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Part – Wood Drying

Test amd Research Project into the Drying of Food and Wood Products with Solar Heat

October 2000

Flemming Corell Frank

Wood Technology

Contents

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Report from Wood Technology, Danish Technological Institute on the Work with a Wood Dryer based on Solar Energy in Ghana

Summary
Based on the results from our visit to Ghana on 4th to 8th October 1999 presented in the Survey Report dated November 1999, we recommend the establishment of a test unit for forced air-drying of wood in Ghana, where the solar energy is used only for operation of the fans.

As mentioned in the report the test unit could be placed at Clipper Design Ltd. in Mankoadze. But as decided earlier DENG and the Ghanaian consultants should propose the final place having looked into i.e. the know-how, experience and its suitability for the placing of the test unit, so it later can be demonstrated to interested partners.

People from DENG in Accra and from the Forestry Research Institute in Kumasi should design, perform and evaluate the test run.

The survey revealed the major problem that the quality of the dried wood in Ghana was unsatisfactory. An analysis of the problems indicates that lack of understanding of wood when it dries and the improper operation of the kilns (including stacking, control etc.) are the main reasons for this situation.

Why Dry Wood?
A more uniform quality of the dried wood will contribute to a general quality lift, when using wood and will add a further value to the timber resources in Ghana.

Freshly felled timber (green timber) contains a certain amount of water. Most of this water must be removed before useful products can be made of wood. The wood must dry.

The moisture of the green timber is in two forms:
- As free moisture in the cavities of the cells
- As bound moisture in the cell walls

When the wood dries, the free moisture leaves the wood first. When the wood no longer contains free moisture, it has reached the Fibre Saturation Point, (FSP) corresponding to a moisture content in most common timbers of approx. 25%. From this point of drying the bound moisture leaves the wood, and the wood will then start shrinking as the fibrewalls contract and stress and distortion can develop.

Wood is a hygroscopic material, which always will tend to have a bound moisture content, which is in balance with the water content in the surrounding atmosphere, the so-called equilibrium moisture content (EMC).

If the moisture content (MC) of the wood is below the actual EMC, the wood will absorb moisture and swell. If the MC is higher than the actual EMC, the wood will dry and shrink.
Obviously, the shrinkage and distortion should take place in the timber before it is finally used. Therefore, the drying is so essential for a successful utilisation of timber.

Drying Process
Air-drying is a slow drying process, in which the three main drying factors: air velocity, air moisture content and air temperature must be characterised as unverifiable.

The ordinary air drying process can be changed. Experiments in different countries have included:

Forced Air-drying
Installation of fans to promote a steady flow of air through the stacks – so-called forced air-drying. The lack of an effective air exchange through the wood stack is one of the main reasons for having bad results in ordinary air-drying. The results indicate that forced air-drying showed a faster and more uniform drying with fewer rejects and less discoloration than with ordinary air-drying.

No amount of increased airflow can, however, bring wood down to a moisture content lower than the one that corresponds to the EMS of the ordinary atmosphere.

Accelerated Air-Drying
Heating of the forced air blown through the stacks – so-called accelerated air-drying. The relative humidity and also the EMC of the circulating air are lowered and the drying effect is therefore increased. The drying will be faster and the timber will dry further down than the EMC in the ordinary atmosphere.

This accelerated air-drying is an attempt to establish good drying conditions throughout the year.

It is, however, very important for the use of this method that the temperature raise and that the heat added to the circulating air can be controlled, as the wood easily can be damaged due to more severe drying conditions.

By an ordinary air-drying in the free in Ghana the moisture content of the wood can be brought down to an EMC related to the surrounding ordinary atmosphere of approx. 20% according to the time of the year. It is, therefore, obvious that air-drying and forced air-drying alone are not sufficient to bring timber fit for indoor uses, where the wood moisture (EMC) will be between 8 and 12%, (see figure 1).

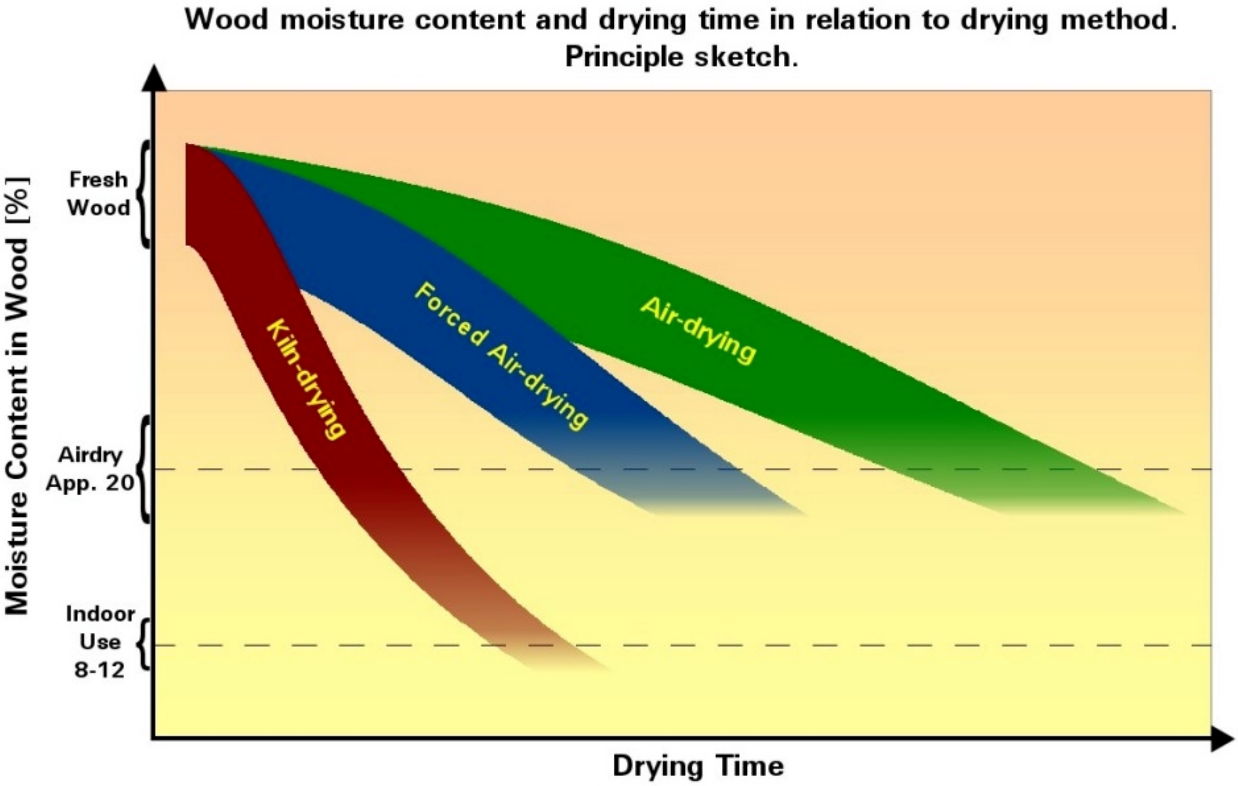


Figure no. 1

Recommendations

The Danish survey team recommends to have the test unit on forced air-drying only and with the solar energy used to run the fans. The final moisture content of the dried wood will be as the ordinary air drying approx. 20%. But the moisture will be more uniform throughout the stack; rejects, stain and discoloration will be reduced.

If the test unit instead should work as an accelerated air drying unit, it would be possible to dry the wood down below the approx. 20% level, but with the results from our survey in mind – mentioned previously, we cannot generally recommend this solution. We shall recommend a strong effort for widening the know-how of wood drying. Operating kilns call for training (know-how), especially, of the operators.

For the future work we will recommend actions in these steps:

1. Evaluation of the test results from this actual project.
2. Training (courses) for a number (5-10) of Ghanaian instructors in drying of wood.
3. The instructors’ activities in Ghana: Education and training of drying operators.
4. Establishment of and test runs with drying units for accelerated air drying.
5. Test runs with fully equipped kilns for wood drying.

Conditions, Calculations and Estimates for the Prototype Wood Dryer

In the following the delimitation and choices are described, which have been carried out in regard to the design of a forced air-drying unit in this DANIDA project.

The drying installation and the construction are based on inexpensive establishment costs in a non-thermic, isolated construction with utilisation of solar energy for operation of the fans.

Moisture Levels

The actual EMC in the Ghanaian climate can be determined on the average of monthly and daily measurements of temperature and relative humidity. It appears from reports prepared by Professor Fred O. Akuffo, Department of Mechanical Engineering, University of Science & Technology in Kumasi, that as a whole it is impossible to dry the wood further than to an EMC of approx. 20% in air drying.

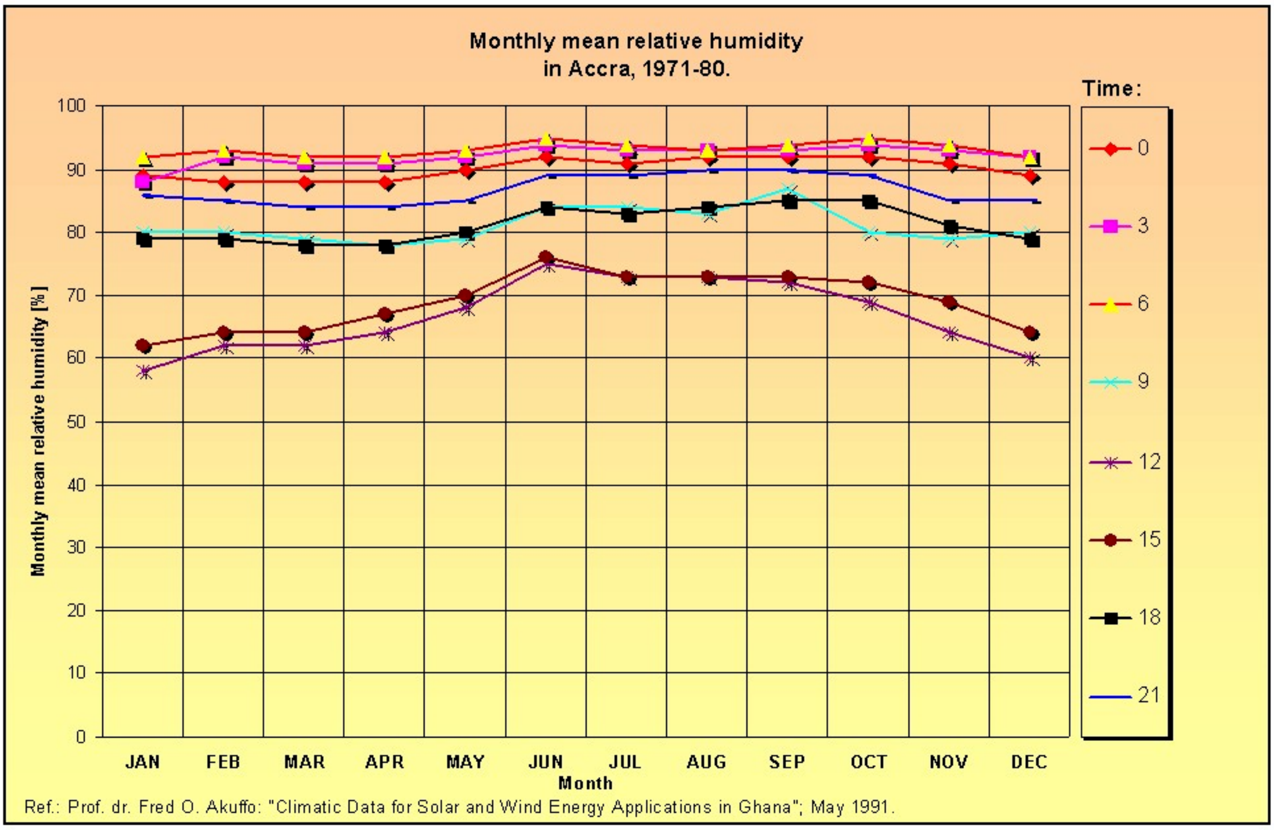


Figure no. 2: Monthly mean relative humidity in Accra.

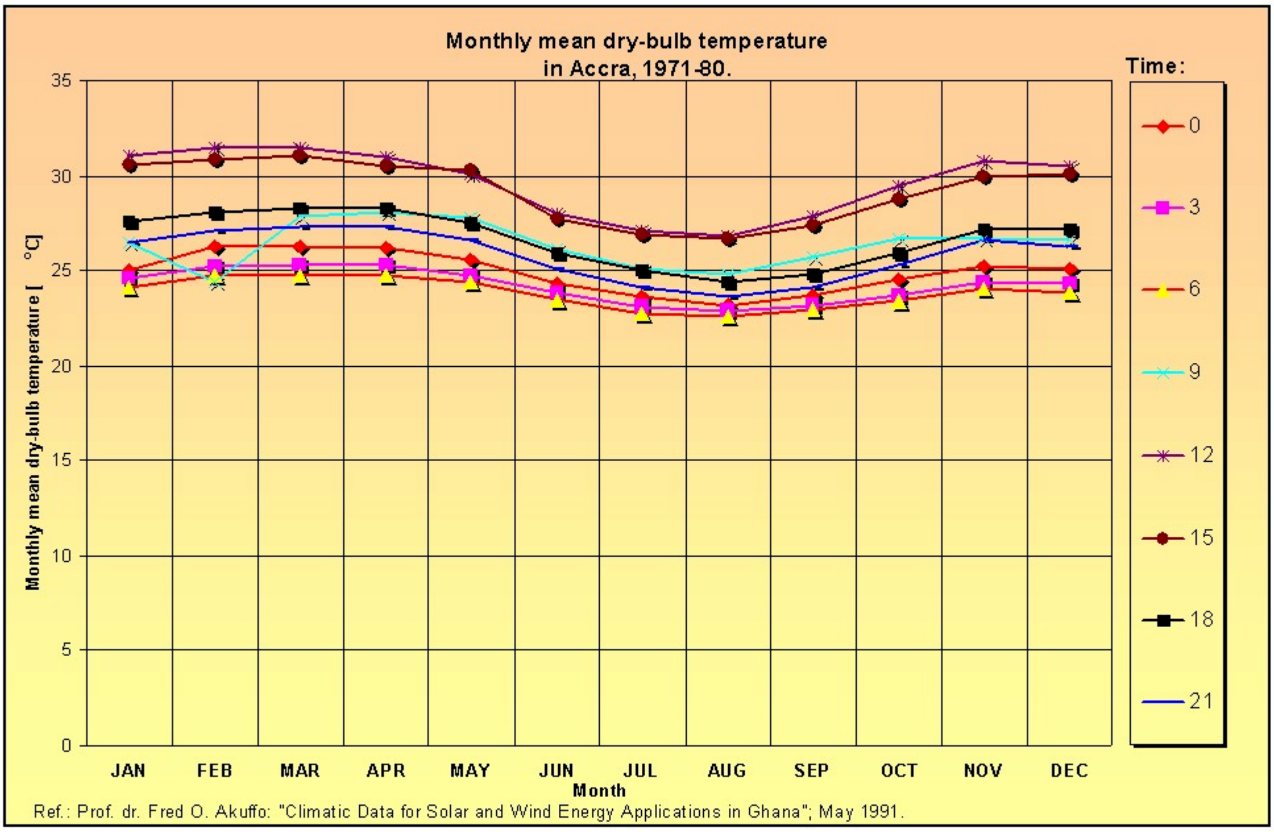


Figure no. 3: Monthly mean dry-bulb temperature in Accra.

As appears from figures 2 and 3 the evening and night climate are not suitable for wood drying, on the contrary, it would contribute to the moistening of the timber. The drying with solar operated low volt fans is, therefore, especially suited for drying of timber.

There is thus no use for batteries for storage of energy for night operation. The drying should be discontinued shortly after sunset and the unit should possibly be sealed to prevent moistening of the outsides of the stacks.

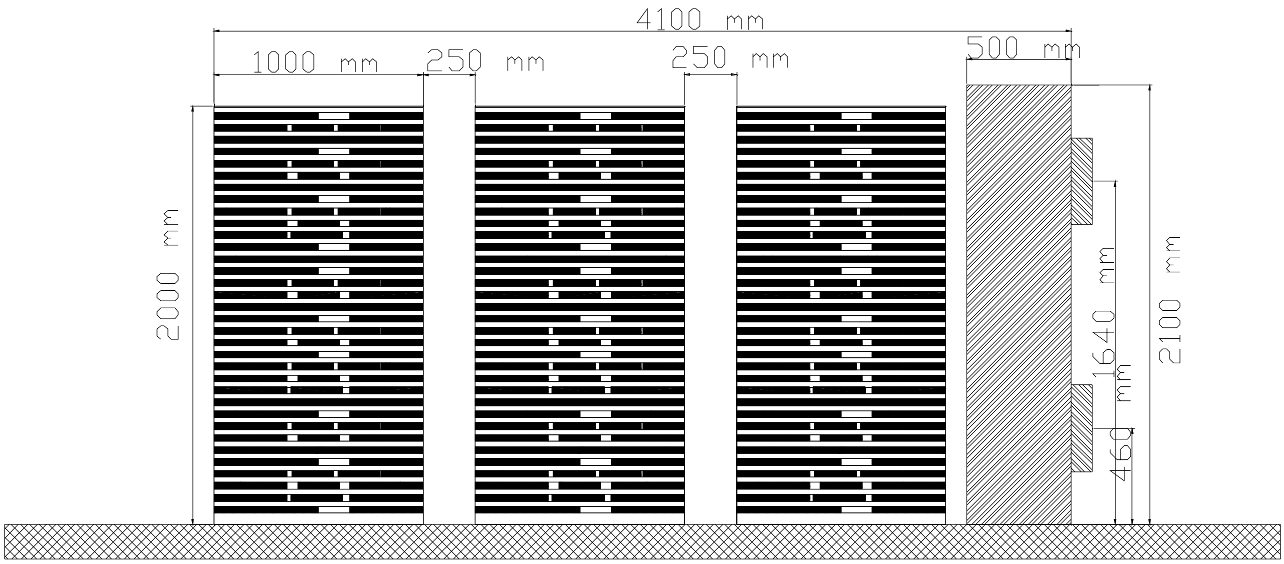
Air Velocity

The water evaporating from the timber will lay a vapour layer – a limit layer - on top of the timber. The thicker this limit layer is, the harder it is for the vapour generated below the surface of the timber to get free of the timber.

The limit layer cannot be removed completely, but it can be made thinner by increasing the air velocity, whereby the air above the timber is renewed. At low air velocities a so-called laminar air movement will appear. This laminar air current is not able to break the limit layer.
At larger air velocities turbulent flows arise, which are able partly to break the limit layer. The air velocity causing turbulence at wood drying is approx. 0.6 m/s between the wood layers that is the joist layer. It is; however, difficult to produce exactly 0.6 m/s. everywhere in the stacks. It is, therefore, suitable to design the fans to a higher velocity. An appropriate air velocity would be between 1 and 2 m/s. For design, please see clause “Fans”.

By applying underpressure (the air is sucked through the stacks) the need for steering the airflow through the wood stacks is eliminated. The tarpaulin will pack airtight around and along the wood stacks, as it will adhere to the stacks. It should only be secured that no false air can get in along the lower edges of the tarpaulin.

Depth of Stack
In the actual project we have chosen to dry 3 stacks of timber with a depth of 1.0 meter in the direction of the drying air. Please see figure 4. The wood stack farthest from the fans will be dried first and can be removed, when the required wood moisture level has been obtained. The other two wood stacks are moved and the new, wet wood stack is placed closest to the fans and the drying is resumed.



Wood stacks

Figure no. 4: Depth of Stack and wind direction.

Drying Batch
In this demonstration project the forced air-drying unit is built to be able to dry approx. 10 m; per batch. The planks to be dried are cut to pieces of maximum 2.5 meters. They are stacked with clean and dry joists across the longitudinal direction of the planks and parallel to the air direction. The measurements of the finished wood stacks are (height x width x length) 2.0 x 2.5 x 4.0 meters. An example of stacking can be seen on figure 5.

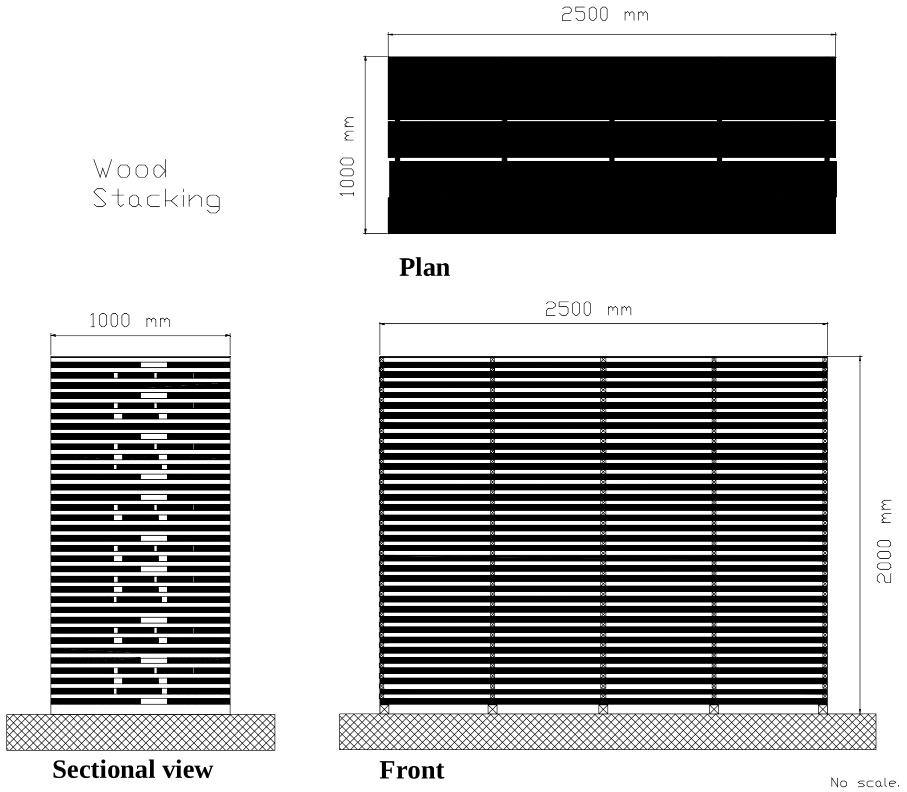


Figure no. 5: Stacking principle and dimensions.

Air Pressure
The drop in air pressure through a wood stack varies with the density of the air (ρ), the air velocity (v), number of stacks in the air direction (n), the average length of the timber (1), length of the stacks (L), height of the stack (H), width of the stacks (N), thickness of joists (d_s), width of planks (b) and number of fans.

Table 1. Level and consistency between pressure and air velocity

Air velocity	**Static drop of pressure, P_s [Pa, (mmHg)]**					
m/s	**1 stack**		**4 stacks**		**20 stacks**	
1	2	(0.2)	7	(0.7)	35	(3.5)
2	7	(0.7)	28	(2.8)	140	(14.0)
3	16	(1.6)	64	(6.4)	320	(32.0)
4	28	(2.8)	100	(11.0)	570	(57.0)
5	44	(4.4)	180	(18.0)	880	(88.0)
6	64	(6.4)	250	(25.0)	1270	(127.0)
10	180	(18.0)	710	(71.0)	3540	(354.0)

Please note that the values vary significantly according to the design of the kiln.
Ref.: Björn Esping, Trätek, Sweden.

Basic data for the above table 1:
Double installed 50 x 100 mm timber, air density (ρ): 1.05 kg/m^3, length of plank (l): 4.5 meter, length of stack (L): 5.6 meter, width of stack (B): 1.5 meter, thickness of joists (d_s): 0.025 meter.

The above parameters are determining for the relations between air velocity and drop in pressure. From the table it appears thus that at an air velocity of 2 m/s and 4 stacks, a backpressure of 28 Pa is to be expected. This information can be used for the calculation of the number of fans for the forced open-air plant, see clause "Fans".

In the actual pilot plant the actual conditions are different, but the above table and parameters are considered to be calculated on the safe side. The conditions of the forced open-air plant can subsequently be changed according to implementation of the first test runs. E.g. the thickness of the joists could be varied according to needs, so that resistance and air velocity subsequently can be adjusted to obtain the required result.

Basis and Covering of the Drying Installation

Prior to establishment of the wood drier an appropriate basis for the wood stacks should be made, which partly should keep free of the vegetation and partly drain running water from the drying timber. An appropriate covering of the drying installation can be established as a shed roof or the like with a big overhang, which can prevent downpour from moistening the timber in the drying installation. In the project a concrete deck is established and the covering is designed as a shed roof with metal covering, on which electric solar cells are mounted. See figure 6.

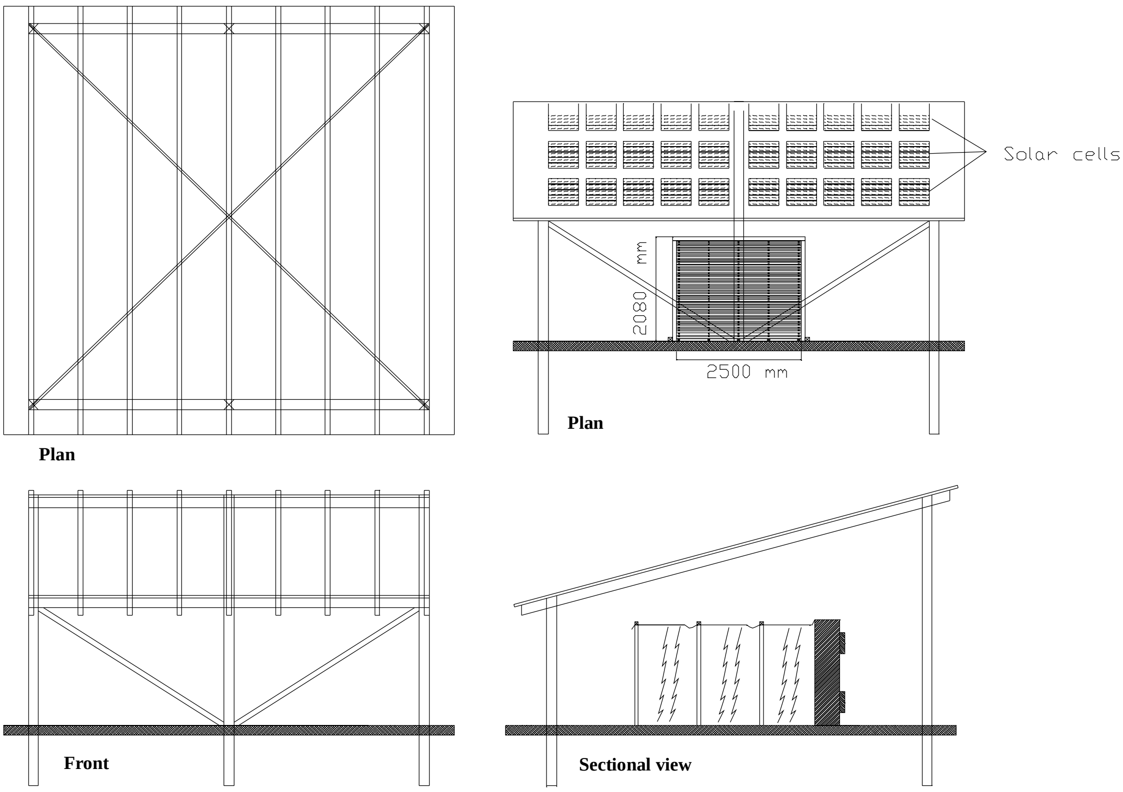


Figure no. 6: Principle of Covering.

”Fan-Box”

The fan-box has 3 purposes, partly, to distribute the airflow behind the fans uniformly, partly, to fix the fans to the front panel, and partly, to secure that the tarpaulin is tight to prevent “false air”.

The fan-box is built as a timber frame construction, which is covered with a material with good, biological durability e.g. plywood with aluminium panels. Sketch appears from figure no. 7.

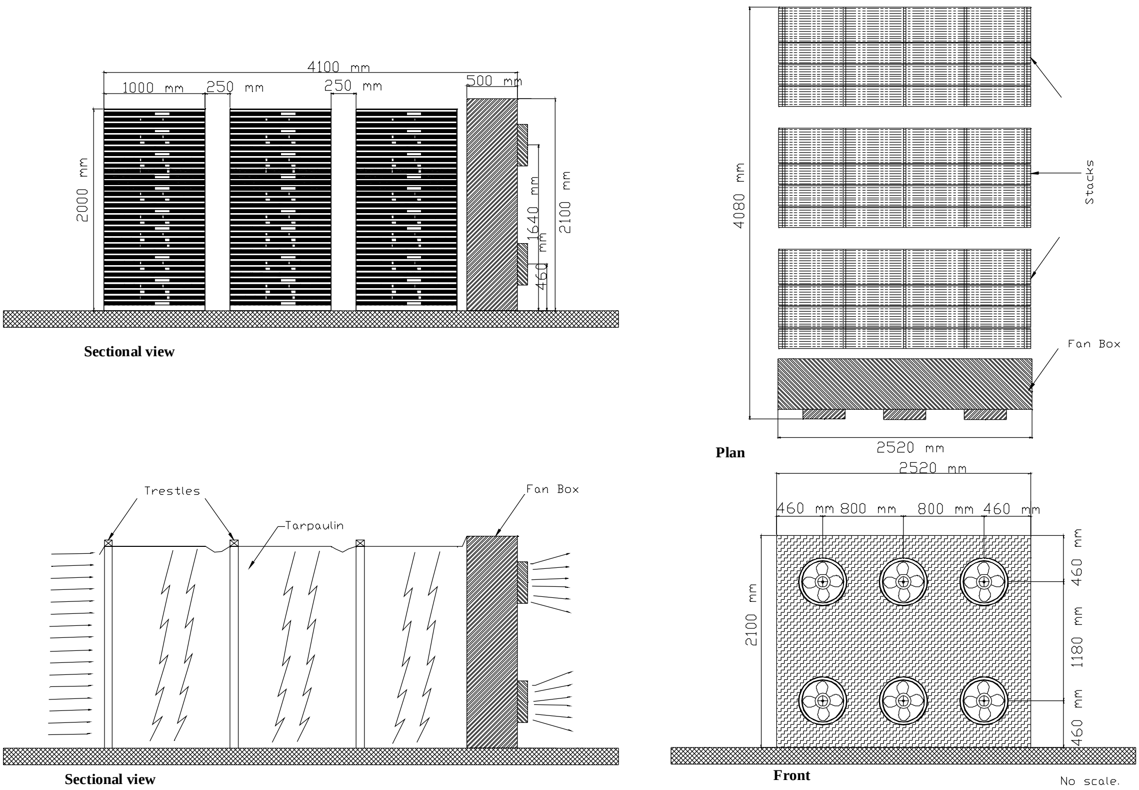


Figure no. 7: Principle of fan-box and stacking alignment.

Fans

Niels Stokholm Jepsen from DENG has purchased a finished fan unit (no. 71-212, 16”) from the USA. The unit consists of a low volt motor with attached fan blades in a steel frame. This fan unit has been tested at the Danish Technological Institute, Energy, the test results appear from Appendix A.

From the graph beneath it is seen from a total performance curve for the blade fan and motor that the following relation is to be expected: The fan unit has a maximum static pressure of 48 Pa at an air flow of 1540 m;/h and a maximum volume of air of 2550 m;/h with a corresponding static pressure of 25 Pa.

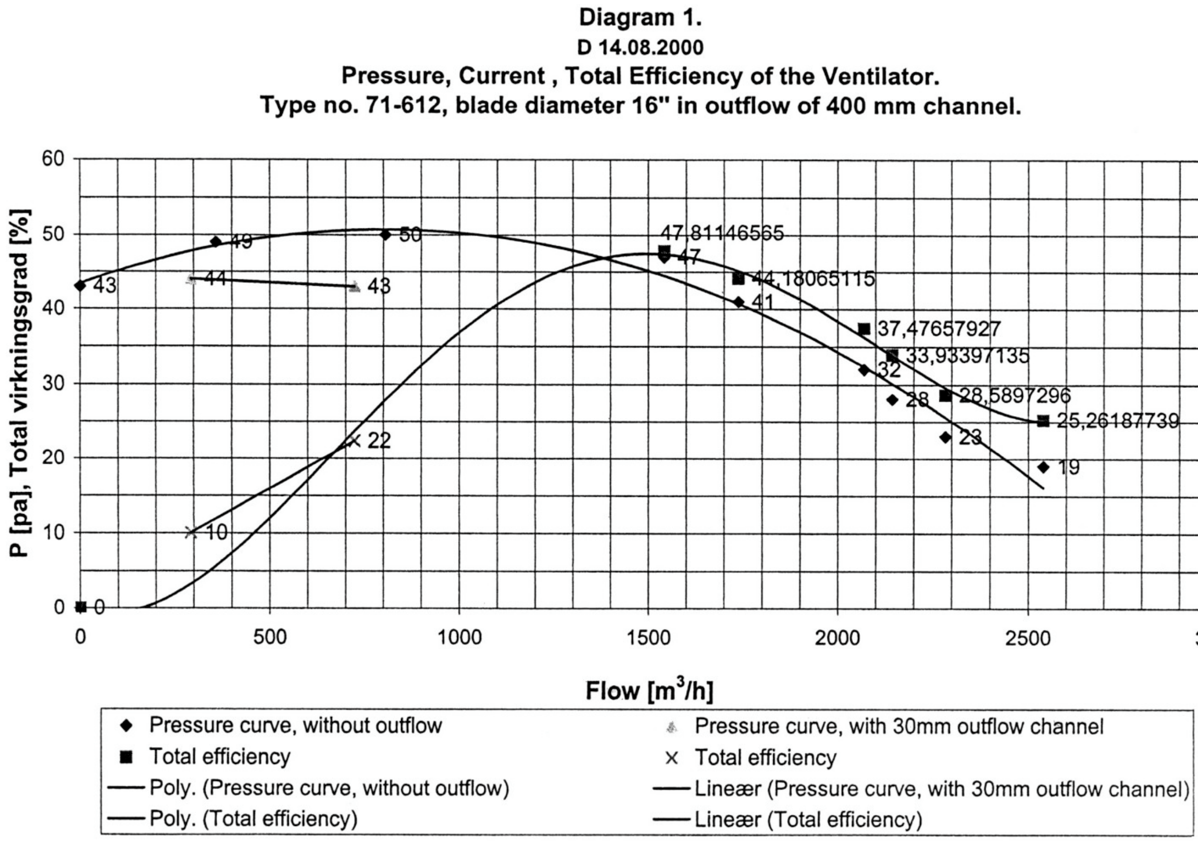


Figure no. 8: Relation between air velocity and air pressure.

For the actual prototype with a channel dimensions of (height x width x length) y 2.1 x 2.6 x 4.1 meter, it has been calculated that at a air velocity of 2 m/s between the planks by drying 32 mm planks and by using 25 mm joists – an air exchange of 15,800 m; per hour should be established through the wood drier.

On basis of the testing carried out of the proposed low volt motor with fans, it can be read on the above graph that it at a pressure performance of 28 Pa will perform airflow of 2.300 m; per hour. At application of 6 pcs of this type of fans, these will theoretically be able to perform (6 x 2.300) 13,800 m; per hour with an energy uptake of (6 x 51 Watt) 306 Watt. 6 fans are thus selected, whereby the maximum average air velocity presumably will be approx. 1.8 – 1.9 m/s through the stacks of wood.

Covering of Wood Stacks
The unit is made of a tarpaulin, which will be drawn over the wood stacks. To secure and ease placing the tarpaulin over the wood stacks, 3 wood trestles are mounted. The trestle appears on figure no. 9.

Energy for Operation of Fans
In this project we have chosen to use solar energy for the operation of the fans. Alternatively, the fuel could be: an electric generator, a diesel engine, a gas generator or a steam engine. The latter could use waste wood and chips from the production.

According to the above calculations solar cells should be established, which could perform 300 watt. To perform 300 watt the efficiency of the actual solar cells should be added and the solar intensity and the soiling from the air of the solar cell panels should be taken into account.

In this project the solar cell panels will be projected and established by Solar Energy Centre, Denmark, SECD and DENG in Ghana.

Economy
The establishment costs of the forced open-air drier are limited, apart from the electric solar cells. The following bill of materials can be drawn up:

Bill of Materials

Pos.	Subject
1.1	Waterproof plywood panels for construction of kiln
1.2	Sealing agent for veneer panels (Polyurethane e.g. Conclad)
1.3	Aluminium panel
1.4	Tarpaulin of a strong quality
1.5	Fan unit
1.6	Structural timber
1.7	Concrete and stone for the decking
1.8	Roof panels
1.9	Nails and furnishings
2.0	Solar cells

The operating costs will exclusively consist of wages and book depreciation of the plant. The interest costs will consist of a return on investment of the construction costs, while the interest costs for timber purchase will be reduced, as the drying time will be shortened (see figure 1), and the amount of rejects likewise is expected to be reduced.

Measurement Equipment
We recommend buying the following measuring equipment to be able to record the climate and the drying process:

- Relative humidity meter
- Electric ohmmeter for determination of wood moisture
- Air velocity meter

Rough Plan for the Drying

The degrade, which occurs during air-drying and also the drying rate can both be influenced to a limited extent complying with the procedures mentioned beneath:

- Plan the yard for handling of stacks etc.
- The site should be drained, vegetation cleared and kept down. Can interfere with air-circulation beneath stacks.
- Sawdust and odd pieces of timber should not be left on the ground. Can form the basis of insects and mould.
- Stack well away from trees and buildings
- Stacks should not be wide (max 6-7 ft), the height limited by stability and ease of handling. A tall stack may often (due to weight) prevent some distortion in i.e. hardwoods
- Sticks should be of clean and dry timber, size most generally 25 x 25 mm (1 x 1 inch). The sticks should be properly aligned to prevent the wood from distorting during drying
- The sticks should be placed carefully in the stack so that the circulating air when entering the stack meets a grating
- Protection of the ends of boards, planks, squares for prevention of checking or splitting: Paints, emulsions, draping tarpaulins etc.
- Examine the wood before stacking or go through the stack before the drying starts. Look especially for discoloration/stain and splits/checks on the side and in the ends
  If such degrades are found after the drying, it is often very difficult to tell, if the degrade also was present before the drying. On the other hand, some degrade is bound to occur due to shrinkage during drying, and, therefore, some
  degrade has to be accepted
- Mixing fast drying timber species with slow drying species, the slow drying species will determine the overall drying time of the stack. It is recommended to grade the timber before stacking
- The specific gravity of the wood can help estimate the overall drying time/drying rate
- When mixing sawn timber with different thickness the thickest timber will determine the overall drying time of the stack. If the thickness of the sawn timber is halved, the drying time will be only about α. Grading can be profitable.
- Quarter sawn timber dry more slowly than flat sawn timber
- It is desirable to be able to follow the drying of the timber in the stacks. It is, therefore, a good practice to incorporate a few typical sample boards from the lot into the stack so that they can easily be withdrawn - and returned - and weighed for estimation of the moisture content. The samples could also be used for estimation of the drying stresses in the wood, any discoloration, splits etc. Some times measurements with moisture meters could be helpful, when the level is below approx. 30%.
- In periods, in which the humidity of the air is very high or very low the actual drying can be very slow respectively very fast. In these periods it may be actual to stop the fans to save waste of power or – in the dry periods – to prevent splitting of the wood

Measuring Programme
The national Ghanaian consultant, K. S. Nketah, Forestry Research Institute, University of Science & Technology, Kumasi, is recommended to prepare and implement the measuring programme.

List of Appendices

A. Testing of 24-Volt DC Fan.
B. Wind-measurements in Ghana and in Denmark.
C. Photo of fan unit.

References

English Titles

Hughenden Valley, Standard for the quality assurance of batch drying of timber, Timber research and development Association, TRADA. England. 1987.

"Timber Drying Manual", B.R.E.P. England, 1974.

Prof. dr. Fred O. Akuffo, "Climate Data for Solar and Wind Energy Applications in Ghana". Kumasi, Ghana, 1991.

Scandinavian Titles

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Th. Thomassen. Forceret frilufttørring, Teknologisk Institut. 1969, Denmark.

"Varme- og klimateknik", Danvak, 1991, Denmark.

Appendix A

Testing of 24 VDC Ventilator

August 2000

240 0 84 75

for
Danish Technological institute
Wood Technology
Gregersensvej
DK-2630 Taastrup

Habs Olsen
Hatacha Gottschalck

Ventilation and Environment

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Test Report

Assignor	Contact person:	Flemming Correll Frank
	Company:	Danish Technological Institute Wood Technology
	Address:	Gregersensvej
	City:	DK-2630 Taastrup
Test specimen	Product: No. 71-212. 16”. Blade diameter. 24 VDC	
Deadlines	The test specimen was tested in August 2000	
Test method	Please see the test set-up	
Result	Please see Appendices	
Conditions	The measurements have been carried out according to the “General Terms and Conditions regarding Commissioned Work accepted by the Danish Technological Institute”. The test report may only be extracted. If the laboratory has approved the extract. The test result is only valid for the tested specimens.	
Place	The measurements were carried out at the Danish Technological Institute, Energy, Ventilation Laboratory, Taastrup	
Contents of report	The report contains 2 pages with description of test set-up. 3 pages with measurement results and calculations. 2 diagrams	

Signature

Hans Olsen
Test responsible

Power, Pressure and Voltage Measurements of Ventilator

The following measurements of the ventilator were carried out with the beneath set-ups.

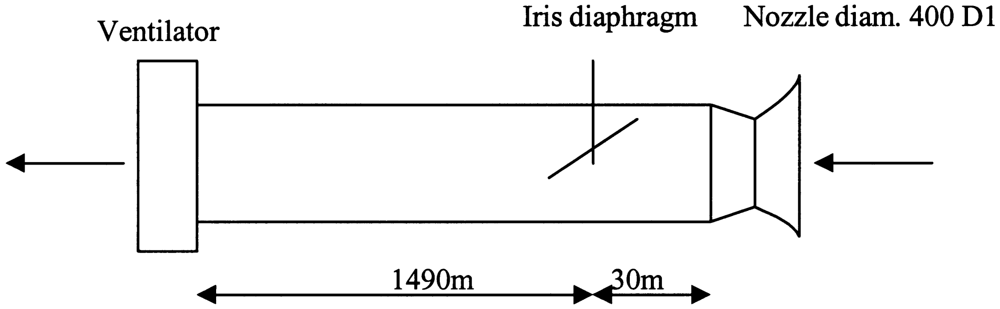
Flow measurements have been carried out with PVC-nozzle, diameter 400 D1 with range of measurement 0.28 – 1.65 mmVs and PVC-nozzle diameter 250 D1 with range of measurement 0.177-0.732 mmVs.

Pressure measurement was carried out with AIRFLOW 270-T-4040 and Pitot tube 0.83 m from the ventilator.
The voltage was measured with Fluke 41B and the current intensity was measured with Fluke 76.
The rotation measurements were carried out with a Chauvin arnoux C.A 27 Tachometer.
The transformer was a Thandar TS 3021S.

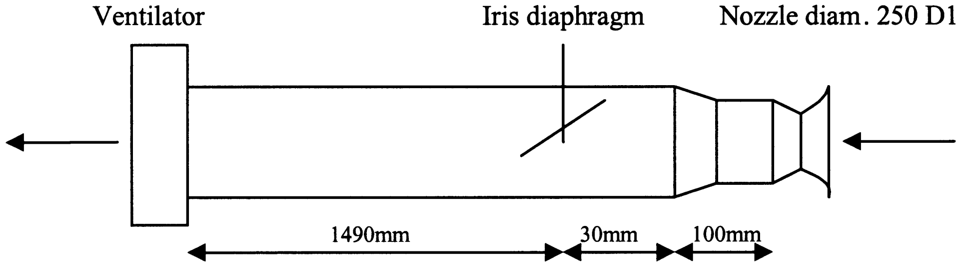
The flow was calculated according to the following formula for PVC-nozzle with a diameter of 400 D1 $q_v=0.5028*P_{nozzle}^{0.478}$ and for the PVC-nozzle with a diameter of 250 D2 $q_v=0.1806*P_{nozzle}^{0.5027}$.

On the corresponding diagrams the measuring points are stated as well as an approximately calculated curve.

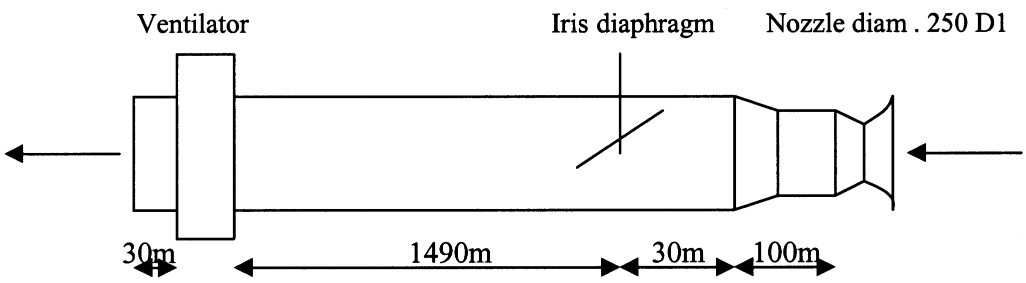
Set up 1



Set up 2



Set up 3


Ventilator
Iris diaphragm
Nozzle diam . 250 D1
30m
1490m
30m
100m

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Pressure and Voltage Measurement of Ventilator Blade Diameter 16", catalogue no. 71-212

Measurements resulting from use of PVC-nozzle 400 D1

Diagram 2. Series 1
Set up 1

Voltage Voltmeter Volt	Voltage Trans-former Volt	Current A	Rotations RPM	Static P at nozzle Pa	Static P at ventilator Pa	Effect W	Total Efficiency %	Adjustment of Iris diaphragm
25.5	25.6	2.072	1300	20	19	53	25	0
24.6	24.7	2.066	1276	16	23	51	29	1
23.6	23.8	2.064	1253	14	28	49	34	2
22.8	23.8	2.062	1253	13	32	49	37	3
21.5	21.7	2.064	1200	9	41	45	44	4
20.2	20.4	2.064	1165	7	47	42	48	5
15.2	15.5	2.066	1023	42	43	32	0	Closed

Measurements resulting from use of PVC-nozzle 250 D2

Diagram 2. Series 1
Set up 2

Voltage Voltmeter Volt	Voltage Trans-former Volt	Current A	Rotations RPM	Static P at nozzle Pa	Static P at ventilator Pa	Effect W	Total Efficiency %	Adjustment of Iris diaphragm
18.5	18.4	2.067	980	15	50	38	29	7
16.9	16.8	2.066	830	3	49	35	14	8

Measurements resulting from use of PVC-nozzle 250 D2 with resistance mounted to the outflow side

Diagram 2. Series 2
Set up 3

Voltage Voltmeter Volt	Voltage Trans-former Volt	Current A	Rotations RPM	Static P at nozzle Pa	Static P at ventilator Pa	Effect W	Total Efficiency %	Adjustment of Iris diaphragm
18.6	18.7	2.068	1000	12	43	39	22	7
17.2	17.2	2.071	880	2	44	36	10	8

Diagram 1.
D 14.08.2000
Pressure, Current , Total Efficiency of the Ventilator.
Type no. 71-612, blade diameter 16" in outflow of 400 mm channel.

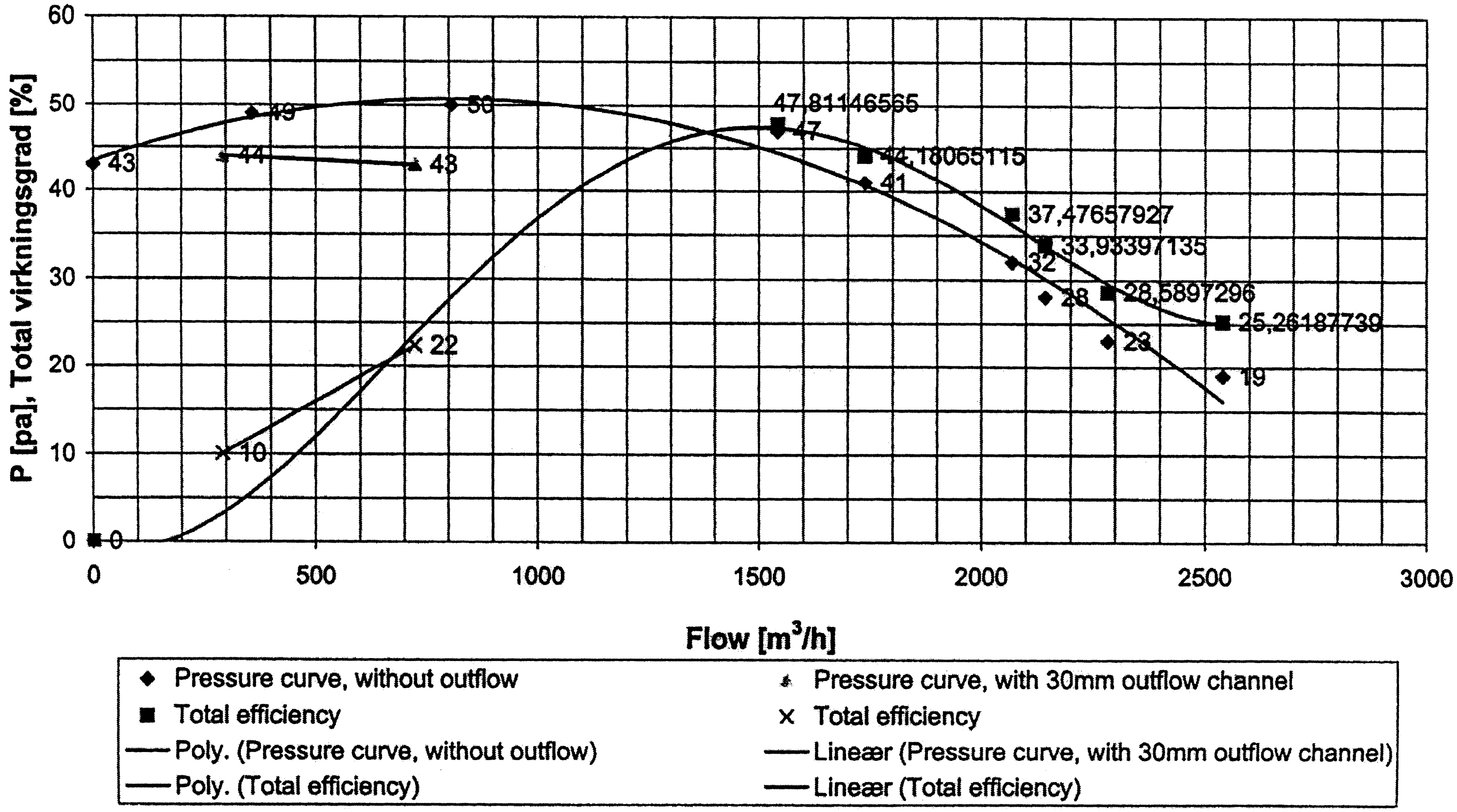
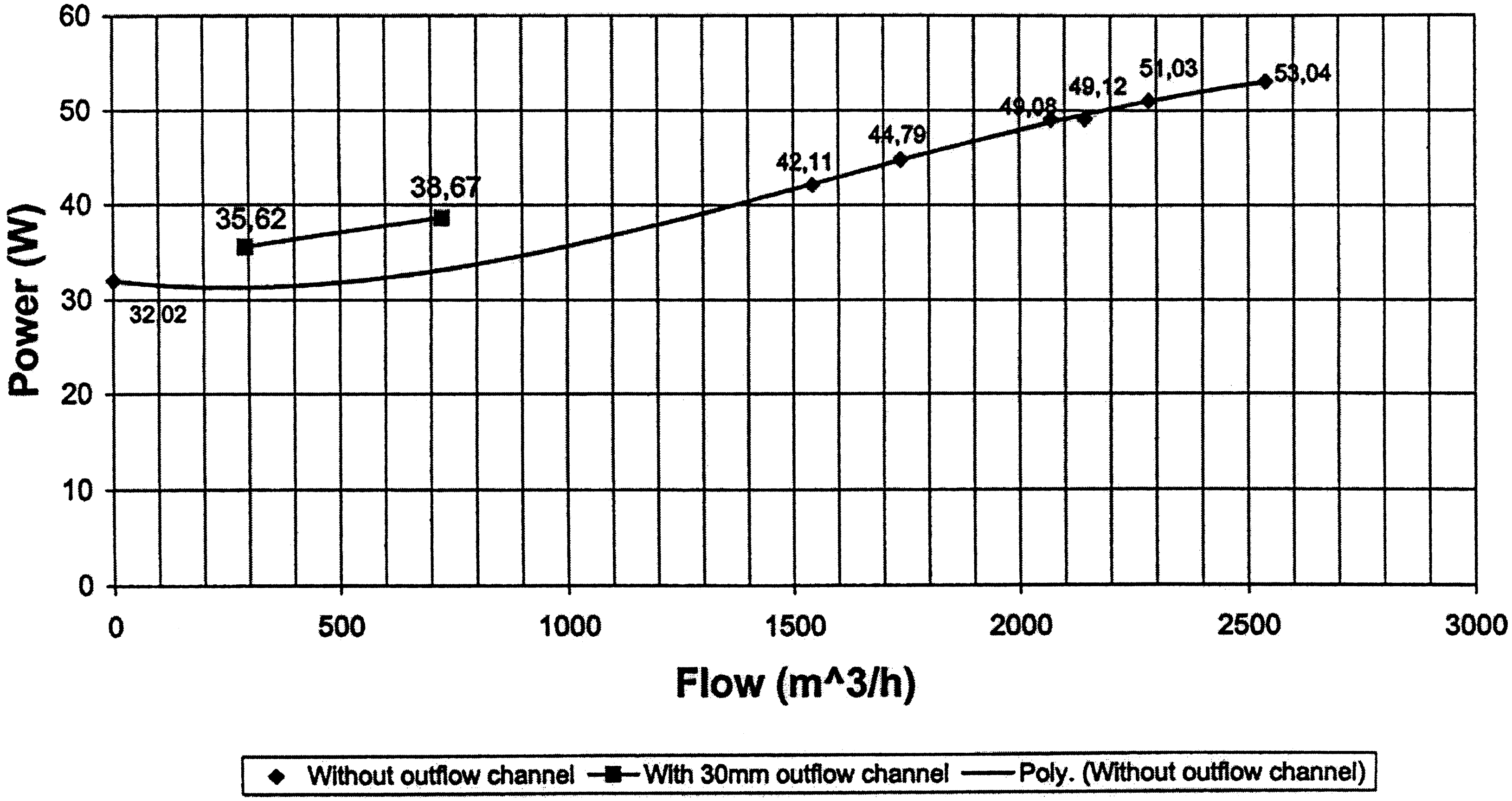


Diagram 2.
D 14.8.2000
Power Consumption Ventilator
Type nr 71-612 blade diameter 16" in outflow of a 400 mm channel.



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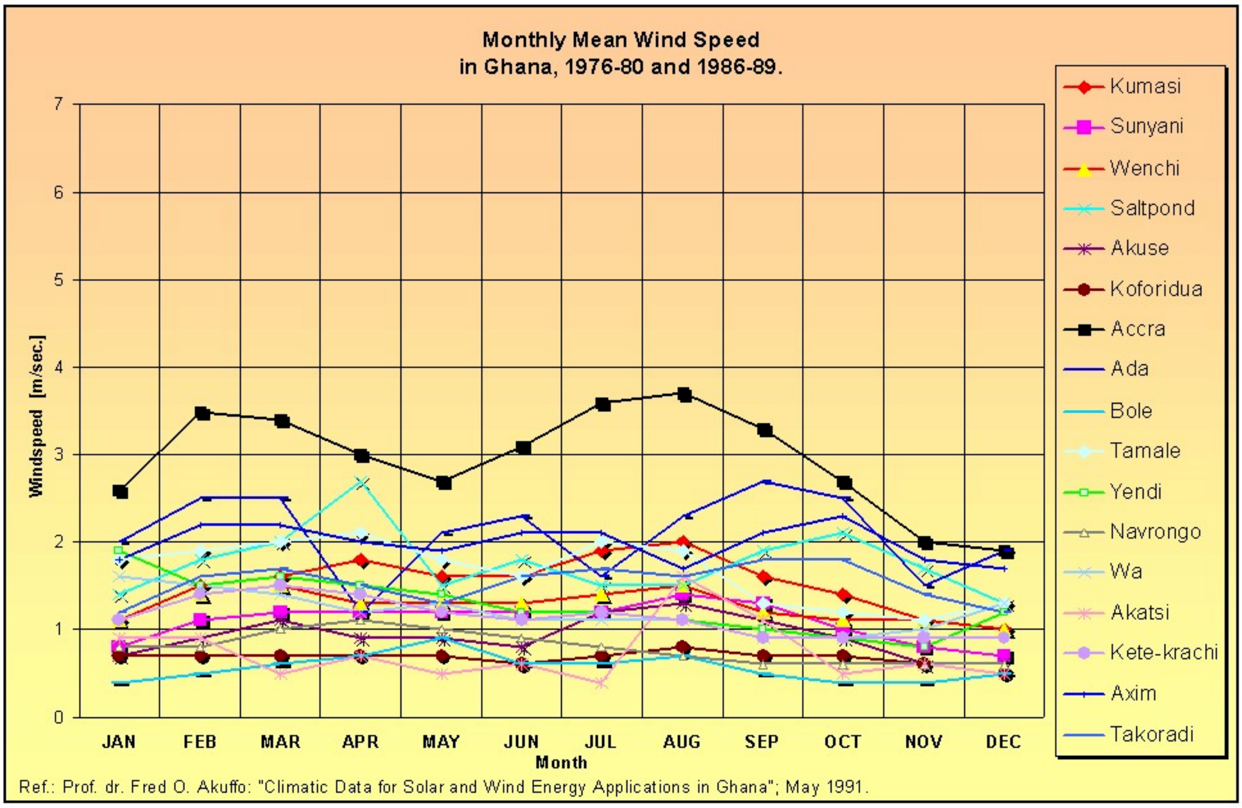
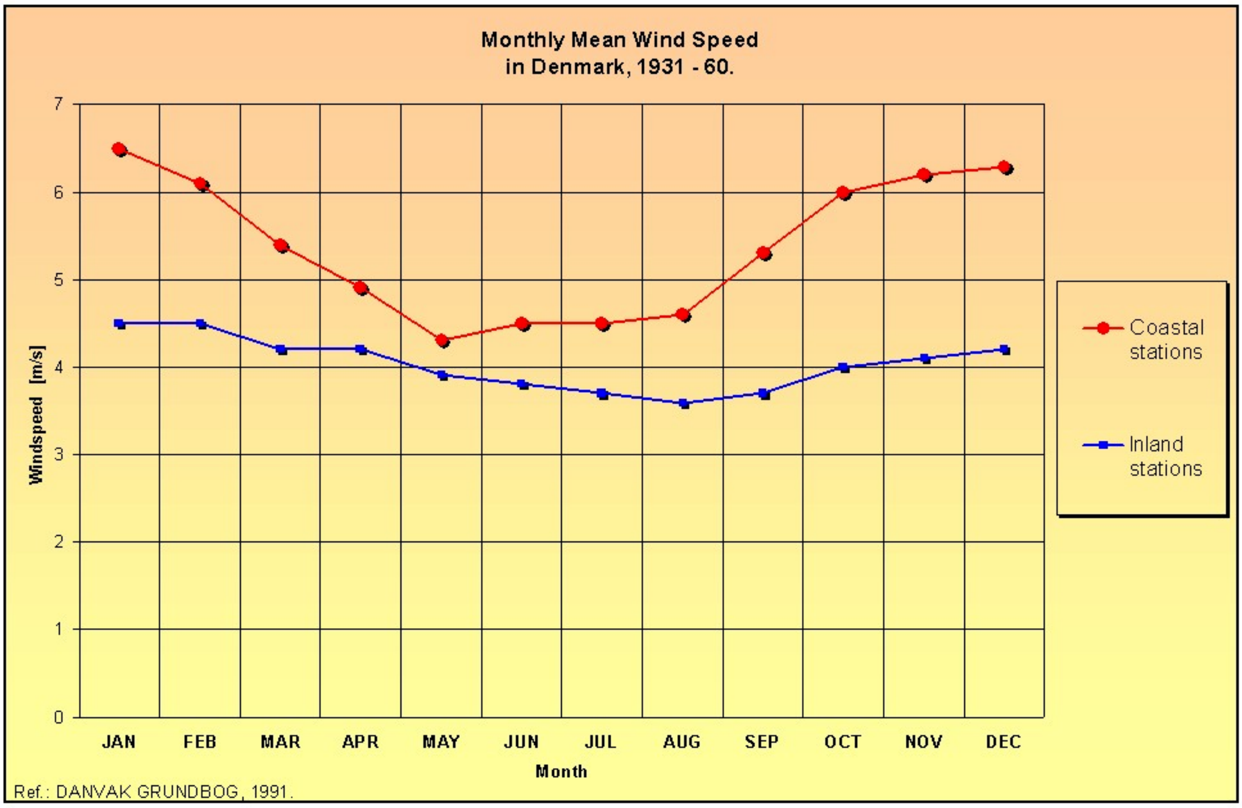
Wind-measurements in Ghana and in Denmark.





Photos of fan unit.