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Artikel: The pilot plant

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2. The pilot plant

2.1 Design data

Studies and preliminary calculations of this kind induced the German Federal Ministry for Research and Technology (BMFT) and its Project Management, Department for Energy Research, KFA Jülich, to provide the funds for the construction of a prototype. A site was selected in the arid region of La Mancha near Manzanares, 170 km south of Madrid, Spain.

The chimney is about 200 m high and has a diameter of 10 m. The solar collector roof is 250 m in diameter and approximately 2 m above the ground (see Figs. 8÷10). Its main data are given in Table 1. These are, of course, not optimum dimensions. As can be seen from Figs. 6 and 7, the facility is much too small overall to achieve a reasonable degree of efficiency but is nevertheless just large enough to provide realistic physical data. The relative dimensions of its various parts are also not optimal. For example, for the diameter of the collector, its roof should be located only approximately 50 cm above the ground in order to achieve the best air current velocity for heating the air underneath the roof. However, this would have led to an unrealistic roof design for later large-scale facilities.

The relationship between the tower dimensions and the radius of the collector was designed to ensure $\Delta T \geqslant 20°$, even for unfavourable climatic conditions. This relatively high ΔT has the advantage of greater accuracy for measuring purposes as well as for verifying the principle, though it also brings the disadvantage of a relatively low collector efficiency $\eta_c = 0.32$.

Chimney tube height	$H_T =$	194.6 m
Chimney tube radius	$R_T =$	5.08 m
Mean collector radius	$R_c =$	122.0 m
Average canopy roof height		1.85 m
No. of turbine blades		4
Blade radius		5.0 m
Operating modes		
a) stand-alone operation with variable speed (optimum utilization of upwind energy)		
b) grid connection mode		
Turbine speed in grid connection mode		100 rpm
Gear ratio		1 : 10
Design irradiation	$J =$	1000 W/m²
Design fresh-air temperature	$T_a =$	302 K
Temperature increase*	$\Delta T =$	20 K
Collector efficiency*	$\eta_c =$	0.32
Turbine efficiency	$\eta_T =$	0.83
Friction loss factor	$\eta_f =$	0.9
Upwind velocity under load conditions		9 m/s
Upwind velocity on release		15 m/s
Power output*	$N_{el} =$	50 kW

*mean for model assumptions at design point

Table 1: Data and design values of the pilot plant

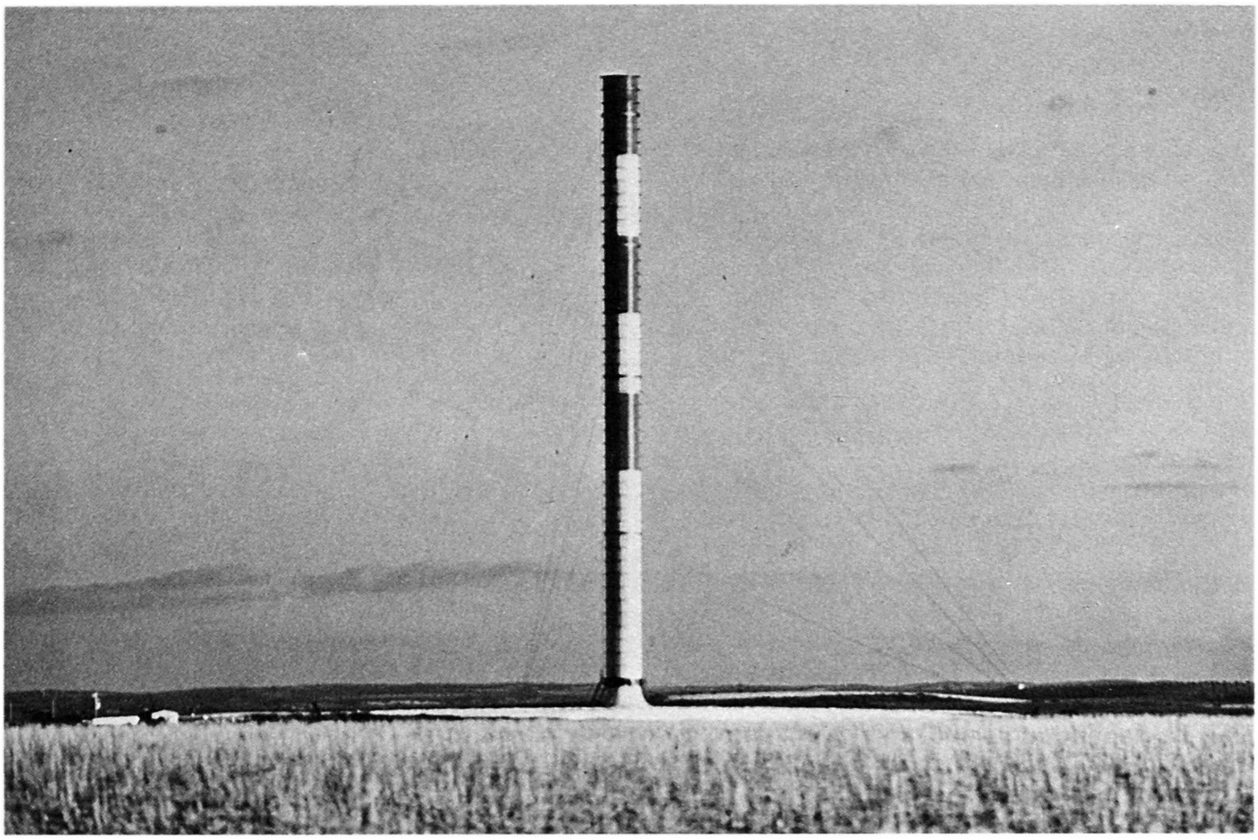

Fig. 8: The solar chimney pilot plant at Manzanares/Spain

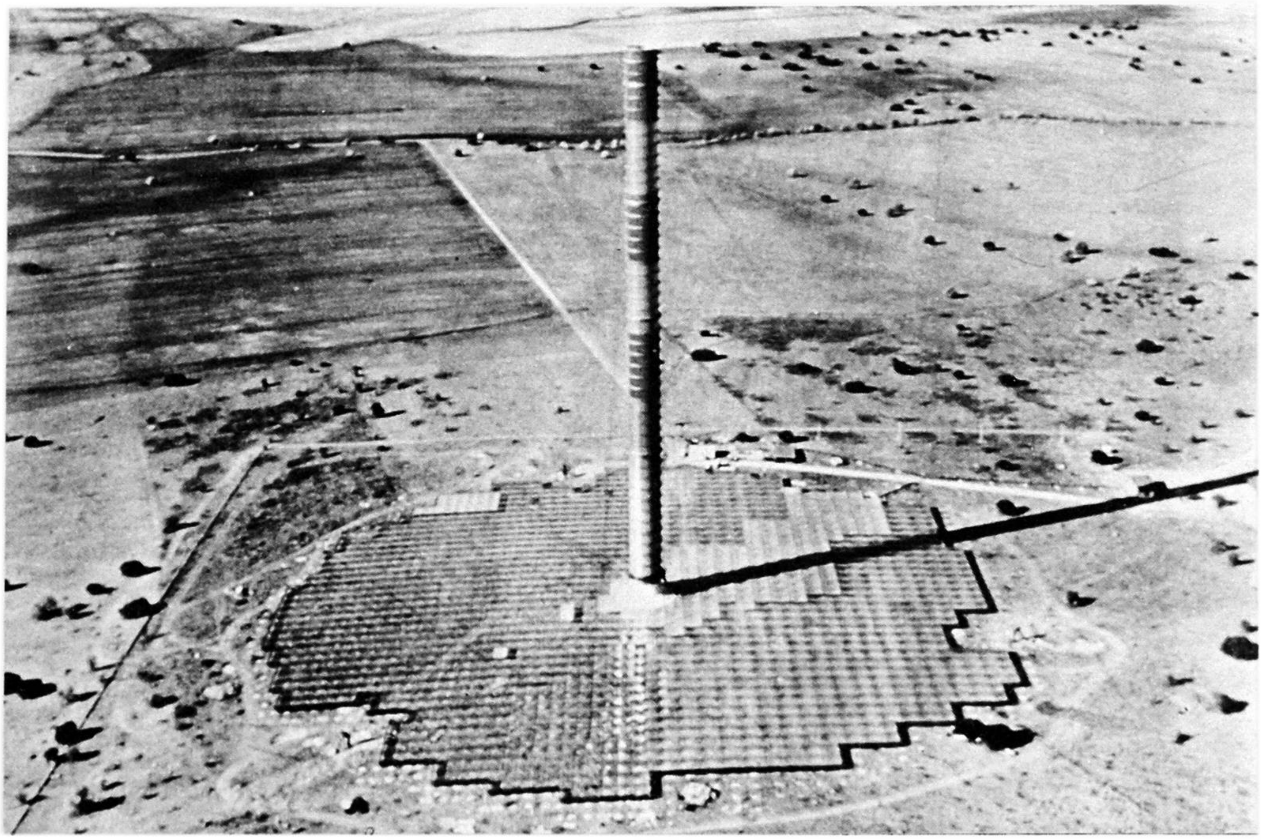

Fig. 9: Aerial view of the pilot plant

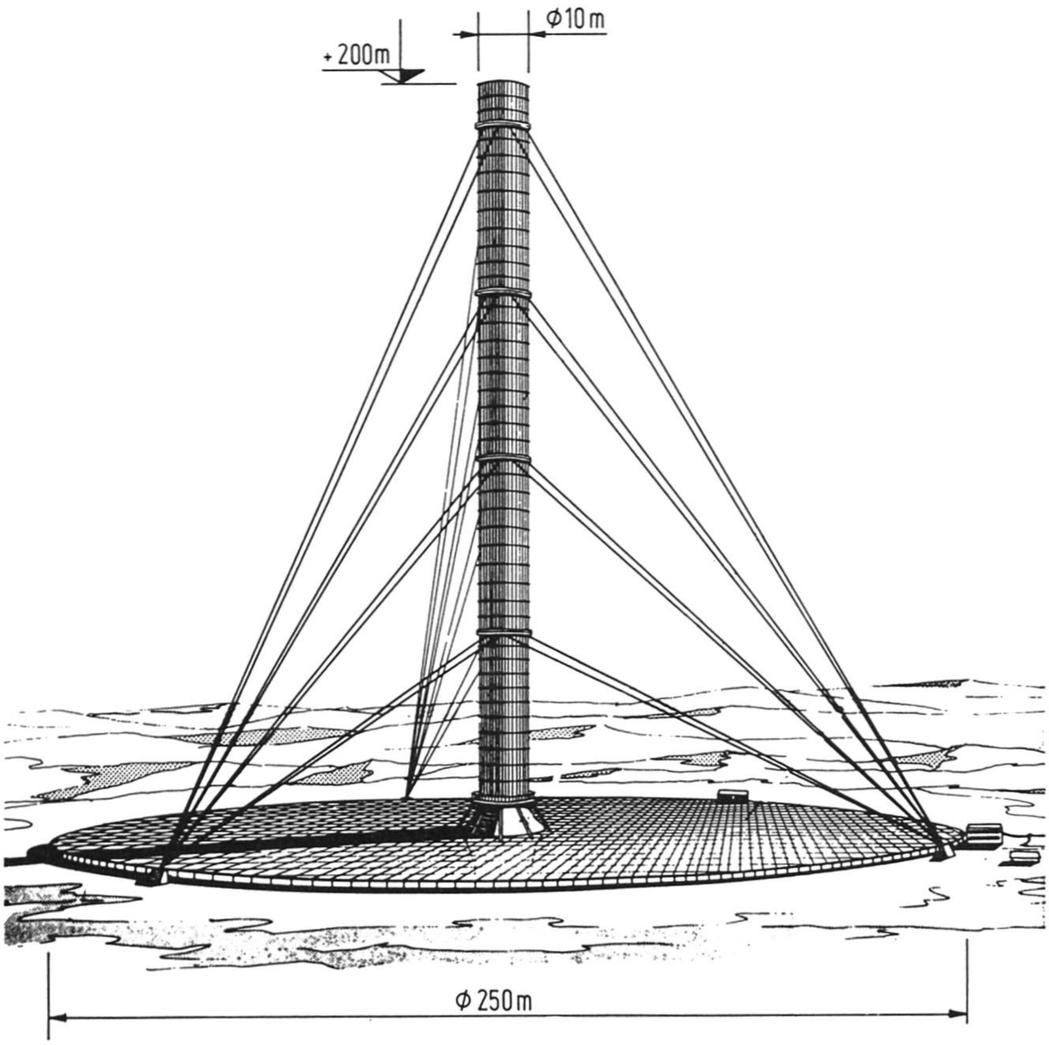

Fig. 10: Main dimensions of the pilot plant

2.2 The chimney

The huge tubes as needed for large solar chimney power plants may be concrete, cable net or membrane structures [4], [5]. The choice depends on individual and local requirements which, as regards the structure, may include soil and seismic conditions, and as regards physical conditions, may include geometrical parameters ($^{H}T/_{R}T$).

For the pilot plant a very slender tube with $^{H}T/_{R}T = {}^{200}/_{5}$ was to be built, in a remote arid area with no infrastructure. It has to be dismantled and the site completely cleared after a few years' measurements. Therefore, a lightweight structure was chosen, a stayed tube of corrugated sheet steel 1.25 mm thick with a valley depth of 155 mm. The sheets are overlapped and bolted vertically every 8 m and stiffened every 4 m by external ring-shaped truss beams (Figs. 11 and 12). The chimney is supported 8 m above the ground by a ring-shaped beam on 8 small-diameter tubes so that the warm air can flow into it with as little turbulence as possible.

A polymer-coated fabric cape forms a smooth transition between the collector roof and the chimney at its base (Figs. 13, 14, 20). The chimney is guyed vertically at four levels and in three different directions to foundation blocks along the periphery of the collector roof (Fig. 10).

The construction method used is worthy of note. The chimney cylinder was erected from the ground upward, by means of an incremental lifting procedure specially developed for the purpose, using a lifting ring and hydraulic jacks, the cylinder growing from below by 8 m per lift, the stays being slackened simultaneously. This permitted complete prefabrication on the ground and erection with a minimum number of skilled labourers (Figs. 14+15). Construction of the foundations started in November 1980 and the chimney was completed in September 1981.

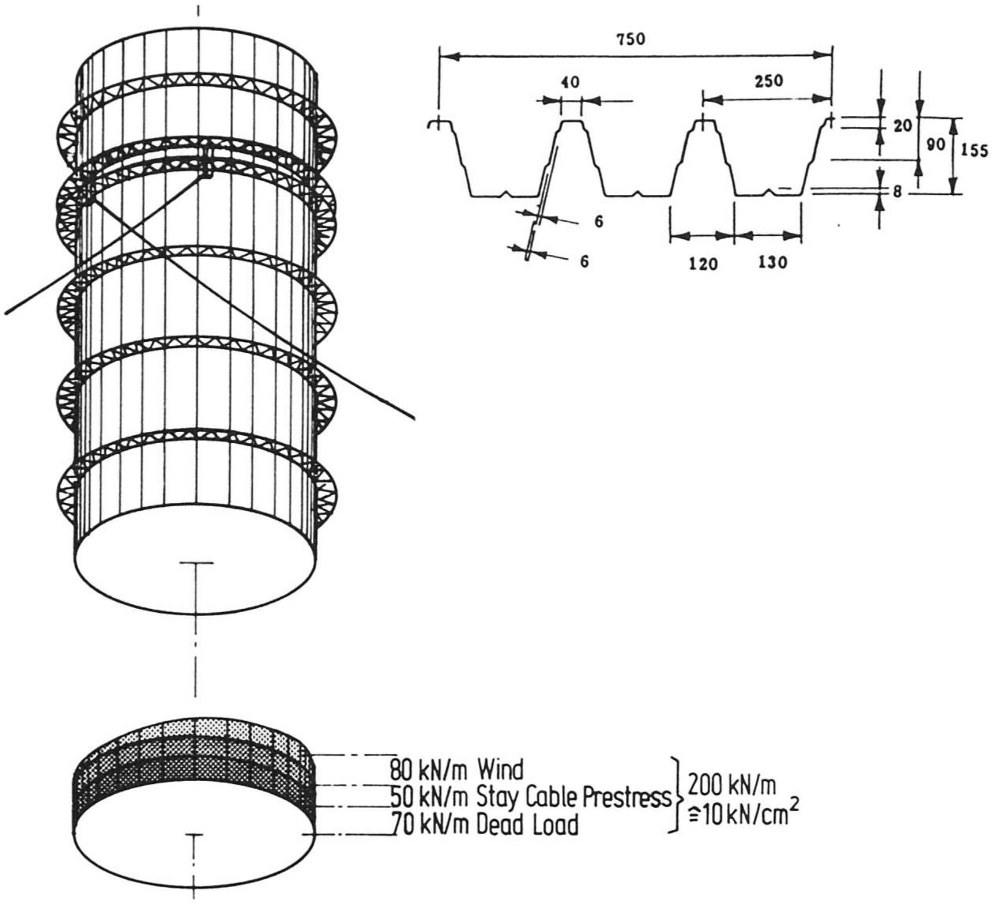

Fig. 11: The chimney tube: dimensions of the corrugated sheet and axial forces

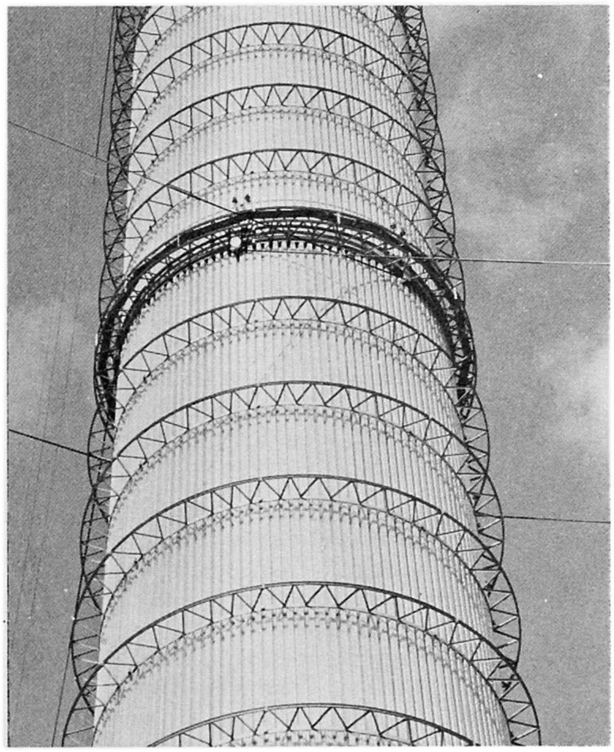

Fig. 12: The corrugated sheet tube and its external stiffeners

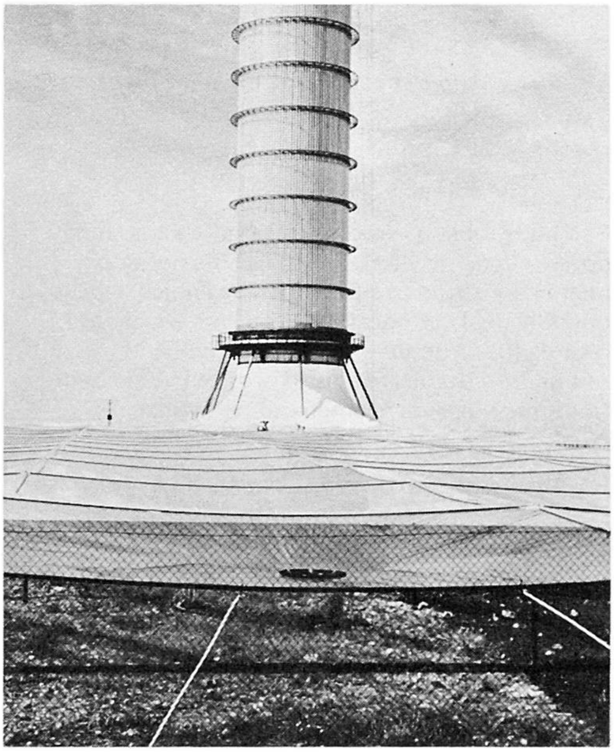

Fig. 13: The fabric cape forming a smooth transition between the roof and the tube (see also Fig. 21)

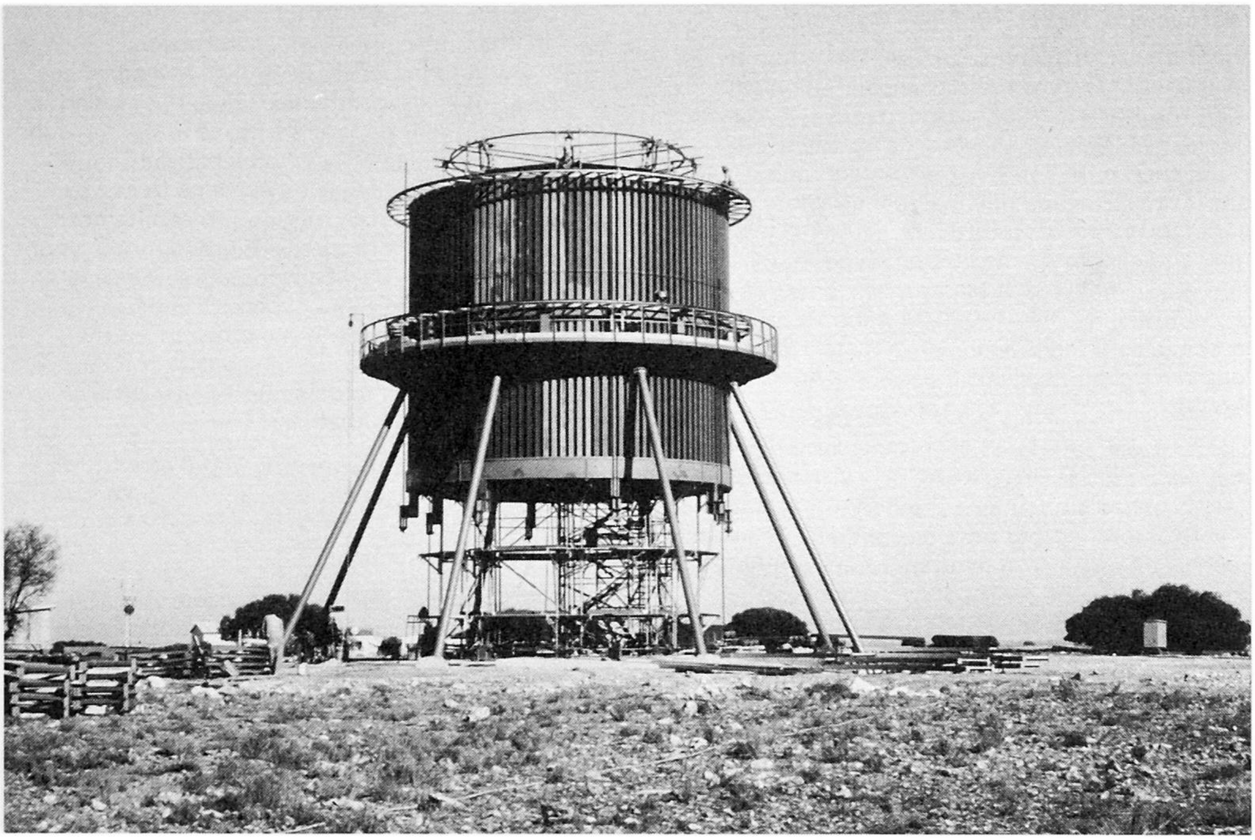

Fig. 14: The erection of the chimney by incremental lifting

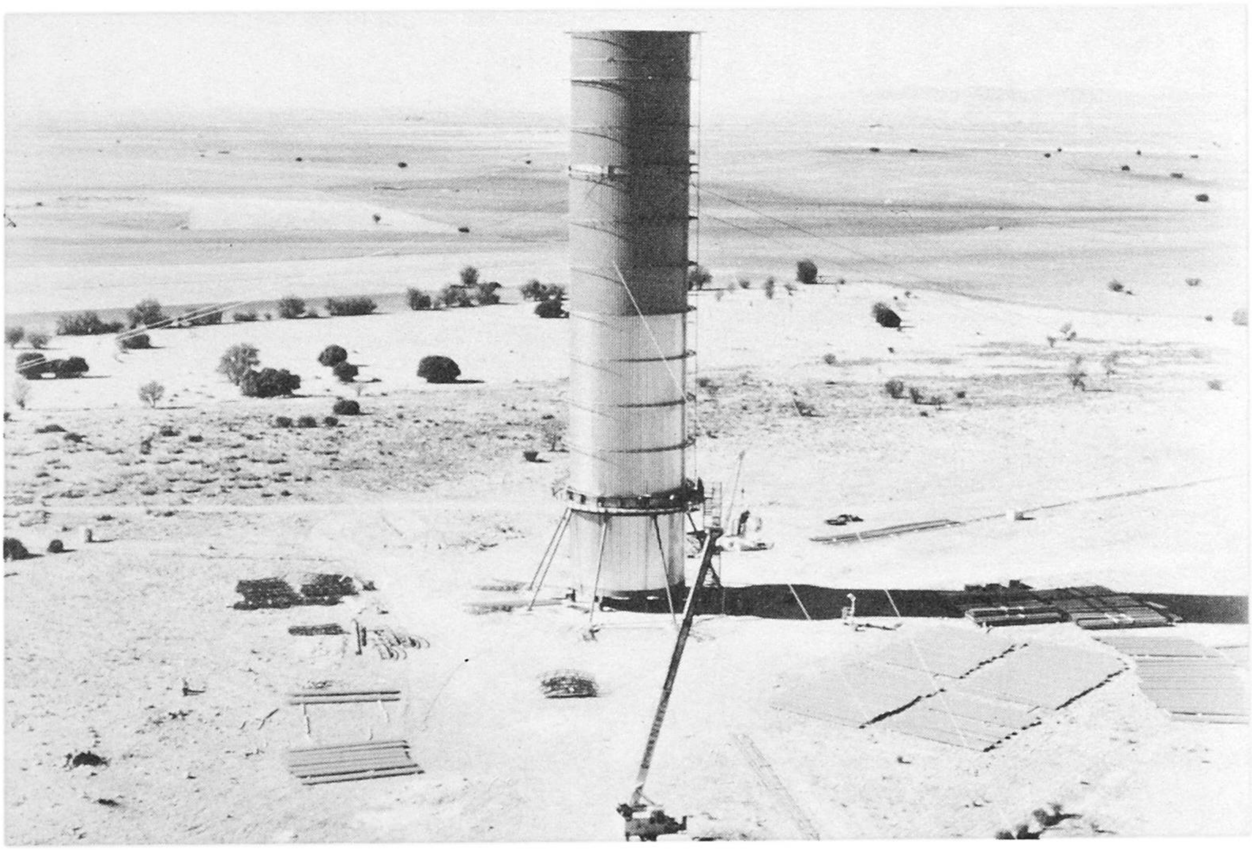

Fig. 15: The erection of the chimney by incremental lifting

2.3 The collector roof and the turbine

From the technical point of view the future of solar chimneys depends in particular upon whether it is possible to develop an inexpensive, long-lasting, thermally efficient collector roof. For the pilot plant, therefore, possibly the cheapest and – with respect to structural detail, dynamic safety and durability – the most difficult material, i.e. plastic film, was chosen. Four different types of plastic film were employed at Manzanares for purposes of comparison. They have 94% transmission in visible light range and approximately 14% in the long wavelength range of thermal radiation (see Fig. 3).

The roof was composed of rectangular, originally flat, panels measuring 6 X 6 m or 4 X 6 m which were clamped along their peripheries in metal frames and supported on tube columns. The panels were stabilized against wind by means of plastic discs placed in the centre of each panel and anchored in the ground. The discs doubled as drainage points for the roof (Figs. 16÷18).

The entire film canopy was erected by an unskilled workforce trained on site. This possibility of employing local labour is of particular importance for the introduction of solar technology in Third World countries.

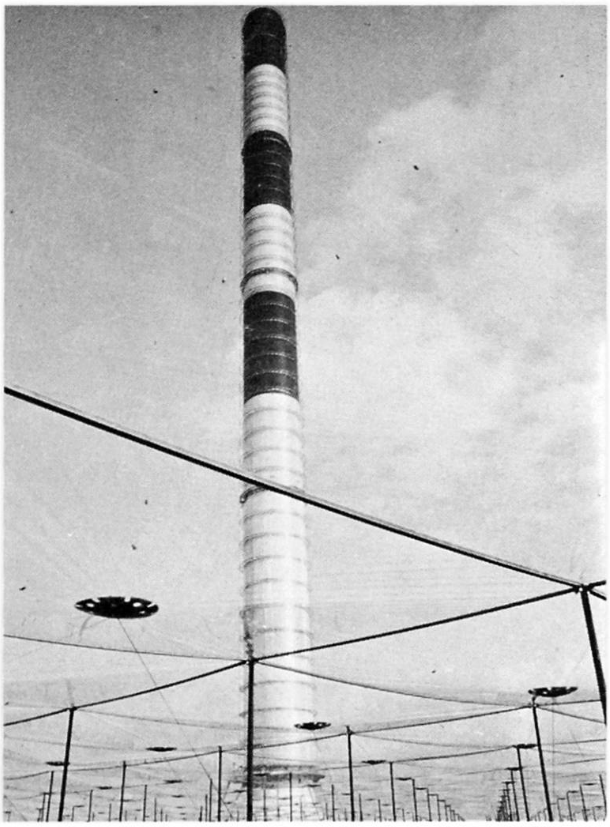

Fig. 16: The translucent collector roof at Manzanares seen from underneath. The earth is not yet blackened

Between the time of the trial construction of the roof in 1981, its completion at the beginning of 1982 and today, there have been several extremely violent storms with wind velocities as high as 160 km/h, causing severe damage in the surrounding area. The design proved to be basically sound. In places where trailing eddy currents from the chimney produced high suction forces a number of panels were torn to shreds. Fibre-reinforced polymers are therefore now being used for the panels. These are, however, more expensive and less translucent. It is crucial to the project that the right material be found for the panels. For this reason glass is also being tested now; it is more expensive but durable.

After the first measurements were taken with the natural earth surface as it was, it was blackened with bitumen to increase its thermal absorption capacity (Figs. 17+19).

Another problem of the collector roof is that it may lose its translucence because of dust. There is no doubt that collector roofs in desert regions would have to be cleaned from time to time. Washing and vacuuming devices have been considered for this purpose. The structural details selected for Manzanares have the advantage that the funnel-shaped polymer panels are automatically cleaned when it rains. As a result, the roof in Manzanares remained completely clean in spite of severe dust storms. Furthermore, investigations have shown that a certain amount of dust on the panels is not detrimental. It does reduce light transmission but reduces the heat losses even more.

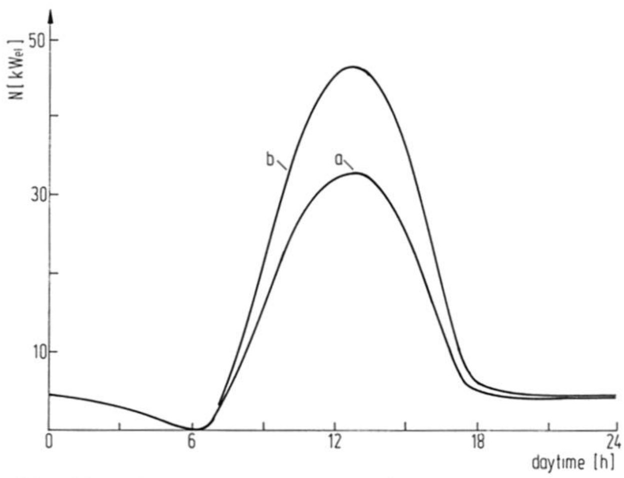

Fig. 19: Electricity output of the pilot plant at Manzanares for varying soil thermal absorption capacity
a) light natural earth
b) blackened earth

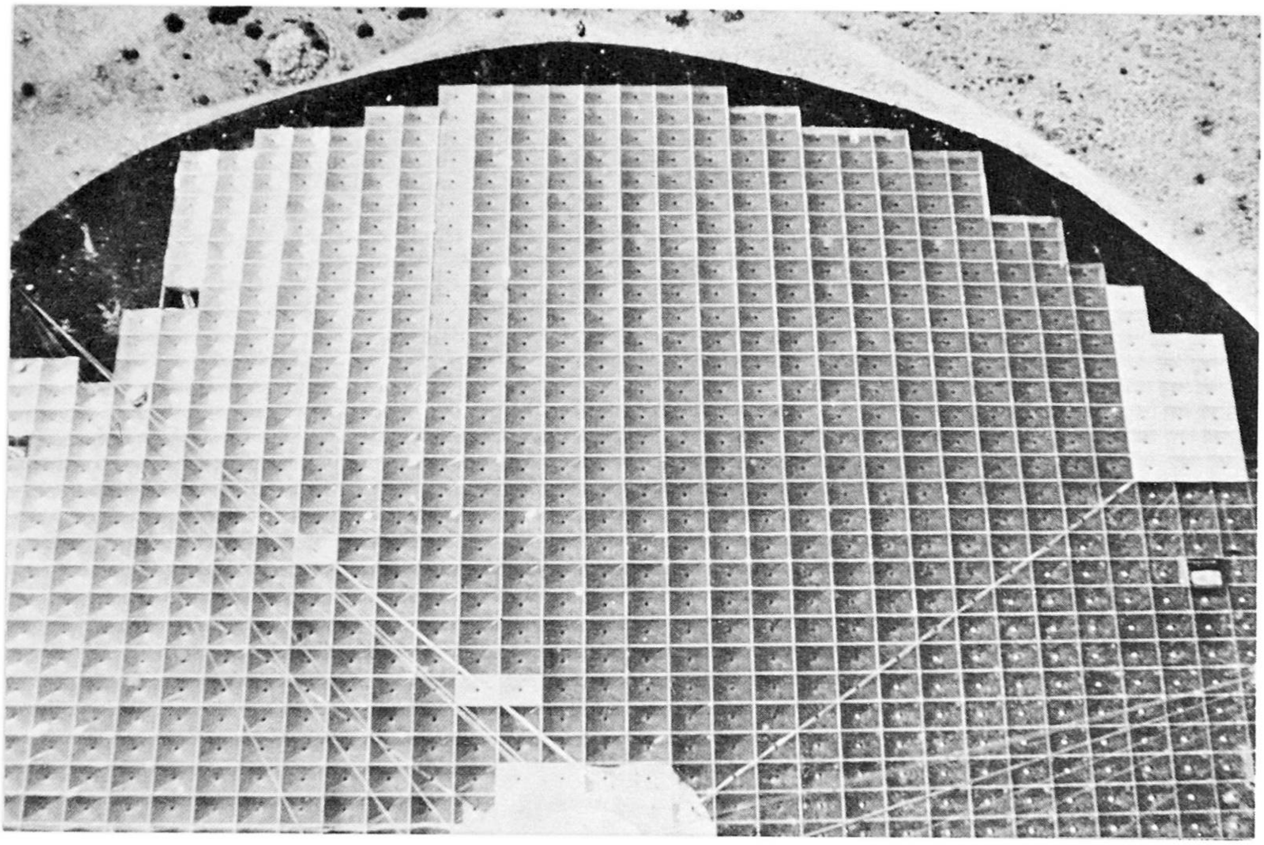

Fig. 17: The translucent collector roof seen from the chimney with the blackened earth visible at the perimeter

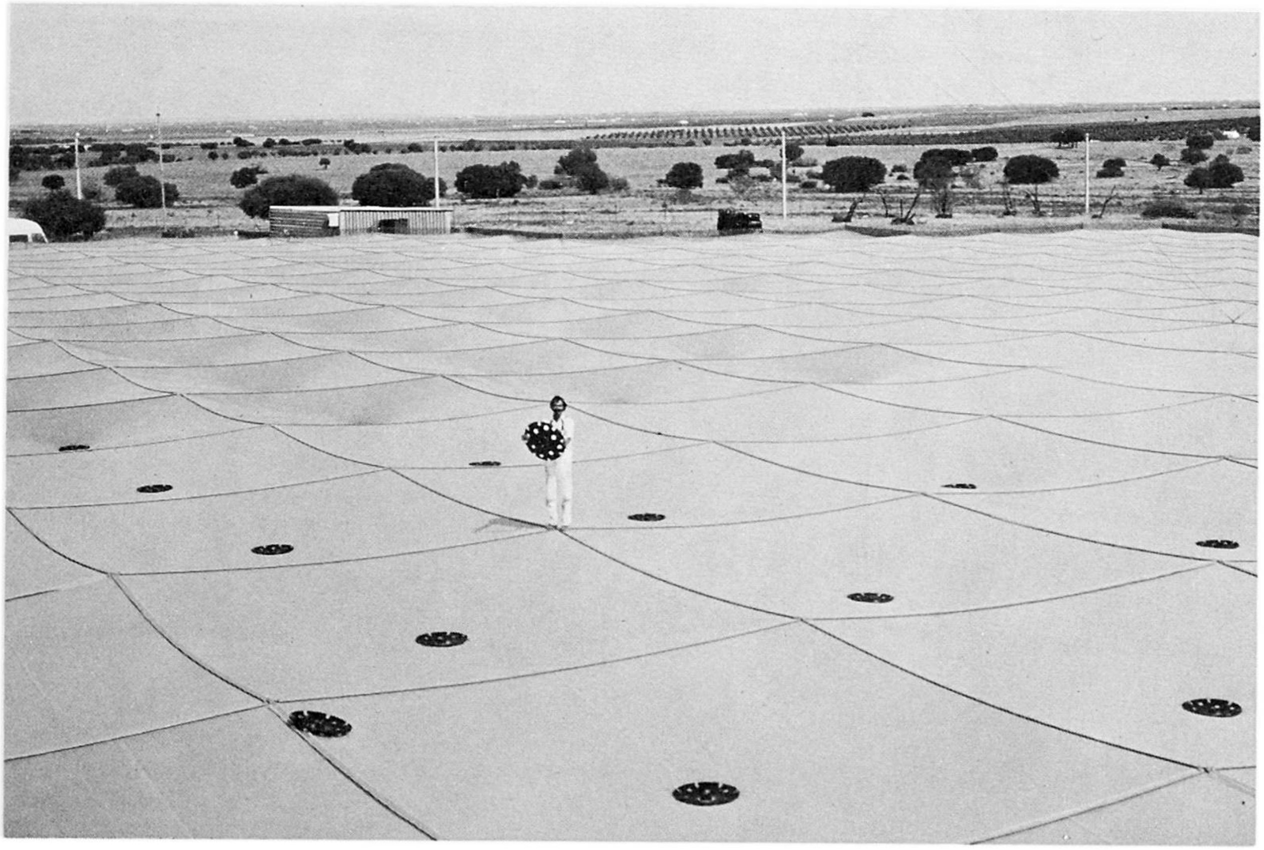

Fig. 18: The 6 m/6 m panels of the collector roof

2.4 The wind turbine

The wind turbine is located at the base of chimney, just above the transition from the cape to the tube; it is supported independently of the chimney on a steel-frame platform 9 m above the ground (see Figs. 20÷22). It has four types FXW-151-A blades whose angles can be adjusted during operation in order to maintain a constant speed or to attain the optimum.one. It can be run at a maximum of 170 rpm and can be switched from a 100 kW A.C. generator to a 40 kW one for maximum night-time electricity generation. The electricity generated is fed directly into the grid. The turbine requires a vertical start-up wind velocity of 3 m/s and can handle velocities of up 20 m/s. The air flow can be controlled and shut off by regulating inlet valves, which are nothing more than doors located at the transition between the collector roof and the chimney. The facility can be operated either manually or fully automatically. Automatic operation includes start-up, accommodation to grid requirements and the setting of the blade angles for optimum operation.

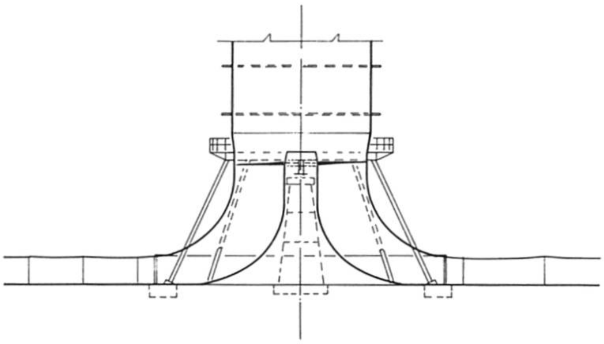

Fig. 20: Section through the base of the chimney

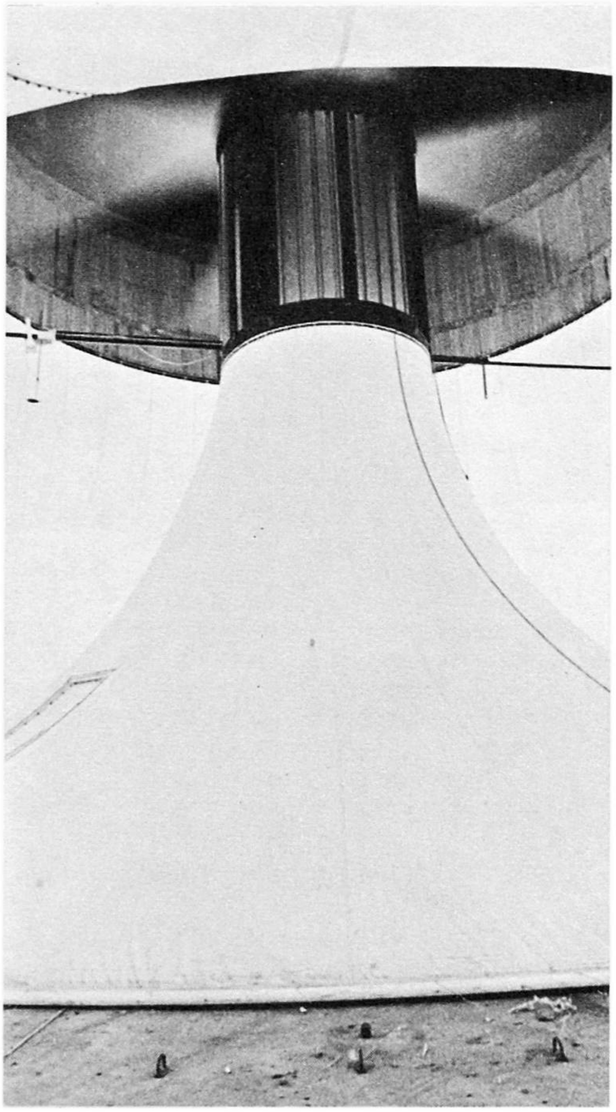

Fig. 21: The funnel providing a smooth transition from the collector's horizontal airflow into the chimney's updraft

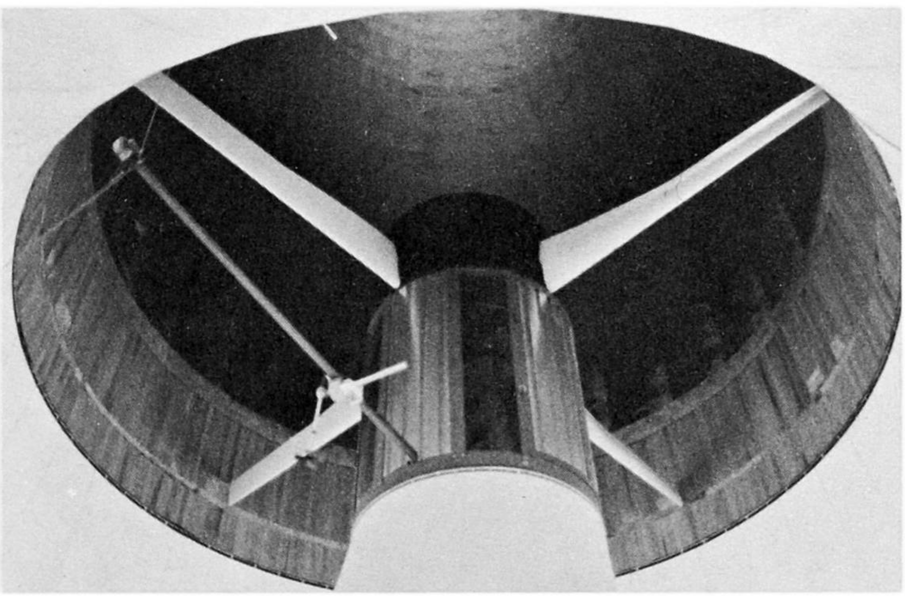

Fig. 22: The wind turbine

2.5 Some results

Extensive measurements have been carried out since fall 1982, and in particular in summer 1983. They include climatic data, solar and sky radiation, film transmission values, temperatures above and below the roof, up to 100 cm below ground level and in the chimney, pressure distribution and losses due to friction in the air flow and finally everything connected with the turbine and its output. Preliminary results are available but they still have to be evaluated and further verified before publication and final assessment (Fig. 23).

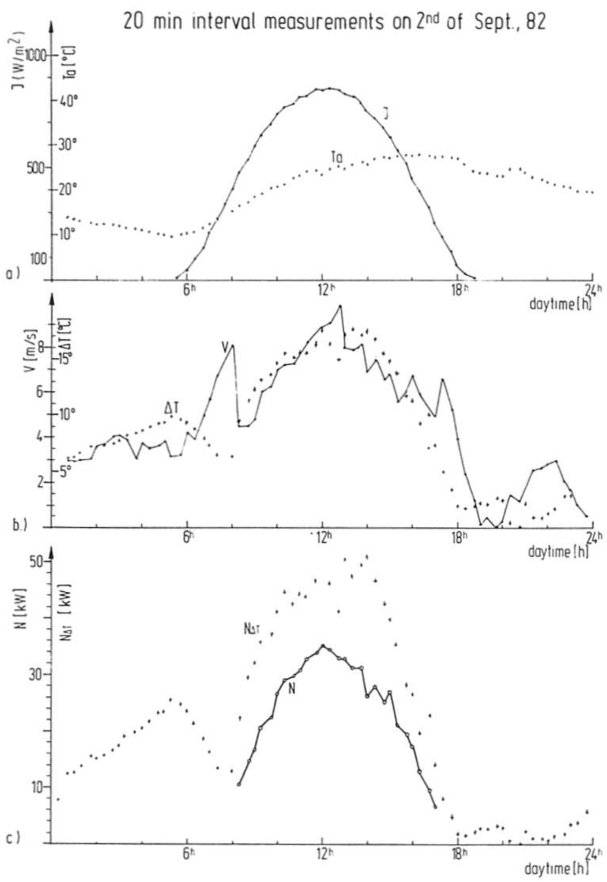

Fig. 23: Momentary measurements at 20-minute intervals on 2nd September 1982 (earth surface not yet blackened):
a) global radiation I and fresh-air temperature T_a
b) temperature difference at bottom ΔT and upwind velocity V
c) terminal output N and potential output $N_{\Delta T}$, the latter calculated from the measured increase in temperature

Even now it may be said that this pilot plant has been a successful undertaking. The simple principle and the reliability were confirmed at this very first attempt.
Since it was put into operation on 7.6.1982 the turbine has only been shut down when there has been a risk of thunderstorms, because of the danger to the control electronics from voltage peaks in the inadequately safeguarded grid. The plant is operated by a single assistant trained on site.

The extent of agreement between the physical model and the measurements is satisfactory (Fig. 24). It may be expected that the predictions made in section 1 with respect to the geometry and the output (Fig. 6) and with respect to the costs (Fig. 7) will be confirmed! With these positive results in hands, detailed design work on larger solar chimneys has already started.

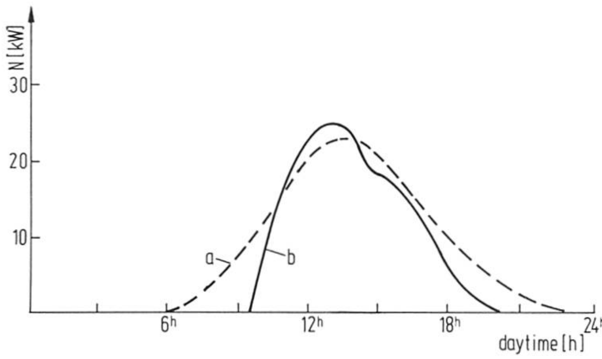

Fig. 24: Comparison of model calculation and measured power output. The climatic data obtained on site were used for the simulation model.
a) power output model calculation
b) power output measured on 12th July, 1982