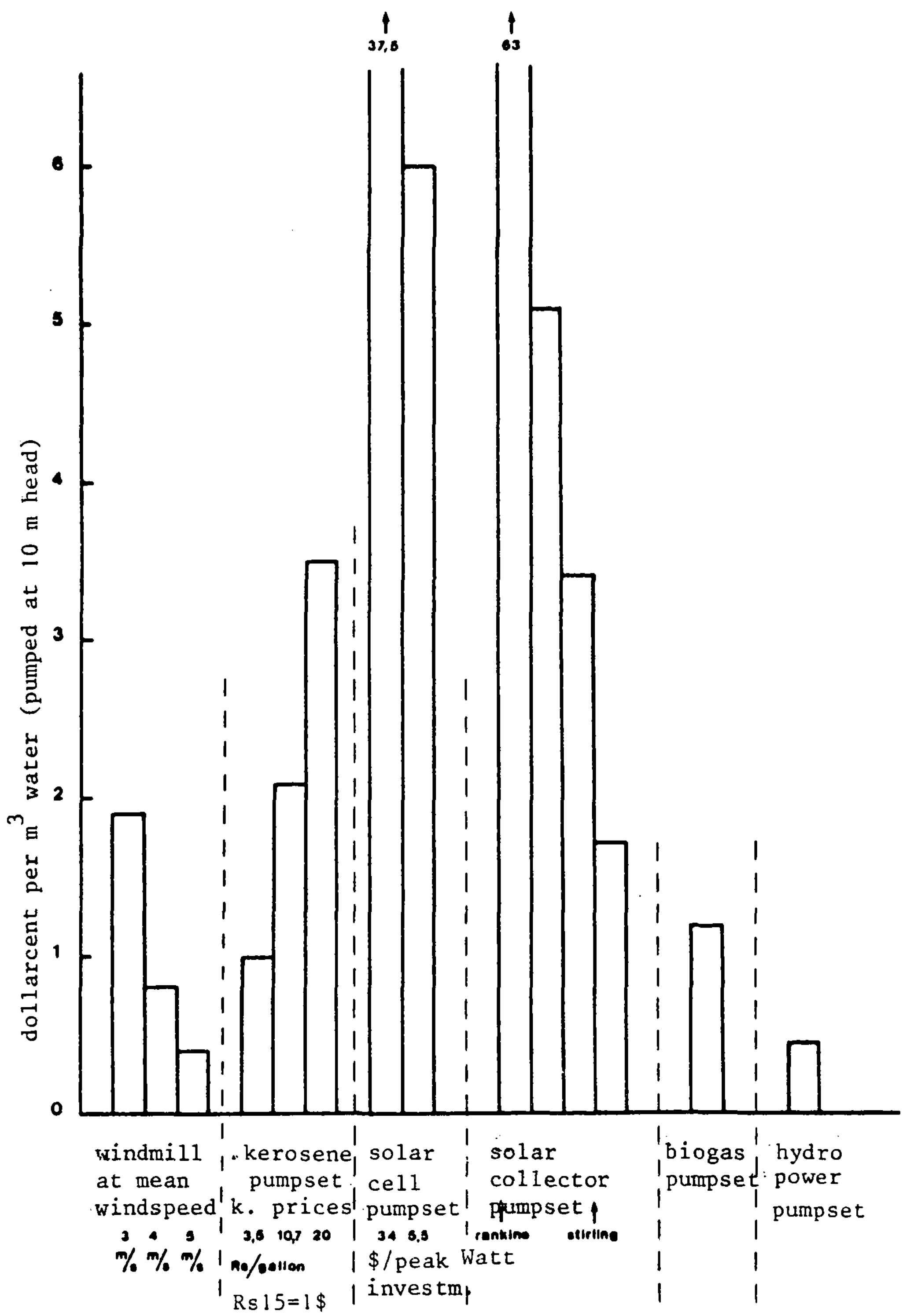
- In the Ghazipur district in Northern India WOT experts have been engaged with the Organization of the Rural POOR (OPR) in developing and introducing windmills in the region.
  At present (september 1980) 15 prototypes 12PU500 (see table 2) have been built in this pilot project and are operating successfully. Seven other windmills are operating as a spin-off of this project in different locations in India.
- At the Allahabad Polytechnic (Allahabad) (APA) a research and development program was started on windmill technology in 1979. This project is intended to support technically the other windmill projects in India. Within the research and development program, 6 windmills have been erected in the village development programmes of the Polytechnic.
- In January 1980, a windmill project was started in co-operation with the WORTH-trust in Southern India.
  At this moment 5 windmills of the 12PU500 type have been constructed. There are plans to extend the project with the construction of 12PU350 windmills.

4. Economic and agricultural aspects

SWD and WOT have gained important experience on the agro-economical side of exploiting wind energy, indicating that even in areas with low average windspeeds (like in India) wind energy can be utilized economically to pump water. Costs of producing windmills locally are far below (a factor 2 to 5) those of importing windmills. (For example: commercial 5 m diameter windmill designs for water pumping cost $ 5,000 to 10,000, while comparable SWD designs vary from $ 1,200 to $ 2,500). In some cases the reliability of the provision of fuel for diesel or kerosene pump sets is less than that of wind energy!

Detailed studies of the economics of using wind energy versus other means have been performed in India, Sri Lanka, Tanzania, Republic of Cape Verde and other countries (see section 2.4 and Annex B).
All these studies indicate that the application of water pumping by wind energy is in most cases economically favourable.
A cost-comparison of wind energy with other energy sources is given on the next page. Details of this comparison can be found in "Programme Proposal 1980-1985", January 1980, SWD (in Dutch).

Cost-comparison of wind energy with other energy sources



5. Other aspects

5.1 Availability of experts

The activities in The Netherlands on the application of wind energy in developing countries have created a potential of experts who can assist in executing wind energy programmes in developing countries. Expertise not only exists on the level of feasibility studies, but also on the technical level of designing and constructing wind energy systems for water pumping. Experience with agricultural aspects of irrigation by wind power is growing.

5.2 Performance and reliability of water pumping wind systems

Performance data of water pumping windmills (see Annex A) that are sufficiently accurate to assess the potentialities of the system in the field are becoming available.

Reliability is a very serious problem that demands time and care to be solved. However, experience up to now is very promising. E.g. safety systems already operating for more than 2.5 years in the field, have proved to be very reliable and have withstood storms with gusts up to 30 m/s without any trouble.

ANNEXES to R 445 D

ANNEX A: details of some prototypes

ANNEX A1: THE-I/2-"piston"

ANNEX A2: THE-I/2-"membrane"

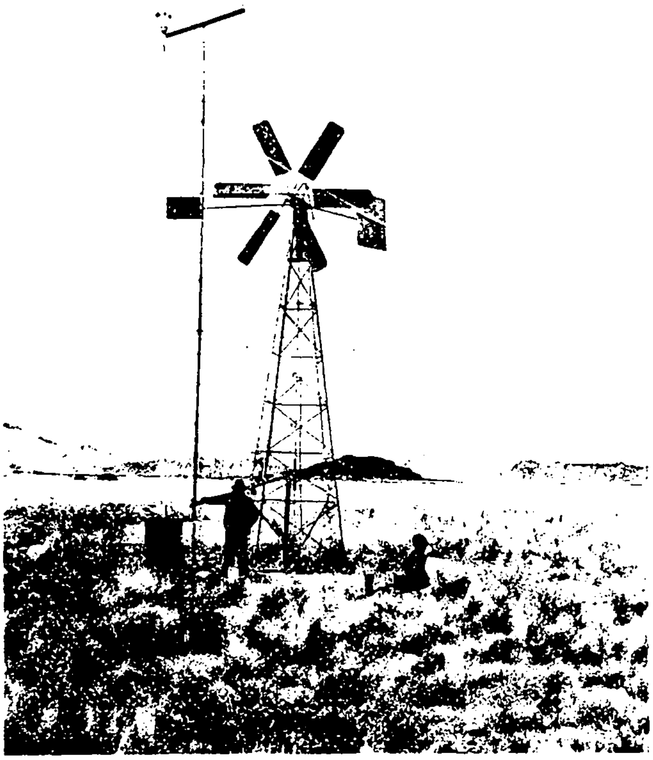
ANNEX A3: WEU-I

ANNEX A4: THE-II

ANNEX B: list of SWD and WOT publications

ANNEX C: leaflet on SWD activities (loose)

ANNEX A1: PROTOTYPE CHARACTERISTICS



THE-I/2-"piston"

WATERPUMPING Ø 2.74 m
PROTOTYPE DRIVING A
PISTON PUMP

(Info dated July 1980)

Developed by the
Wind Energy Group,
Dept. of Physics,
Eindhoven University of
Technology

Work done under auspices of the

Steering committee
Wind energy
Developing countries

(SWD)

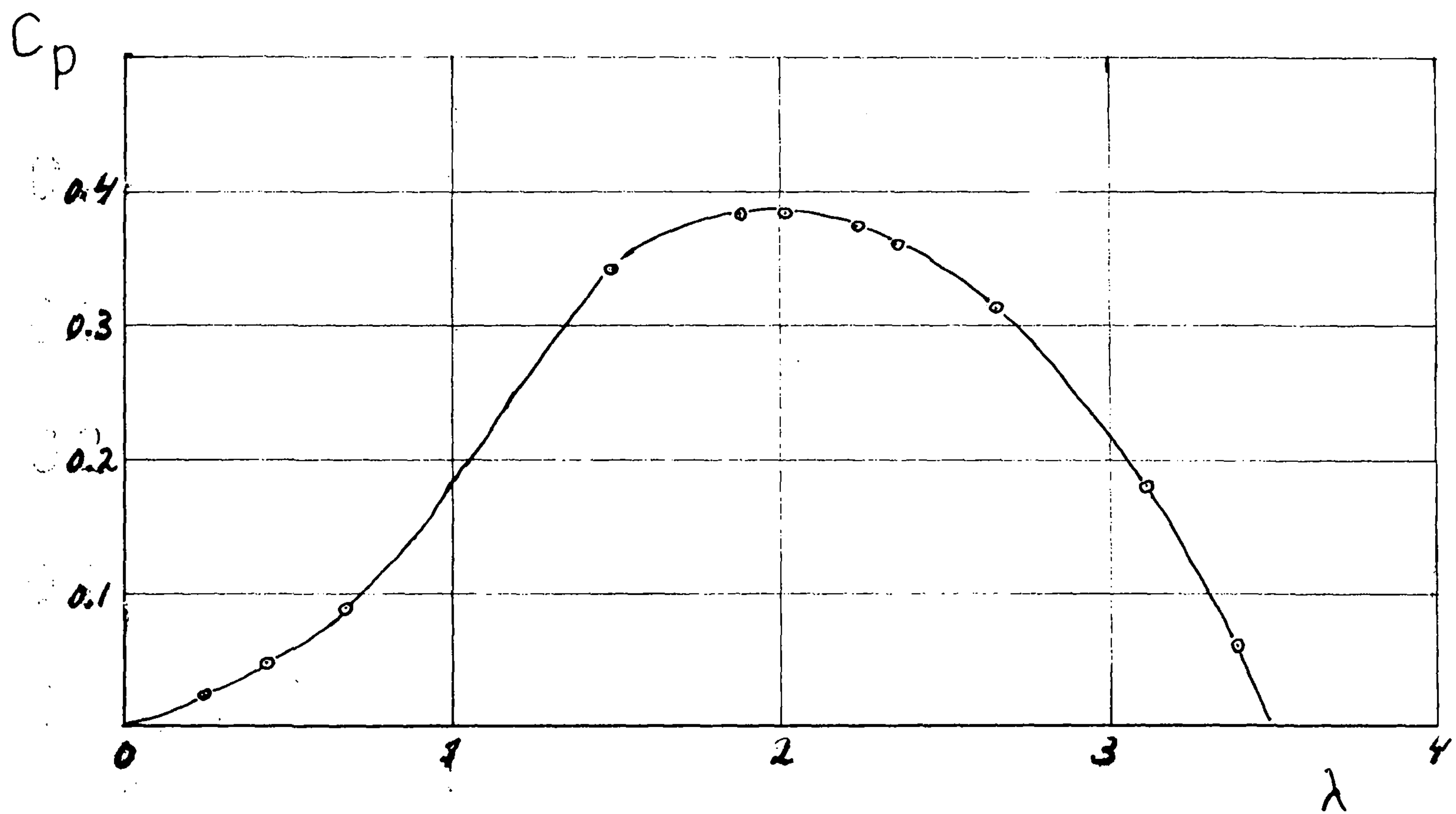
Application range	The THE-I/2-"piston" has been developed for conditions on the shores of Lake Victoria in Tanzania; the lifting head is 8 m at a mean wind speed of c. 4 m/s.
Completed prototypes	One has been built at the testfield of the Wind Energy Group in Eindhoven; another in Ayaviri, Peru, which is used as a drinkwater lifting device.
Expected future applications	- Pilot project in Tanzania, for lifting water for irrigation and domestic use (1981). - Pilot project on Cape Verdian Islands (after modification) (1981). - Pilot project in Pakistan, Karachi (end of 1980).
Status	- Rotor tested in windtunnel. - Tower, head and safety mechanism have been operating in the field for over 2.5 years - Total wind system has been operating on the test field for 3 months - Drawings available - Manual available (excl. manual of pump; this will become available September 1980)

TECHNICAL DATA OF THE-I/2-"piston"

Water yield at V_{design}	2.6 m^3/hr at 8 m head
Rotor diameter	2.74 m
Rotor solidity	0.336
Rotor construction	10% curved metal plates mounted on poles
Blade chord	0.32 m
Number of blades	6
$C_{p\ max}$	0.38 (measured in windtunnel)
Rotor starting torque	0.11 (measured in windtunnel)
Design tip speed ratio	2 (measured in windtunnel: 2.0)
V_{cut-in}	3.5 m/sec (estimated)
The starting wind speed	is diminished by means of an artificial leakage in piston
V_{design}	3.8 m/sec (calculated)
n_{design}	0.88 rps (calculated)
q_{design}	0.00073 m^3/sec (calculated)
	Note: the design speeds of the mill can be adjusted by varying the stroke
V_{rated}	7 m/sec (estimated)
n_{rated}	2.2 rps (estimated)
q_{rated}	0.00166 m^3/sec
n_{max} (loaded)	3 rps (estimated)
$V_{furling}$	12 m/sec (measured, rotor parallel to wind)
$V_{locking}$	20 m/sec (vane is locked automatically parallel to rotor plane)
Safety system	hinged tail vane with auxiliary vane
Transmission	crank/connecting rod/swing arm/pumprod
Stroke	adjustable between 0 and 60 mm
Design stroke	50 mm
Pump internal diameter	145 mm
Stroke volume (Q)	0.000825 m^3
Suction head	depends on dimensions of pipes and air chambers
Total head	max. 10 m
Tower height	5.5 m
Tower basis	1.5 m
Tower weight	155 kgs
Weight of rotor and head	91 kgs

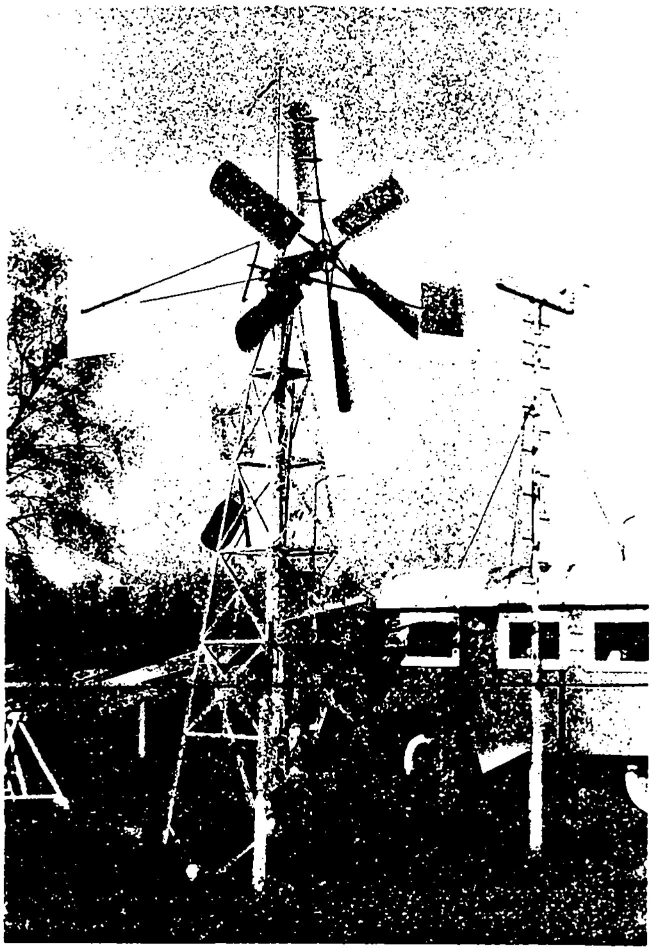
Overall power coefficient of the system at V_{design} 0.28 (estimated)

Note: test data will become available in August 1980 and will be reported at the Copenhagen Conference.



Performance of THE-I/2 model rotor in the windtunnel

ANNEX A2



THE-I/2-"membrane"

WATERPUMPING Ø 2.74 m
PROTOTYPE DRIVING A
MEMBRANE PUMP

(Info dated July 1980)

Developed by the
Wind Energy Group,
Dept. of Physics,
Eindhoven University of
Technology

Work done under auspices of the

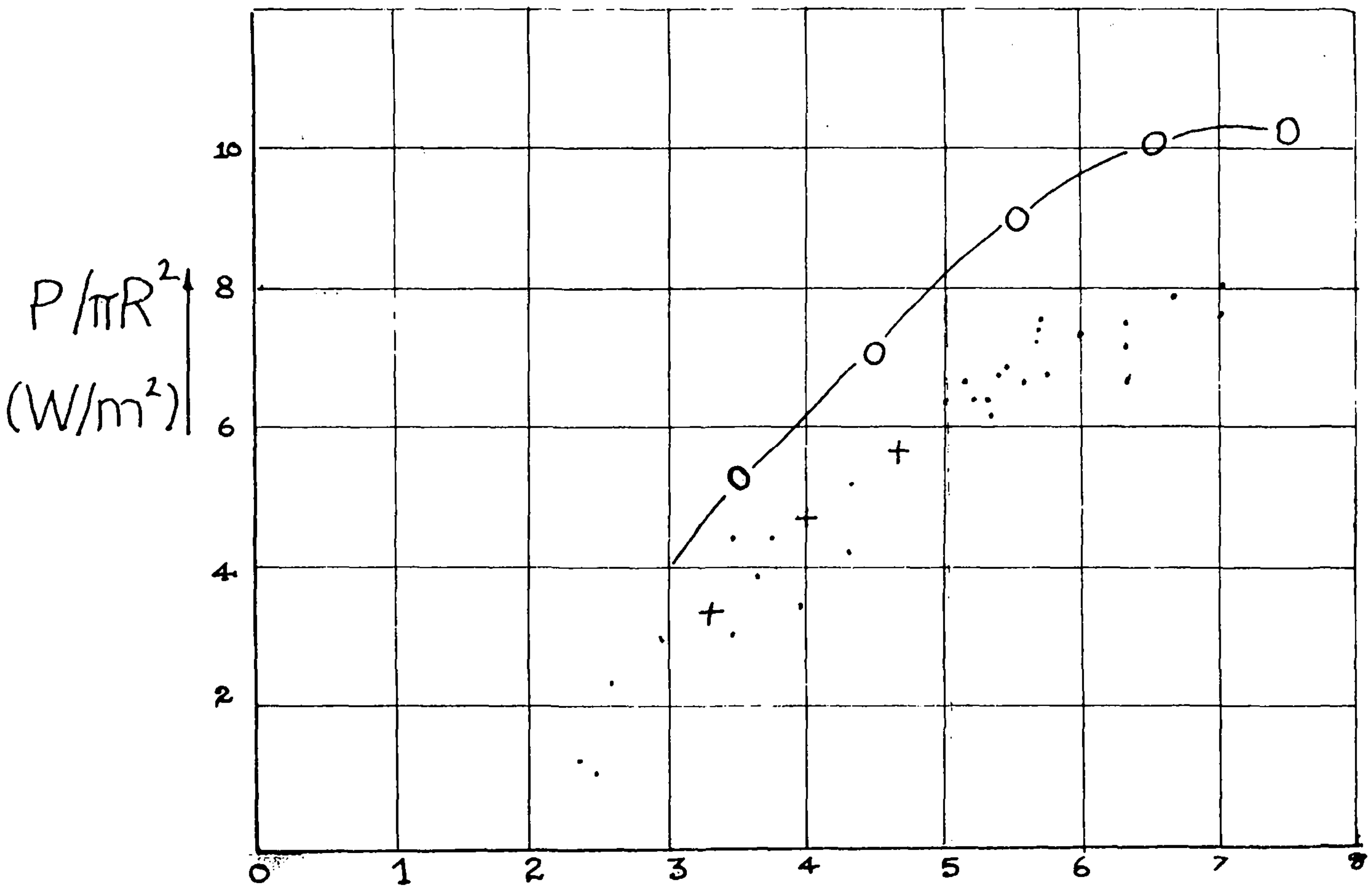
Steering committee
Wind energy
Developing countries

(SWD)

Application range	The THE-I/2-"membrane" has been developed to irrigate about 0.5 hectare in wind regimes with V_{mean} appr. 3 m/s from shallow wells. The system starts delivering water at a wind-speed of 2 m/s; the maximum lifting head is 8 m.
Completed prototypes	One prototype has been built at the test field of the Wind Energy Group in Eindhoven.
Expected future applications	Future application depends on the result of the evaluation (mid 1980) of the membrane pump for feasibility, reliability and efficiency.
Status	- Rotor tested in windtunnel - Pump tested in laboratory - Tower, head and safety mechanism have been operating in the field for over 2.5 years. - Total system tested in the field for six months - Drawings available - Manual available (excl. pump) - Performance data available

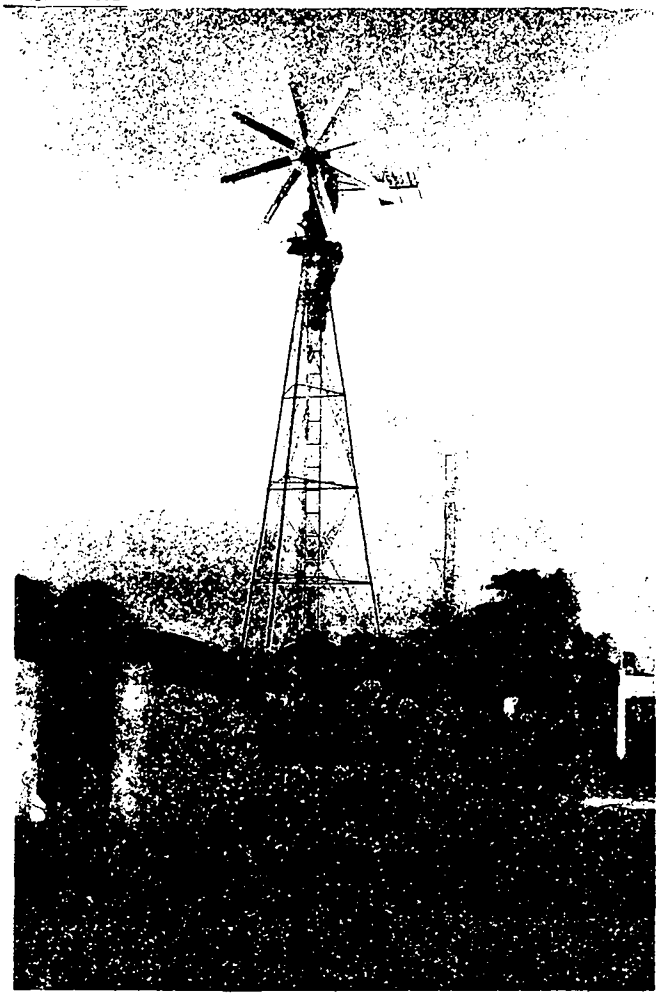
TECHNICAL DATA OF THE-I/2-"membrane"

Water yield at V_{design}	5.2 m^3/hr at a head of 4 m
Rotor diameter	2.74 m
Rotor solidity	0.336
Rotor construction	10% curved metal plates mounted on poles
Blade chord	0.32 m
Number of blades	6
$C_{p\ max}$	0.38 (measured in windtunnel)
Rotor starting torque	0.11 (measured in windtunnel)
Design tip speed ratio	2 (measured in windtunnel= 2.0)
V_{cut-in}	2 m/sec (measured in the field)
The starting wind speed	is diminished by means of an airsnifter on the pump)
V_{design}	3.84 m/sec
n_{design}	0.88 rps
q_{design}	0.0016 m^3/sec
	Note: the design speeds of the mill can be adjusted by varying the stroke
V_{rated}	7 m/sec
n_{rated}	2.2 rps
q_{rated}	0.002 m^3/sec
n_{max} (loaded)	3 rps
$V_{furling}$	12 m/sec; rotor parallel to wind
$V_{locking}$	20 m/sec (vane is locked automatically parallel to rotor plane)
Safety system	hinged tail vane with auxiliary vane
Transmission	crank/connecting rod/swing arm/pumprod
Stroke	adjustable between 0 and 60 mm
Design stroke	30 mm
Stroke volume (Q)at V_{design}	0.0016 m^3
Suction head	max. 4 m (tested)
Total head	max. 8 m (not tested)
Tower height	5.5 m
Tower basis	1.5 m
Tower weight	155 kgs
Weight of rotor and head	84 kgs
Overall efficiency at V_{design}	0.15 (measured in the field)



Field measurements of the effective power output (per m^2 swept rotor area) of the THE-I water pumping windmill.
The three field data indicated with "+" are long term measurements of several hours. The curve represents the theoretical output based on the measurements on the rotor in the windtunnel and on the laboratory tests with the membrane pump.

ANNEX A3



WEU-I

WATERPUMPING Ø 3 m
PROTOTYPE DRIVING A PISTON PUMP

(Info dated July 1980)

Developed by the
Wind Energy Unit,
Water Resources Board,
Sri Lanka

Work done with consultancy of

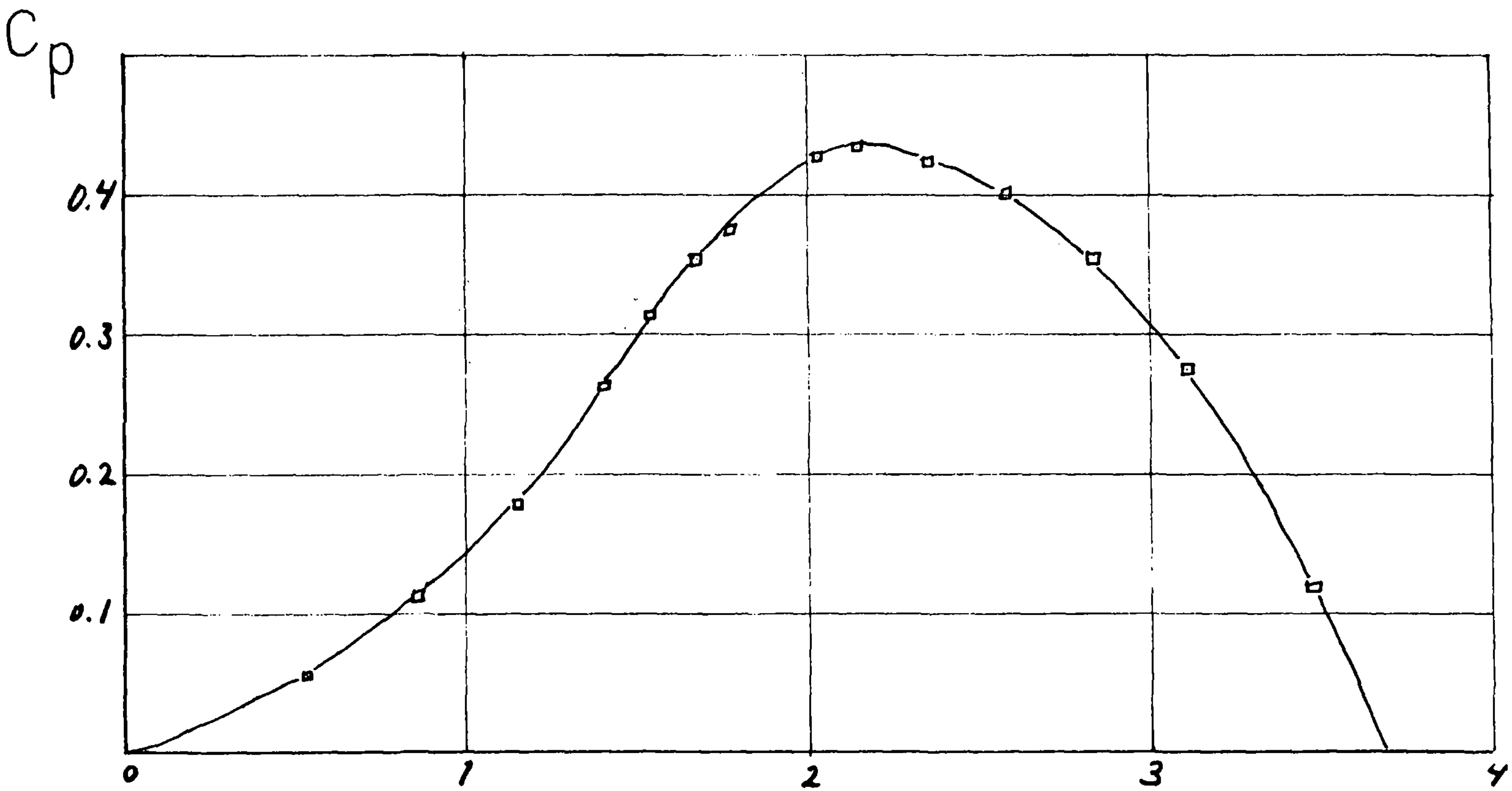
Steering committee
Wind energy
Developing countries

(SWD)

Application range	The WEU-I has been developed for conditions in Sri Lanka; it can lift water from heads up to 10 m.
Completed prototypes	- 5 in Sri Lanka, of which 4 are owned by private farmers. They use the mill for irrigation purposes. - 1 in Eindhoven.
Expected future applications	After redesign (by WEU and SWD together) in July-September 1980, the prototype will be used in a pilot project on Sri Lanka. This project aims at having 100 of these windmills in operation at the end of 1981.
Status	- Rotor tested by SWD in windtunnel. - Field experience since 1978. - New drawings will be ready October 1980.

TECHNICAL DATA OF WEU-I

Water yield at V_{design}	3.6 m^3/hr at a head of 8 m
Rotor diameter	3 m
Rotor solidity	0.30
Rotor construction	10% curved metal plates mounted on poles
Blade chord	0.216 m
Number of blades	8
$C_{p\ max}$	0.43 (measured in windtunnel)
Rotor starting torque	0.097
Design tip speed ratio	2 (measured in windtunnel 2.2)
V_{cut-in}	3.5 m/sec
V_{design}	3.8 m/sec
n_{design}	0.806 rps
q_{design}	0.001 m^3/sec
$V_{furling}$	12 m/sec
Safety system	hinged tail vane
Transmission	crank/rod with guides
Stroke	adjustable between 0 and 0.11 m
Design stroke	0.07 m
Pump diameter	0.15 m
Stroke volume	0.00124 m^3
Suction head	depends on dimensions of pipes and airchambers
Total head	max. 10 m
Tower height	9 m
Tower basis	1.8 m
Weight of rotor	40 kgs



Performance of WEU-I model rotor in the windtunnel

ANNEX A4

o

THE-II

WATERPUMPING Ø 5 m
PROTOTYPE DRIVING A
PISTON PUMP

(Info dated July 1980)

Developed by the
Wind Energy Group,
Dept. of Physics,
Eindhoven University of
Technology

Work done under auspices of the

Steering committee
Wind energy
Developing countries

(SWD)

Application range	The THE-II is being developed for the specific conditions on the Cape Verde: mean wind speed 7 m/sec and head (stator + dynamic) up to 80 m.
Completed prototypes	The second half of 1980 will see the simultaneous construction of two prototypes: one in Eindhoven, one on the Cape Verde.
Expected future applications	Production project of this type of windmill on Cape Verde (start 1981).
Status	- Geometrically similar rotor tested in windtunnel - Drawings completed

TECHNICAL DATA OF THE-II

Water yield at V_{design}	3,43 m^3/hr at 80 m head
Rotor diameter	5 m
Rotor solidity	0.39
Rotor construction	10% curved metal plates mounted on poles
Blade chord	0.48
Number of blades	8
$C_{p\ max}$	0.38 (measured in windtunnel with similar rotor) in further calculations C_p = 0.35 is used
Design tip speed ratio	2
V_{cut-in}	5 m/sec (estimated)
V_{design}	6 m/sec (calculated)
n_{design}	0.764 rps (calculated)
q_{design}	0.000952 m^3/sec (calculated)
V_{rated}	appr. 8.5 m/sec. (estimated)
n_{rated}	appr. 1.07 rps (estimated)
q_{rated}	appr. 0.0013 m^3/sec (estimated)
n_{max} (loaded)	1.6 rps
$V_{furling}$ (90^o)	10 m/sec
Safety systems	ecliptical with spring and stop, using eccentric placing of rotor shaft
Transmission	crank/connecting rod/swing arm/pumprod
Stroke	adjustable 0 - 120 mm
Design strokes	0.12 m
Pump internal diameter	0.115 m
Stroke volume (Q)	0.00125 m^3
Total head = pressure head	70 m (static!)
Tower height	6 m
Tower basis	1.76 m
Tower weight) Weight of rotor and head)	total 654 kgs excl. pump
Overall efficiency ($C_p \cdot \eta_{pump}$ at V_{design})	0.3 (estimated)

ANNEX B.1 SWD publicaties

Feasibility studies

SWD 76-1 "Wind Energy Utilization in Sri Lanka: potentialities and constraints", by A.D. Fernando and P.T. Smulders, January 1976.

SWD 76-4 "L'énergie éolienne au Cabo Verde, une étude préparatoire des besoins et des possibilité's de l'utilisation de l'energie éolienne", par J.C. van Doorn et L.M.M. Paulissen, Août 1976.

* "L'énergie éolienne dans le Sahel", par L.M.M. Paulissen en J.C. van Doorn, Mars 1977.

SWD 78-1 "Feasiblity study of windmills for water supply in Mara Region, Tanzania", by H.J.M. Beurskens, March 1978.

* "Feasibility study of windmills for water supply in the Yemen Arab Republic", by W.A.M. Jansen, March 1980.

* "Wind energy for the Tibetan SOS children's village Choglamsar, Ladakh, India", by E.H. Lysen and B. de Vries, June 1980.

* "Wind energy in Sudan: potential assessment, requirements for a wind energy centre, project proposal", by Yahia H. Hamid and W.A.M. Jansen, July 1980.

SWD 80-1 "The use of wind energy to exploit ground water resources in the Republic of Cabo Verde", by H.J.M. Beurskens, July 1980.

---- "Pre-feasibility study of a regional wind energy application centre for the Sahel in Cabo Verde", by H.J.M. Beurskens, (to be published).

* internal reports

R and D reports

SWD 76-2 "Literature survey; horizontal axis fast running wind turbines for developing countries", by W.A.M. Jansen, March 1976.

SWD 76-3 "Horizontal axis fast running wind turbines for developing countries" (analysis of theory and experiments), by W.A.M. Jansen, June 1976.

SWD 77-1 "Rotor design for horizontal axis windmills", by W.A.M. Jansen and P.T. Smulders, May 1977.

SWD 77-3 "Static and dynamic loads on the tower of a windmill", by E.C. Klaver, August 1977.

SWD 77-5 "performance characteristics of some sail and steel-bladed windrotors", by Th.A.H. Dekker, December 1977.

SWD 78-2 "Savonius rotors for water pumping (experiments and analysis of literature)", by E.H. Lysen, H.G. Bos and E.H. Cordes, June 1978.

SWD 78-3 "Matching of wind rotors to low power electrical generators", by H.J. Hengeveld, E.H. Lysen and L.M.M. Paulissen, December 1978.

"Low speed water pumping windmills: rotor tests and overall performance", by H. Beurskens, A. Hageman, G. Hospers, A. Kragten and E. Lysen, March 1980.
Proceedings of the 3rd International Symposium on Wind Energy Systems (BHRA), Copenhagen, 26-29 August 1980, p.501-520.

Scheduled:

- Introduction of wind energy for developing countries
- Guide for wind measurements
- Basics of wind energy
- Rotor design, part 2
- Pumps for windmills
- Coupling of centrifugal pumps to windrotors

Note: Detailed description of R and D activities of SWD have been reported in approx. 100 internal reports.

Manuals

SWD 77-4 "Construction manual for a Cretan Windmill", by N. van de Ven, October 1977.

---- "Building instructions of the THE-I/1 prototype", by A. Kragten, March 1980. Internal Report, Wind Energy Group, THE

---- "Building instructions of the 6-bladed THE-I/2 rotor", by A. Kragten, March 1980. Internal Report, Wind Energy Group, THE

Scheduled:

- Building instruction of the THE-I/2 pump
- Building instruction of the THE-II prototype

Economics

SWD 77-2 "Cost comparison of windmill and engine pumps", by L. Marchesini and S.F. Postma, December 1978.

* "Economics of windmills in Sri Lanka; four case studies", by B. Buch-Larsen, May 1979.

SWD 79-1 "Catalogue of wind machines", by L.E.R. van der Stelt and R. Wanders, September 1979.

* internal report

Scheduled:

- Agro-economic aspects of irrigation by windmills; experience obtained in the TOOL-ORP project in Ghazipur, India. By A. van Vilsteren
- Catalogue of anemometers
- Socio-economical study of the WEU-project (in co-operation with Erasmus University, Rotterdam).

Country projects

---- Case-study Sri Lanka windmill project (to be published).

The Sri Lanka windmill project (WEU) started in April 1977; it has been described in progress reports, reports of visits, evaluation reports, project proposals and in the weekly correspondence between WEU and SWD.
The experience gained in this project will be reported in a case study, to be published in the near future.

ANNEX B.2 WOT Publications

1. "Construction manual for a Cretan windmill"
   by N. van de Ven, October 1976 - SWD/WOT
   (available in English, Dutch, French)

2. "Design aspects of the WOT Cretan windmill"
   by N. van de Ven, October 1976 - WOT
   (internal report, only available in Dutch)

3. "Technical report on the ORP/TOOL-windmill project"
   by N. van de Ven, September 1979 - TOOL/WOT
   (internal report, available in English)

4. "Catalogue of wind machines"
   by L.E.R. van der Stelt & R. Wanders, September 1979 - SWD/WOT
   (available in English)