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Vienna, 19 - 23 November 1973

SOLAR KILNS: THEIR SUITABILITY FOR DEVELOPING COUNTRIES 1/

by

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SUMMARY

The paper presents a review of development work on solar kilns since 1961 when the first information was published. A solar kiln is a closed chamber for drying timber where all the heat required is produced by solar energy as opposed to other forms of drying where either the timber is not fully enclosed or where artificial heat is employed.

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The competing methods of seasoning are discussed briefly (air drying in stacks and in sheds, forced air drying, pre-driers, conventional kilns, dehumidifiers and radio frequency drying) and compared with solar kilns. The development of solar kiln technology is discussed, and their suitability for use in developing countries is examined.

The method is an improvement over air drying since moisture contents suitable for furniture manufacture may be obtained. Although drying takes longer than with conventional kilns, the capital costs of construction and their smaller economic batch size make the use of solar kilns an attractive proposition for use in developing countries (where requirements for seasoned timber of any production unit are often small) particularly when preceded by air drying.

Once the wood-using industry has reached the stage where 10 - 40 m^3 of seasoned timber is used per month by individual productive units then there is likely to be a demand for solar kilns.

Although centralised research is recommended to discover the nature of energy losses, to test alternate designs and to find the best covering material, work on specifics of size and shape should be left to individual workers in interested countries so that they can suit kiln designs to particular conditions.

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SOLAR KILNS:
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CONTENTS

I. INTRODUCTION

It is important to bear in mind the alternative methods of drying timber when considering solar seasoning since, unless solar kilns are likely to be competitive with them or complementary to them, solar seasoning is never going to be used on a commercial scale and it will remain, what it has been up till now, an interesting research exercise. The following, then, are the main methods of drying timber currently in use, which are likely to compete, to any appreciable extent, with solar kilns.

Air Drying in Stacks

This method is widely used whereby timber is stacked on supporting bearers in an open yard either with, or without, waterproof or sunproof covers. Drying is by circulation of air through the stacks which picks up moisture from the surface of the timber. There is no control of temperature, humidity or rate of air flow other than can be obtained by correct orientation and spacing of the stacks and good methods of stacking. The method is apparently cheap and simple to carry out, but the costs of holding stocks of timber for long periods of time and maintaining yards can be considerable.

Air Drying in Sheds

Here the timber is under cover of an open-sided shed. Protection against rain and sun is normally better than with open stacks, but it is more difficult to design sheds with as good a circulation of air as can be obtained with a good layout of stacks. The cost is greater than with open stacks as the capital costs of sheds are greater.

Forced Air Drying

Here air is forced through a stack of timber, normally under cover of a shed, by the placing of one or more fans at one side of the stack. No extra heat is applied. There is an added cost of fans and the power to drive them and the fans normally have to be large to give an even flow of air through the stack.

Pre-dryers

These are similar to conventional kilns but with less complicated heating, ventilating and control systems. They are normally larger than normal kilns and have been used extensively in cold climates to dry large quantities of timber down to about 20 per cent moisture content after which drying is completed in conventional kilns.

Conventional Kilns

There are many designs and degrees of sophistication of conventional dry kilns, but in all of them the temperature, the humidity and the ventilation are controlled to give optimum drying conditions for any given species of timber. For the kilns to be used efficiently timbers must be sorted into individual species before being dried and each species must be dried according to a specific schedule.

Dehumidifiers

These are kilns where no external heat is applied but instead humid air from the kiln is refrigerated. This causes the water to condense and the dried air is then allowed to reheat and is returned into the kiln or exhausted. This method of drying timber has proved successful in drying small quantities of timber in warm climates, but it suffers from the disadvantage that, since no heat is normally applied to the timber, the rate of moisture movement within the timber is not accelerated.

Radio Frequency Heating

Timber can be dried by heating it internally, using radio frequency. This is, however, expensive and impracticable for large quantities of timber.

The main forms of timber drying which are likely to be competitive with solar kilns are, therefore, air drying in stacks or sheds, pre-dryers, forced air drying, conventional kilns and possibly dehumidifiers. The performance of solar kilns needs, therefore, to be compared with these methods of drying.

II. REVIEW OF RESEARCH ON SOLAR KILNS

Table 1 gives a list of the research work on solar kilns which is known to the writer. References 1 - 14 have been published, reference 15 refers to verbal information given to the writer by Mr. P.J. Wood, formerly Utilization Officer of the Tanzania Forest Department, and references 16 and 17 deal with unpublished work carried out by the writer while he was working with the Forest Department in Uganda. These two kilns are described later in the paper.

Research into solar drying appears to have started more or less simultaneously in two places with the work of Rahman and Chawla in India (1) and that of Johnson and Peck in the United States (2) and (3).

Dehra Dun, India

Rahman and Chawla worked on a laboratory scale and tried out nine designs of miniature kiln. The first used a small pump to cause a flow of air through the timber placed inside one chamber. Another chamber was used to heat the air and connected by a pipe to the chamber containing the timber. The other kilns used convection as a means of circulating air through the timber, some by having the heating chamber underneath the chamber containing the timber and some by the use of a chimney. Small gains in speed were found over normal air drying but all models suffered from the fact that there was no method of recirculating heated air which consequently was lost after a single pass through the timber. It is a matter of regret that the research appears to have stopped there since, as far as is known, no further work has been published.

Wisconsin, U.S.A.

Peck, working at the Forest Products Research Laboratory at Madison, Wisconsin, U.S.A., approached the problem from a different angle and designed a small kiln similar to a conventional dry kiln but with a roof sloping towards the south and a double layer of weatherable polyester sheet to trap solar radiation and insulate the heat inside the kiln. A black painted corrugated aluminium sheet was stretched across the top of the kiln six inches inside the inner layer of polyester to absorb heat, and air was passed by means of one fan over both surfaces of the aluminium sheet. Inlet and outlet vents were used for letting in and evacuating limited quantities of air. Speeds of drying were very appreciably faster than air drying, being in the region of 60 per cent of air drying times for timber dried from green to air dry. Drying defects were found to be less than for air drying and, although costs were roughly the same as for air drying, they were half those of kiln drying. Costs of interest on capital tied up in timber during the drying process were included. The kiln was, however, only a small one capable of taking one cubic metre of timber.

Colorado, U.S.A.

Johnson built a small home-made kiln in Colorado to dry small quantities of lumber for his private use. The kiln consisted of a chamber in which boards were stacked in racks and solar heat was absorbed by window-type absorbers on the south facing side. Air was circulated by wind-powered fans. The kiln dried one-inch timber in two to six weeks, depending on weather conditions.

Puerto Rico

Later in 1962 Peck and Maldonado published a paper (4) describing a kiln capable of taking 4-5m^3 of timber; it was built in Rico Piedras in Puerto Rico. This was similar to, but larger than, the one built by Peck in Wisconsin. Air was circulated by four sixteen inch fans powered by a 1½ h.p. electric motor. Otherwise it was almost identical in design to the Wisconsin kiln. The performance of an enlarged version of this kiln was subsequently described in detail by Chudnoff, Maldonado and Goytia (7).

Colorado, U.S.A.

In 1963 Troxell in Colorado (5) published a paper in the proceedings of the Western Dry Kiln Clubs, but this writer has not seen a copy of the paper; a subsequent paper by Troxel and Mueller (10) is summarised later in this paper.

Taiwan

In 1966 Z.L. Sun published an article describing a small solar kiln built in Taiwan (6). Its performance is compared with kiln drying and air drying. The solar kiln is a small plastic covered chamber with a false ceiling and an internal fan mounted above the stack. Reductions of moisture content recorded in the kiln were 25 per cent greater than by air drying in a small shed.

Puerto Rico

One of the main contributions to the literature on solar kilns was published in 1966 by Chudnoff, Maldonado and Goytia in the form of a very full account of the operation of an enlarged version of Peck's and Maldonado's kiln at Rio Piedras (7). The kiln had been enlarged to a capacity of 7.1m^3 by lengthening it and the original 1 mil. P.V.F. sheet on the inside of the kiln had to be replaced with 2 mil. sheets after one year's use. The roof panels of 2 mil. P.V.F. sheet had to be replaced by glass after two years' use. The breakdown of the sheet was attributed mainly to flexing but some brittleness due to degradation from ultra violet radiation was observed on the roof panels. Trials were subsequently started using 4 mil. P.V.F. sheet and 5 mil. weatherable polyester sheet. A comparison was made between speeds of drying and weather conditions including solar radiation; temperatures inside the kiln were 28° (15.5°C) above the outside temperatures. Similar comparisons of humidity were made and it was found that comparable humidity differences were 21 per cent. The equilibrium moisture content for air dried timber varied from 13 to 15 per cent according to the time of year while E.M.C.'s within the kiln varied from 8 to 10 per cent. Trials of different timbers were carried out and they were grouped into Mahogany (<u>Swietenia macrophylla</u>) and mixed hardwoods varying in density at 12 per cent m.c. from 0.48 to 0.82 specific gravity. One inch (25 mm.) Mahogany dried from 50 per cent m.c. to 12 per cent m.c. in 18 days, while 1½ inch (28 mm.) took 25 days and 2 inch (50 mm.) took 41 days. Mixed hardwoods 1½ inch thick took 43 days to dry from 60 per cent to 12 per cent m.c. The quality of timber produced was as good as or better than timber dried by air drying. Some trouble was experienced with case hardening and mist sprayers were installed to humidify the atmosphere inside the kiln during the early stages of drying and for conditioning case hardened timber. The water for the sprayers was heated by a solar water heater before being sprayed into the kiln. Speeds of drying were between two and four times as fast in the solar kiln as compared with air drying.

Philippines

Casin in 1967, (8), and Casin, Ordinario and Tamayo in 1968 (11) described a small portable kiln built in the Philippines with a capacity of 1m^3. It was orientated north-south unlike most of the previous kilns; it had plywood end walls and a door in the north wall. Circulation of air was produced by a single 24 inch fan powered by a 3/4 h.p. motor. Three 4 inch x 4 inch vents were placed on one side of the kiln. Trials were carried out on four species, *Shorea polysperma*, *Pterocarpus indicus*, *Shorea negrosensis* and *Dipterocarpus grandiflorus*. The rates of drying were considerably faster in the solar kiln indicating that the kiln not only dried timber in about half the time, but also dried it to a lower moisture content than was possible with air drying. Temperatures in the kiln were between 13 and 21°F. (7.2 and 11.7°C) higher than comparable outside temperatures. The writers report, however, that case hardening was severe in some of the timber dried in the solar kiln and they considered humidification was necessary in future trials.

Uganda

The present writer started trials with a small 3.3m^3 solar kiln in 1954 and the results of these trials were published in 1967 (9). The main features of the kiln are a double layer of 5 mil. weatherable polyester film which has lasted six years and which has, at the time of writing, only deteriorated in the outer roof layer. The inner roof and walls are still sound. The kiln is orientated north-south with two small vents on the north and south walls. Two 18 inch cross shaft fans are powered by an externally mounted 3/4 h.p. motor. Curved aluminium reflectors are used on each side of the kiln to reflect solar energy into the kiln from the sides. The false ceiling, central partition in line with the fans and other internal parts, including the floor, are painted with a matt black blackboard paint. Nine different species in differing thicknesses of timber were tried and comparisons were made between air drying under shed and in a small open stack under a cover, solar kiln drying and steam kiln drying. The quality of timber produced by drying in the solar kiln was as good as or better than that produced by air drying or kiln drying; it was possible to dry timber to 12 per cent m.c. in the solar kiln in a reasonable time whereas air dried timber never came below 15-20 per cent (normally about 17 per cent) which is not low enough for furniture or high-grade joinery use. Drying speeds in the early stages of drying were not very much faster than air drying, but the gain was decisive below 30 per cent moisture content. Normal medium weight furniture timbers such as *Chlorophora excelsa* one inch thick could be dried from green to 12 per cent m.c. in a month or less. Since 1967 the kiln has been in almost continuous use drying timber for the Forest Department or for Government, or private, furniture workshops. Possibly because of the small vents little or no trouble has been experienced with case-hardening. The kiln can be seen beside the two newer and larger kilns in plate 3.

Colorado U.S.A.

Troxell and Mueller reported in 1968 (10) on a $2.8m^3$ capacity solar kiln at Fort Collins. A single layer of fibreglass reinforced corrugated polyester sheet was used to cover the kiln. This translucent material was tested against glass, to compare the properties of the two materials in transmitting solar radiation, using an Eppley Pyrheliometer. It was found only slightly inferior to glass in this respect. Previously P.V.F. film had failed in the high winds common in Fort Collins. The kiln was equipped with two 24 inch fans giving an air velocity of between 100 and 300 feet per minute (30-100 metres per minute). It was east-west orientated with a north-south slope on the roof. Differences in temperature were found in the middle of the day in summer. It was reported that vent control was important in obtaining optimum conditions. Using the pyrheliometer it was calculated from radiation reaching the inside of the kiln and timber moisture content that between 25 and 45 per cent of the solar energy reaching the inside of the kiln was used in drying the timber. The rest was dissipated. Trials with Engelman Spruce and Lodgepole Pine gave satisfactory rates of drying.

Ghana

Martinka in Kumasi (12) used an old glass covered greenhouse, capable of taking about $4m^3$ of timber, as an improvised solar kiln to compare solar drying with pre-drying in a converted oven and with air drying. The pre-dryer was capable of taking 96 board feet ($0.23m^3$). A single fan was used in the kiln to circulate the air and black painted aluminium sheet was used to absorb heat inside the kiln. Using *Nauclea* and *Entandrophragma angolense* he found that the solar kiln was intermediate between air drying and the pre-dryer in speed of drying. This was possibly due to poor insulation of the greenhouse and less good air circulation than in the pre-dryer. It could also be due partially to the much smaller size of the pre-dryer.

Madagascar

Queneau in 1970 (13) described a solar kiln at Tananarive similar in design to the Fort Collins kiln but orientated north-south and with the slope on the roof facing west. It was covered with a single layer of corrugated fibre glass reinforced polyester sheet. Two fans were used to circulate the air and a hygrometer to record conditions of humidity inside the kiln. The cement on the floor was painted black. Polystyrene was used to insulate the joins between the fibreglass sheets. The cost of building the kiln was 417,000 F.M.G. (approximately $1,500 U.S. or £625 Sterling). Two vents were placed on the high side of the kiln near the roof and two more near the floor on the opposite side. Trials were carried out using *Pinus kesiya* and *Dalbergia baroni* and these showed reductions in drying time using the solar kiln compared with air drying of 34 to 68 per cent for pine and 48 per cent for the *Dalbergia*. Savings in time were particularly apparent below 20 per cent m.c. and it was recommended that the solar kiln should be used after a preliminary period of air drying to bring timber down to the required E.M.C. of 10 per cent.

Wisconsin, U.S.A.

Wengert in an interesting paper (14) identifies sources of energy loss from the Fort Collins solar kiln and indicates that only some 16 per cent of the solar energy reaching the outer surface of the kiln is effective in evaporating water from the timber; the rest is lost as follows:

approximately 30 per cent through the walls and roof by convection or conduction;

17 per cent as reflected solar energy;

11 per cent conducted through the floor;

7 per cent used in heating the fabric of the dryer or stored in the dryer;

13 per cent in loss of longwave energy, and

14 per cent in loss through air vents.

The total energy loss plus the 16 per cent exceeds 100 per cent owing to an unmeasured input of energy from the fans and experimental error. The kiln used had only a single layered fibreglass reinforced polyester covering and Wengert suggests a double layer is required; he also suggests better insulation of the floor, baffles in the roof of the kiln painted black to absorb more of the energy falling on the roof, and improvements in the system of venting. He proposes coating the walls with infra-red reflecting chemicals, such as titanium dioxide, to reduce longwave radiation loss from the kiln. It will be interesting to see what improvement in drying rates is achieved by improvements in design suggested in this paper. Tests are now required to see what increase of efficiency can be achieved.

Tanzania

In 1968 a solar kiln was built at Moshi in Tanzania designed by P.J. Wood (15). It was flat roofed with a single layer of glass on the roof and had polythene covered side walls. A galvanised iron absorber placed 6 inches inside the walls was painted black and air was circulated by means of three fans placed above the absorber; the latter was carried across the kiln as a false ceiling. The kiln's capacity was 6m^3. Unfortunately, no information is available on its performance. Plates 1 and 2 show the kiln under construction.

Uganda

Since 1967 two further solar kilns have been built in Uganda and as no information has, as yet, been published regarding them they will be described briefly here.

Uganda Solar Kiln No. 2

The first kiln in Uganda proved both useful and remunerative since, after research had been completed, it was used to season timber on contract for other Government or commercial organizations. It was, therefore, decided to design a larger kiln of a size that would be large enough to interest joinery and furniture workshops throughout the timber trade in the use of solar kilns. The result was Kiln No. 2 of which the major design details are shown in Figures 1 and 2. The main principles of the kiln are the same as in the case of the first kiln, except that the air is circulated down the side of the kiln and then turned by a curved sheet of aluminium through 180° to go up and through the stack. Four 20 inch fans, powered by two 2 h.p. motors mounted on the roof of the kiln are used to circulate air. The fans are reversible. The kiln is capable of taking a stack of timber 24 x 7½ x 5¼ ft. (7.2 x 2.3 x 1.6 metres approximately). Improved reflectors the same length as the kiln were made and are polished with silicone car polish to reduce, as far as possible, dulling of the surface through oxidation. The kiln covering material is 5 mil. weatherable polyester sheet in two layers 1 3/4 inches (4.4 cm.) apart. The sheet is stretched vertically, rather than along the length of the kiln, and held along the joints by timber battens. This means that wall frames and roof trusses are spaced to coincide with the 42 inch width of the sheet.

Four vents (see Fib. 2) are placed opposite the fans, just under the eaves of the roof on each side of the kiln, and are controlled as shown in Figures 1 and 2. The reflectors are placed beside the kiln and half moons (C on Fig. 2) have been marked with the time of day at which the pin F holding the reflector should be in a particular hole in the half moon on the reflector stand so as to give a band of light reflecting at right angles in through the side of the kiln on to the black painted aluminium absorber. Reflectors are eight feet wide and 12 feet long (2.4 x 3.6 metres) and there are two on each side of the kiln. The floor of the kiln is concrete laid free of charge by a building firm wanting timber dried for use in a hotel. The trolley and rails were fabricated, from old sugar trolleys and rail, channel, iron, two rolled steel joists and 1½ inch shafting, in the Forest Department's Utilization Section workshop. Plate 6 shows the kiln being loaded with <u>Chlorophora excelsa</u> to be dried for use in the Ministry of Works furniture workshop. An extra source of heating has been added in the form of a home made solar water heater connected to a single coil of 3 inch pipe painted black and fitted to the wall of the kiln between the inner layer of plastic and the aluminium absorber. This forms a continuously circulating hot water system. It is doubtful, however, if it contributes much to raising the temperature in the kiln, owing to its small heat capacity compared to that of a full load of green lumber.

Operation

This second kiln was compared with the first kiln and found to be about 10 per cent slower. The quality of timber seasoned was better than in Kiln No. 1. The vents are too large for optimum seasoning and need to be kept almost closed throughout the whole seasoning period.

Costs

Since not all costs were borne by the Forest Department it was not possible to calculate the cost of building the kiln, but it is estimated that it was about Shs.12,000 E.A. (U.S.$1,700 or £706 Sterling).

Experience with the kiln

Since 1968 the kiln has been used almost continuously for commercial seasoning of furniture timber. Normally, charges have been made up of a single species at a time but often, where small quantities of any one species were required, this species was mixed with others in the kiln. In cases where species were mixed, or timber thicknesses were mixed, the slowest drying species or size was placed at the bottom of the kiln so that the quicker drying material could be removed without breaking down the whole stack. It was found inadvisable to mix small quantities of green timber with a charge of semi-dry timber unless it was a timber that dried fast with little degrade since sudden drying in an atmosphere of low humidity is liable to cause case-hardening and other degrade. There is no doubt, however, that the kiln is much more versatile than a conventional kiln with respect to its capacity to safely dry a mixed lot of green timber because of its slow drying rate.

The plans illustrated in Figures 1 and 2 were drawn after the kiln had been built from draft plans. They have been handed out to those interested in building their own kilns. Only two kilns of this design other than the one built by the Forest Department were built in Uganda, one by Prison Industries to supply dry timber for their furniture workshop and one by a private company manufacturing furniture. Neither became fully functional because the first was covered with light gauge polythene which disintegrated rapidly and the second was never completed owing to the fact that the manager interested in the kiln left the firm concerned and had not taken steps to get the correct P.V.F. covering material. It is to be regretted that neither got into commercial operation but they may do so yet.

Uganda Kiln No. 3

While the second kiln has been successful in that it has operated well and is in continuous use, it is wasteful in space and material in relation to its timber holding capacity and, therefore, in terms of its potential for earning money. It is also not geared to being mass-produced and was complicated and time consuming to build. A third kiln was designed in 1970 and built in the first half of 1971 with the aim of doubling the kiln capacity while at the same time keeping the cost and the complications of building it to a minimum. It is illustrated in Figures 3-5 and a photograph of it in the process of being built is shown in Plate 8.

Design

One difference in design is that the air is not taken down the side of the kiln and then up and through the stack as is the case with the second kiln. It passes, mainly on the inside, but also partly on the outside, of the absorber which stretches along the side of the kiln. Vents are positioned so that they are partially covered by the upper edge of this absorber and only a small proportion of the air passing through the fans can come in at one vent and out at the opposite vent. They are smaller and better sealed, if lined with felt or similar material, than the vents in No. 2 kiln. The main structure of the kiln remains the same but the plastic sheet (in this case 4 mil P.V.F. sheet for the roof and 2 mil. P.V.F. sheet for the walls, since the weatherable polyester became unobtainable) is stretched over standard sized panels which are bolted together before the sheet is finally fixed on the outside of the panels. The standard panel is shown in Figure 4. In all, twenty-two standard sized panels are used in the construction of the walls, the door and upper sections of the roof. Only four non-standard panels are required for the lower panels on the roof; the panels on the fan shaft side are smaller than those on the opposite side. There are six 20 inch (50 cm.) fans, instead of the four in the previous kiln, in order to cope with the greater stack width and height, but they are still powered by the same two 2 h.p. motors which have ample power to drive three fans. The motors in this kiln are mounted at the end of the kiln to avoid shading the roof and reducing the amount of radiation entering the kiln. The door design has been altered to enable it to be made from standard size panels and it can also be removed completely to one side. To lower cost the floor is made of rammed gravel covered by tarmac. The trolley rails are laid on pressure treated timber sleepers with a concrete beam under each rail to give added bearing strength to prevent the rails sinking.

Costs

Costs of material and labour were kept while the kiln was being built and are given in Appendix 2. The estimate of revenue and operating costs is, of necessity, tentative as the kiln has not been in operation long enough to have been tested. Interest on money invested has not been included but would be low in relation to revenue and other costs. Estimates of costs of repairs, replacements and depreciation are low but are based on experience with the other two kilns where actual costs of repairs have been very low. The fans and motors have worked virtually trouble-free apart from the occasional need to tighten and grease bearings. The roof of the small kiln has required a new outer layer but only after 6 years' operation. It remains to be seen how long the P.V.F. sheeting lasts. Occasional cleaning or repainting of the black surfaces inside the kilns is required but, normally, only once every two years. No permanent operator is required since the kilns are switched on in the morning and off in the evening and the reflectors are moved hourly. This is done by a timber inspector working on other work during working hours and a watchman out of working hours. It is of interest that the Ministry of Works has its own electrically heated, automatically controlled dry kiln capable of taking about $2m^3$ per charge. It is estimated that it costs cts.-/35 per board foot (E.A. Shs. 148.40 per m^3) as compared with the cts.-/20 per board foot (E.A.Shs.84.80 per m^3) charged for solar drying (US $0.05, 22.70, 0.03 and 13.00, respectively).

III. DISCUSSION OF DESIGN FEATURES

Insulation

Wengert demonstrated that a large proportion of the heat loss was due to poor insulation of the roof, walls and floor. He was dealing with a kiln which had only a single layer of fibreglass polyester sheet and kilns with double layers of covering material are almost certain to be more efficient. Where flexible plastic sheet is used the double layer is likely to be less effective than a rigid sheet which retains a constant air space and reduces the movement of the air within the space during the vibration of the kiln caused by the fans. Doors could, almost certainly, be made to fit better with little extra cost and vents need to be more efficient and easily adjustable in order to be able to control, more exactly, the quantity of air entering and leaving the kiln.

The type of covering material used is controlled by the limited number of transparent or translucent weatherable materials available. Since the covering material forms a large part of the cost of building a kiln, a compromise has to be made between the ideal material and economy of costs. It is unfortunate that the Mylar 500 - W weatherable polyester sheet (costing US $2.30 per m^2) used on the first two Uganda kilns is now out of production, and in Uganda any suitable covering material, other than glass which is expensive to use, has to be imported specially from abroad usually with an attendant delay of six months. Undoubtedly, this, more than anything else, has prevented the wider use of solar kilns in Uganda.

Air Circulation

The rate and evenness of flow of air through the timber stack is important in controlling the rate of drying. If kilns are only partially filled a great deal of the air flow will go over the top of the stack. A piece of plastic sheet attached at one side to the roof of the kiln (or false ceiling), and rolled round a piece of timber which is lowered onto the top of the stack, provides an easy method of preventing this. Correct design of absorbers to give an even flow of air through the timber and good heat absorption is important.

The control of vents is important and requires study. In the writer's opinion over-ventilation has been a fault of many solar kilns and a correct balance has to be found between humidity and temperature. In the early stages of drying and particularly in the region of fibbe saturation point the limiting factor is the rate at which water will pass from the centre to the outside of the timber. Too large a moisture gradient causes case-hardening and, in the early stages of drying, high temperatures and high humidities are required. It is only in the latter stages of drying that it is possible in a solar kiln to get high temperatures and low humidities. There is, therefore, a need for considerable further study to improve vent design and control.

Size of Kilns

In order to be of interest for use as a commercial dryer a solar kiln needs to have a capacity of 10-20m^3 even in a developing country where furniture and joinery workshops are run on a smaller scale than in the more developed countries. Most of the experimental kilns have so far been small ones and more work is required with sizes of kiln where the ratio of surface area of kiln to volume of timber is smaller. The third Uganda kiln is an attempt to study this problem and if it is successful it could provide a basis for a commercial kiln design for Uganda's conditions.

Reflectors

With kilns of the 10-20m^3 size or larger as much heat is required as possible, and, where possible, this should be collected from as wide an area as possible. In Uganda, which lies across the equator, it is easy to design and operate simple reflectors which reflect a considerable quantity of solar energy through the sides of the kiln. Away from the equator this would be more difficult but should not be impossible. It might also be possible to design simple air heaters to preheat air before it is drawn in through the vents; this should not prove unduly expensive.

Costs

While it is possible, no doubt, to increase the efficiency of solar kilns greatly it is important to consider the cost of doing so. The main justification for solar kilns is in their low cost and ease of building as compared with conventional kilns. There is no point in losing this major advantage in order to employ some sophisticated method of increasing kiln efficiency.

Quality of Solar Kiln Dried Timber

Almost all research workers in solar drying have reported on the high quality of timber produced. The reason for this is almost certainly that the lack of solar heating at night and the consequent lower temperatures, higher humidity and lack of air flow allow a nightly "conditioning" period where internal and surface moisture contents have time to even out. This is particularly important with the harder, heavier, slower drying species. Good conventional kiln schedules properly applied can give the same results but skilled operation is required.

IV. THE ABILITY OF SOLAR KILNS TO COMPETE WITH OTHER TIMBER DRYING METHODS

The main competing methods can be dealt with individually:

Air Drying

Costs of drying by solar kiln are generally accepted as being as high as, or higher than, air drying, even taking into account the extra length of time during which capital is tied up in air drying timber. Solar drying has three major advantages over air drying. Firstly, it is quicker, normally about twice as fast to E.M.C. of air dried timber in the climate concerned. Secondly, it is possible to dry timber to a moisture content lower than the E.M.C. of timber within closed buildings which means that it can be dried sufficiently to be suitable for furniture and high grade joinery manufacture; this is, undoubtedly, the greatest advantage of solar drying over air drying. Thirdly, solar dried timber is almost always superior in quality to air dried timber since humidity is more uniform in all stages of drying; the timber is also not subjected in the same way to better air flow and the incidence of more sunlight or heat at the ends of the timber than in the centre of the stack which is common even in the best air seasoning. There is, therefore, less chance of degrade in the form of end split than there is with air dried timber.

The major disadvantage of solar seasoning is in the small capacity of the kilns.

Forced Air Dryers

There is a possibility that with research forced air dryers could be made competitive with solar kilns. Large fans are required unless complicated baffle systems are designed and they suffer from the disadvantage that, to be effective, they need to be covered by a roof and fans need to be mounted in a wall or partition. The capital costs are, therefore, considerable without giving the advantages of higher temperatures and humidity control of the solar kiln. At present, therefore, they do not threaten, seriously, to compete with solar kilns in tropical areas.

Predryers

Predryers have been designed, in the past, to dry large quantities of timber down to around 20 per cent m.c. prior to kiln seasoning. Their purpose has been to conserve kiln time and lower costs. In this role they do not conflict in any way with solar kilns since the latter are most efficient, and can best be used for the final stages of drying. It is unlikely, therefore, that they will compete in this way. If, however, they are modified to form simple low cost conventional kilns with a simple form of heating suitable to developing countries, then the chances of their competing with solar seasoning are much greater; it might well be possible, for instance, to augment solar heat with a simple hot water system based on an open fire fed on wood waste and a 44 gallon drum.

Conventional Kilns

Solar kilns have proved in all cases, where costings have been carried out, to be cheaper than conventional kilns. Within the limitations of their size they are, therefore, competitive but, since they are slower and require to be placed so that they are exposed to direct sun for most of the day, they require a much larger area of ground per unit of timber seasoned than conventional kilns. In their present form, therefore, they are more suitable for seasoning small quantities of timber than for mass production of seasoned timber. This indicates an initial use for small joinery and furniture concerns using limited quantities of timber. It is possible that later they may be used in batteries for seasoning larger quantities of timber but development on a comparatively small scale is required first. One advantage of solar kilns is that they do not require highly skilled operators and only require periodic attention.

Dehumidifiers

The writer is not well acquainted with these, but having seen one operating on drying tea chest battens the impression gained is that they are suitable for drying timber of small dimensions, but in the case of larger dimensions the lack of applied heat and consequent slow movement of the water through the timber will reduce the efficiency of this method of drying. There does not, therefore, appear to be much likelihood of competition from this direction.

General

The only costings carried out comparing solar seasoning and other methods of seasoning were reported by Peck (3). In Uganda neither the Forest Department steam kiln nor the Ministry of Works electrically-operated kiln were representative of potentially competitive commercial kilns since they were too small and expensive to run. No costings were available for the only commercially operated kilns in the country which were located 50 miles away from the solar kilns. Charges for drying timber in these commercial kilns were 25-30 Uganda cents (3.8 - 4.6¢ US) per board foot of one inch thick timber indicating a cost of 15-20 cents allowing for a reasonable profit. Ignoring interest on capital invested, comparable costs for the second solar kiln would have been approximately 12 cents and, hopefully, 7-8 cents for the third kiln. These costs assume that timber is green at the beginning of the solar drying process. If the timber was partially dry at the start of solar drying then costs would be lower. It is not considered valid to compare air seasoning costs with those of solar seasoning since the best way of using a solar kiln is almost certainly to air season first before solar drying down to a moisture content which cannot be reached by air drying alone.

V. SUITABILITY OF SOLAR KILNS FOR DEVELOPING COUNTRIES

In developing countries the individual units in the timber industry are normally small and often separated from each other by considerable distances; sometimes communications are poor. Requirements for seasoned timber are correspondingly low in any unit and this favours the solar kiln with its low capital and running costs and small output of seasoned timber. At the same time most developing countries have climates which favour solar seasoning. A certain degree of sophistication of the industry is necessary since the "bush" carpenter is not going to be able to pay for a solar kiln nor does it matter to him or his customer if the timber used is not absolutely dry. Once the industry has developed to the stage where 10-40m^3 of timber is used per month by individual units, or where there are co-operatives of smaller units, then there is likely to be a demand for solar kilns. At this stage of development it is often not the cost per unit of timber dried that determines the use of a method of drying, but the initial capital cost of kilns, sheds or stack supports. It is, therefore, essential to keep initial investment as low as possible. It is also necessary to design kilns that are as easy as possible to make from materials that are as easy as possible to obtain. In this respect modular systems of building and standardized components are an advantage combined with good drawings and instructions on how to build.

VI. RECOMMENDATIONS

Co-ordination and Centralization of Basic Research

Research along the lines suggested by Wengert (14) is required in order to discover the nature of energy losses and to test alterations in design intended to reduce them. Research directed towards finding the best covering materials is particularly required. This research needs to be done somewhere where there are staff, funds and facilities to do it; the results will be applicable to all areas of the world. The design of the best size and shape of kiln, which will vary from country to country, should be left to individual research workers in interested countries so that they can suit kiln designs to the particular conditions in their countries.

Supply of Key Materials

The difficulty of obtaining the right plastic, fibreglass or glass for covering the kilns has, undoubtedly, held back the commercial use of solar kilns in Uganda and possibly elsewhere. Information on the various suitable materials, sources of supply and prices would be useful possibly combined with a system for distributing them.

Funds for Research and Development

In many developing countries funds for research are short and especially for the kind of research represented by solar kilns where immediate financial returns are not likely to be forthcoming in any quantity. Since "seeing is believing" it is unlikely that commercially operated kilns will become a reality in any country until it is possible to demonstrate in that country, or a nearby one, a solar kiln of commercial size in operation. There is, therefore, a need for funds not only for research but also for the prototype commercial models. These funds could be directed through an international agency to selected countries where research is already being carried out or where genuine interest, combined with favourable conditions for solar seasoning, can be found.

Dissemination of Information

Much of the research on solar kilns has been carried out by workers without knowledge of all the research done elsewhere. A corresponding committee, of those engaged on work with solar kilns in different parts of the world, would keep them up to date with the work being done. A convenor or secretary would be required to keep information circulating.

VII. ACKNOWLEDGEMENTS

The writer is indebted to Mr. M.L.S.B. Rukuba, Chief Conservator of Forests, Uganda for permission to publish information gained in Uganda and to use Forest Department plans; he is also grateful for the encouragement and funds which made the research in Uganda possible.

He is also indebted to the staff of the Uganda Forest Department Utilisation Section without whose skill, hard work and interest there would have been no solar kilns in Uganda.

The contribution of Mr. P.J. Wood who supplied the information regarding the Tanzania kiln and the photographs of it which appear in Plates 1 and 2 is also gratefully acknowledged.

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16. **PLUMPTRE**, R.A. Unpublished information on a solar kiln with 9 m^3 capacity built at the Forest Department Utilization Section, Kampala, Uganda.

17. **PLUMPTRE**, R.A. (1971) Unpublished information on a solar kiln with 19 m^3 capacity built at the Forest Department Utilisation Section, Kampala, Uganda.

TABLE 1

List of Known Published or Unpublished Information on Experimental Solar Kilns

Author or Source of Information	Date	Ref. No.	Location	Kiln Capacity or Dimensions	Design
Rahman, M.A. and Chawla, O.P.	1961	1	India	Nine small laboratory scale kilns	Various designs using separate chambers for air heating and timber and convection movement of air.
Johnson, C.L.	1961	2	Colorado U.S.A.		South facing roof, plastic double layer, wind powered fans.
Peck, E.C.	1962	3	Wisconsin U.S.A.	425 board feet (1 m^3)	South facing roof, double layer of plastic sheet, single fan.
Peck, E.C. and Maldonado	1962	4	Rio Piedras Puerto Rico	2000 board feet (4.7 m^3)	South facing roof double layer of plastic sheet 4 x 16 inch fans.
Troxell, H.E.	1963	5	Central Rocky Mountain Region U.S.A.	Not known	Not known
Sun, Z.L.	1966	6	Taiwan	Laboratory scale	Plastic covered box with false ceiling and fan.
Chudnoff, M., aldonado, E.D. and Goytia, E.	1966	7	Rio Piedras Puerto Rico	3000 board feet (7.1 m^3)	As in Ref.4 but increased size and roof covered with glass.
Casin, R.F.	1967	8	Philippines	480 board feet (1.1 m^3)	North-south orientated, single layer plastic sheet. 1 x 24 inch fan.
lumptre, R.A.	1967	9	Uganda	1400 board feet (3.3 m3)	North-south orientated, double layer plastic sheet. 2 x 18 inch fans reflectors.

Author or Source of Information	Date	Ref. No.	Location	Kiln Capacity or Dimensions	Design
Troxell and Mueller	1968	10	Central Rocky Mountain Region U.S.A.	1200 board feet (2.8 m^3)	South facing roof fibre glass reinforced polyester covering 2 x 24 inch fans.
Casin, R.F. Ordinario, E.B. Tamayo, G.Y.	1969	11	Philippines	480 board feet	As in Ref.8
Martinka, E.	1969	12	Kumasi Ghana	1700 board feet (4 m^3)	Converted greenhouse, single fan
Queneau	1970	13	Tananarive Madagascar	Similar to Ref.10	North-south orientated fibreglass translucent covering 2 fans
Mengert, E.M.	1971	14	Wisconsin U.S.A. and Colorado	As in Ref.10	Study of heat gains and losses and suggestions for improvements
Wood, P.J.	1971	15	Moshi Tanzania	Approx. 4000 board feet (6 m^3)	Flat glass roof north-south orientated polythene walls 3 fans
Plumptre, R.A.	1971	16	Uganda	4000 board feet (9.4 m^3)	North-south orientated pitched roof weatherable polyester covering (two layers) 4 x 20 inch fans reflectors
Plumptre, R.A.	1971	17	Uganda	8000 board feet (18.9 m^3)	North-south orientated pitched roof 6 x 20 inch fans weatherable P.V.F. covering (two layers)

TABLE 2

Solar Kiln No. 3 Building Costs

Item	Cost	
	Shs. Uganda	U.S.$
Main Structure		
Treated timber (1000 board feet)[1] for frames from own stock	500.00	76.50
Bolts and nuts and washers	240.00	36.70
Galvanised sheet for absorbers	950.00	145.30
Nails and screws	90.00	13.70
"Tedlar" 4 and 2 mil. P.V.C. transparent sheet, 244 m^2 at Shs. 15 per m^2	3,650.00	558.00
TOTAL	5,430.00	830.20
Timber Trolley and Rails		
Rolled steel joints	540.00	82.50
Wheels and rails (second hand)	300.00	45.90
Timber sleepers	530.00	81.00
Shafting	80.00	12.20
Channel Iron	700.00	107.10
TOTAL	2,150.00	328.70
Air Circulating Machinery		
Fans	1,800.00	275.00
Shafts	210.00	32.10
Bearings	720.00	110.10
Pulleys	500.00	76.50
Motors and starters	1,000.00	153.00
Electrical connexion charges	300.00	45.90
TOTAL	4,530.00	693.60
Foundations and Floor		
Cement	280.00	42.80
Sand	150.00	22.90
Stone	270.00	41.30
Tarmac	310.00	47.40
TOTAL	1,010.00	154.40

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[1] This lumber was costed to the kiln at cts. Uganda -/50 per board foot. The commercial price would have been about double.

TABLE 2 Continued

Item	Cost	
	Shs. Uganda	U.S.$
Reflectors		
Aluminium sheet	520.00	79.50
Piping	100.00	15.30
Concrete	50.00	7.60
Timber	100.00	15.30
TOTAL	770.00	117.70
Labour		
5 carpenter months at 400.00 p.m.	2,000.00	306.00
Welder	200.00	30.60
Labour (unskilled)	600.00	91.70
TOTAL	2,800.00	428.30
GRAND TOTAL	16,690.00	2,552.90

Note: The above costs were for a government organisation purchasing at government rates. Timber was charged at the cost of producing it in the Forest Department Sawmill.

TABLE 3

Solar Kiln No. 3

Estimated Revenue and Operating Costs Per Annum

Estimated	Cost Shs. Uganda	 U.S.$
1. **Operating Costs**		
Item		
Electricity 4 h.p. for 10 hours per day	3,600.00	551.00
Labour for loading and unloading kiln 50 man days at 6/- per day	300.00	45.90
Repairs and replacements	500.00	76.50
Overheads	500.00	76.50
Depreciation over 10 years	1,670.00	1 255.60
TOTAL	6,570.00	1,005.50

2. **Estimated Revenue**

Seasoning charges 8,000 board feet per month (18.9 m^3) at cts. -/20 (3.06¢) per board foot - Shs. 1600.00 per month or Shs. 19,200 per annum (US $2,938)

3. **Estimated sum available for insurance, interest charge, inventory cost and profit** - Shs.12,630 per annum (US $1,933)

Note: 17.00 Shillings Uganda = £1 sterling = 2.6 dollars U.S.

PLATES

Plate 1 View of solar kiln at Moshi, Tanzania from the rear. Wet and dry bulb chart recorder is on right behind the ladder. Fans can be seen above the absorber.

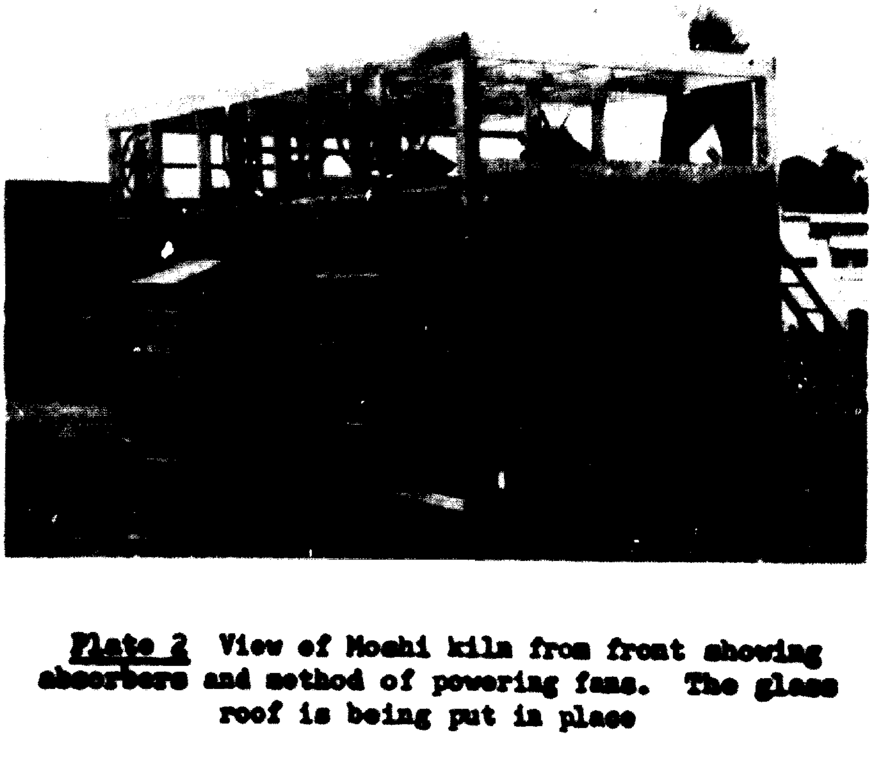


Plate 2 View of Moshi kiln from front showing absorbers and method of powering fans. The glass roof is being put in place

Plate 3

View of the three Uganda kilns and end of conveyor from sawmill. Kilns are in order of No.2, No.1 and No.3 from camera.

Plate 4

View from rear of Uganda kiln No.2 showing reflectors, solar water heater and wet and dry bulb recorder at rear of kiln. Motors and fan shafts can be seen on roof and switchgear between reflector and kiln.

Plate 5 View of Uganda kiln No.2 showing reflectors, [illegible] water heater and lagged pipe leading to heating coil, also vents and vent control lever.

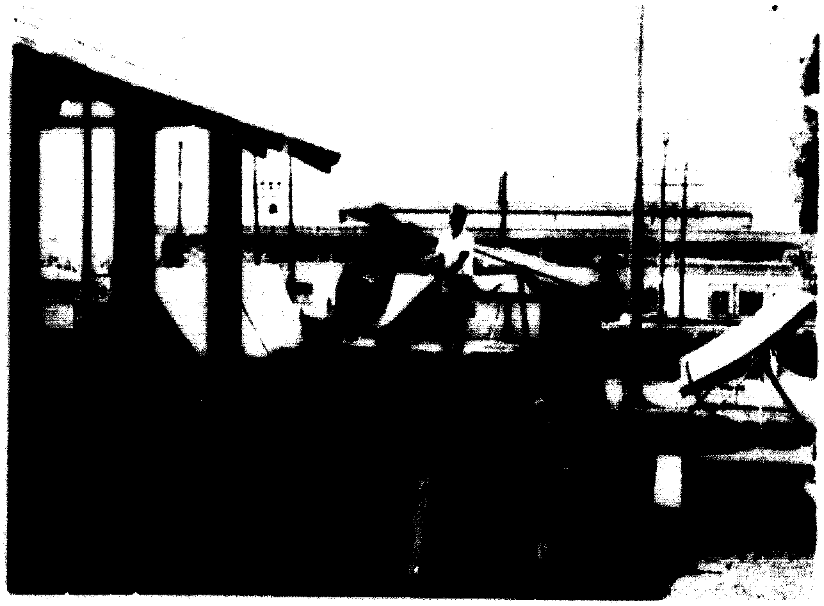


Plate 6 Loading prime *Chlorophora excelsa* for drying for Ministry of Works Uganda.

Plate 7 View from inside Uganda kiln No.2 showing absorber and baffles to turn air up and through stack. Timber trolley is being loaded with furniture timber 1¼ inches thick.

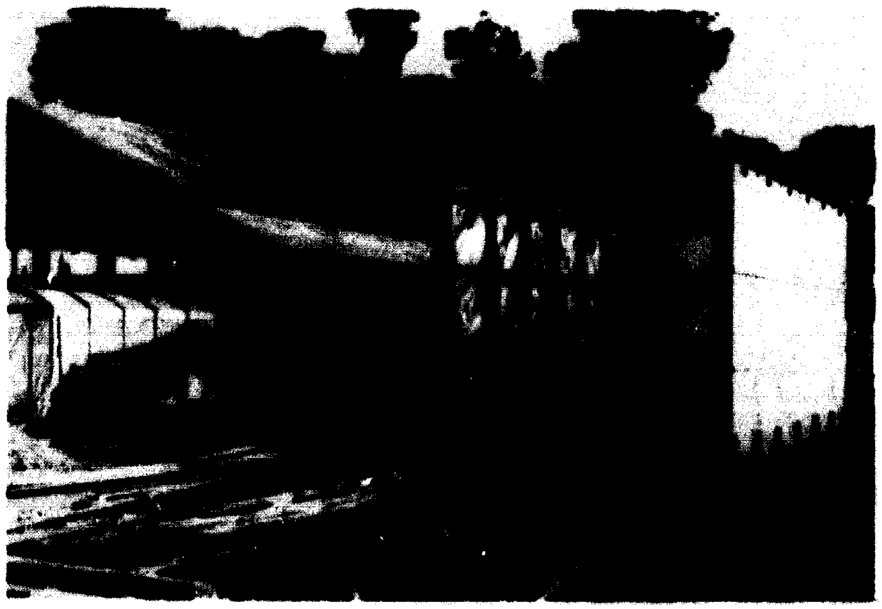


Plate 8 View of Uganda kiln No.3 under construction with kiln No.1 on left.

FIGURE 1

Cross Section of Uganda Kiln No.2.
(See key for details of labelled components)

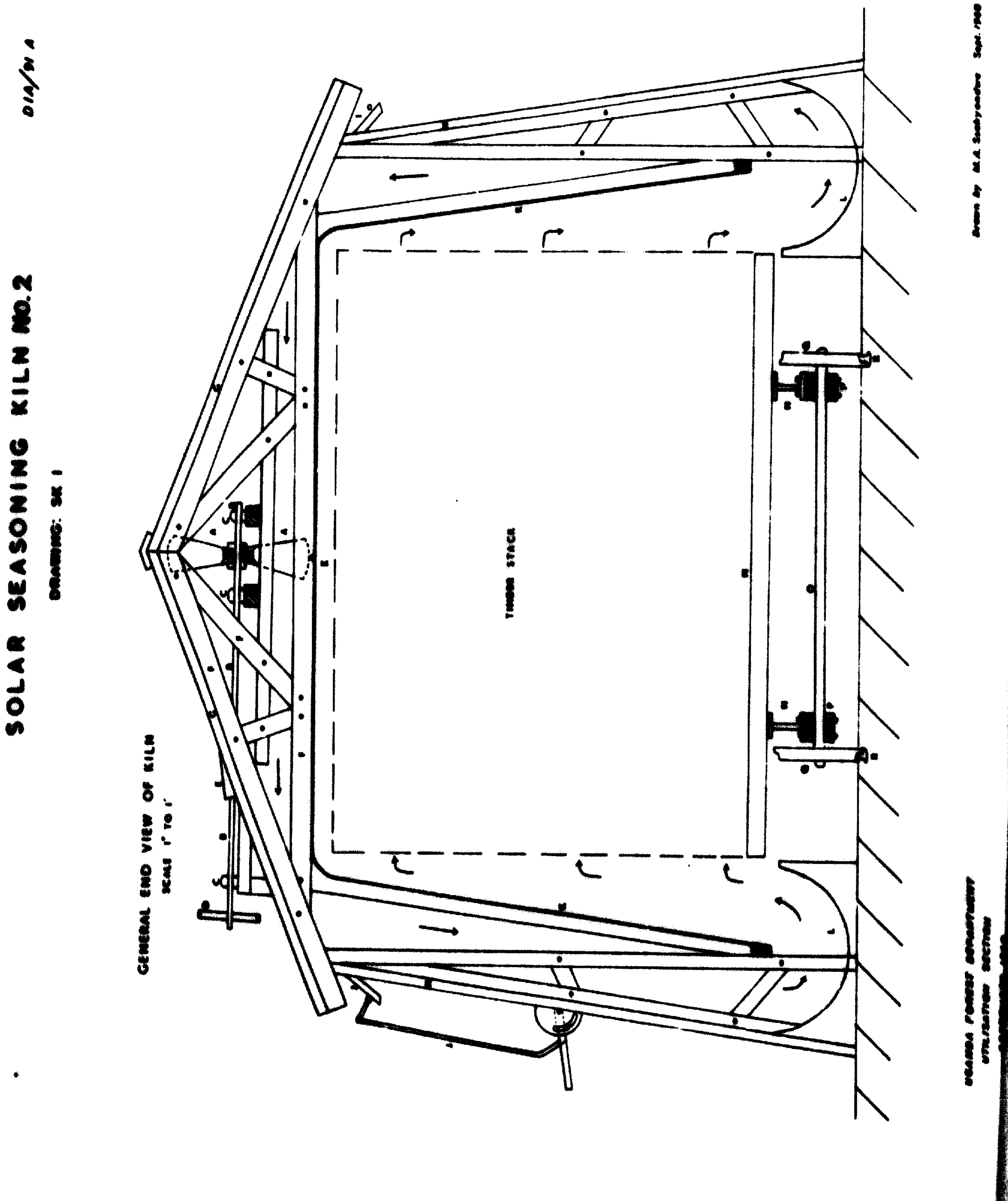


FIGURE 2

Uganda Kiln No. 2

Details of fans, vents, trolley and reflectors.
Kiln No. 3 is identical except for vent design (see Figure 5)
number of fans and width of trolley.

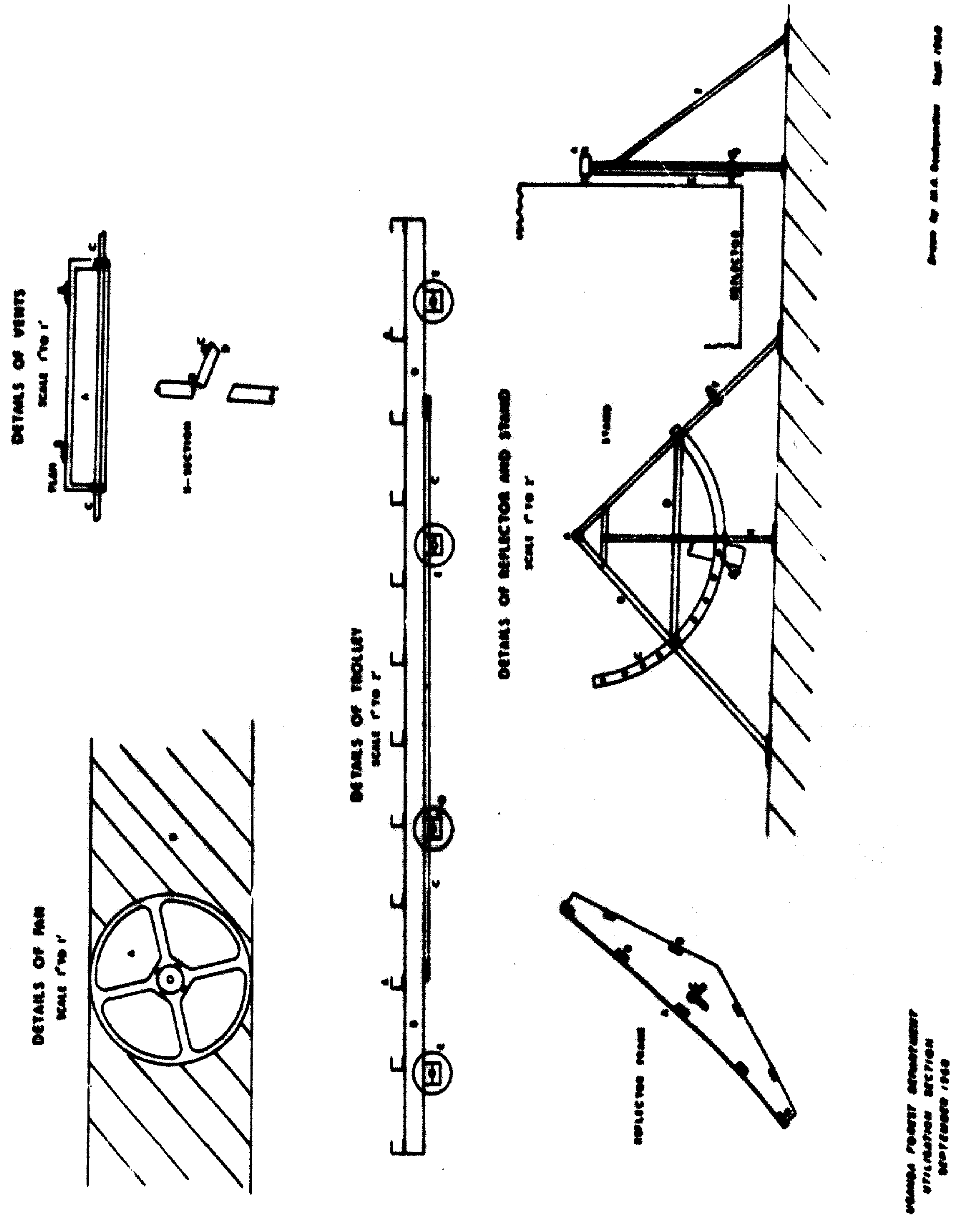


FIGURE 3 - Cross Section of Kiln No. 3 with Details of Component Parts

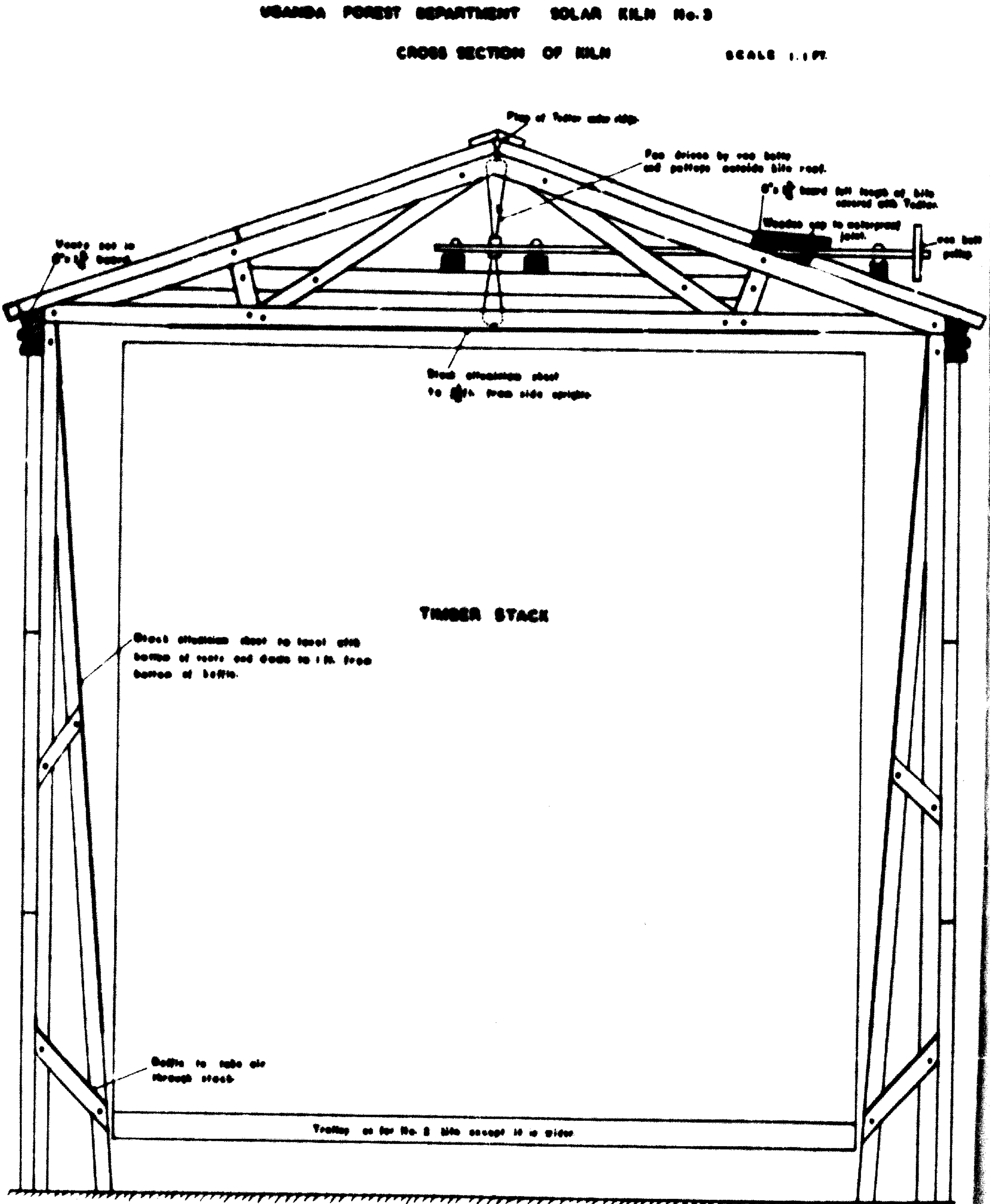
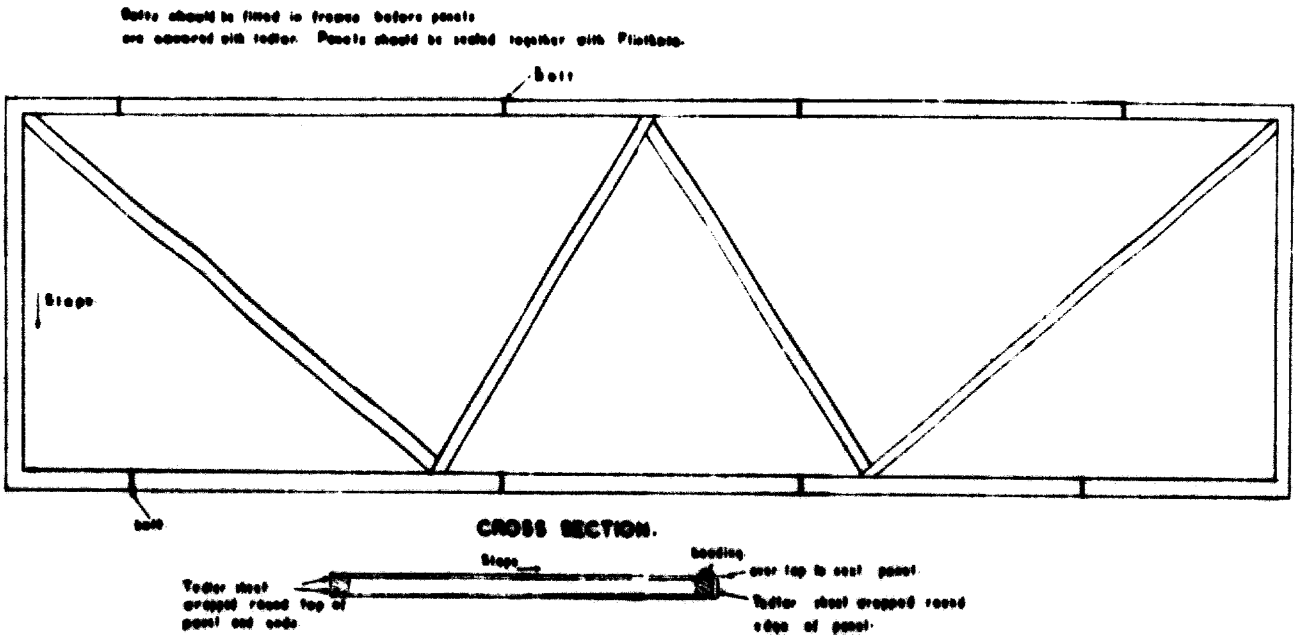


FIGURE 4 - Details of Standard Panel and Fans for Kiln No. 3

UGANDA FOREST DEPARTMENT SOLAR KILN No.3

STANDARD PANEL PLAN SCALE 1"=1FT



UGANDA FOREST DEPARTMENT SOLAR KILN No.3

SIDE VIEW. SCALE 1cm.=1FT.

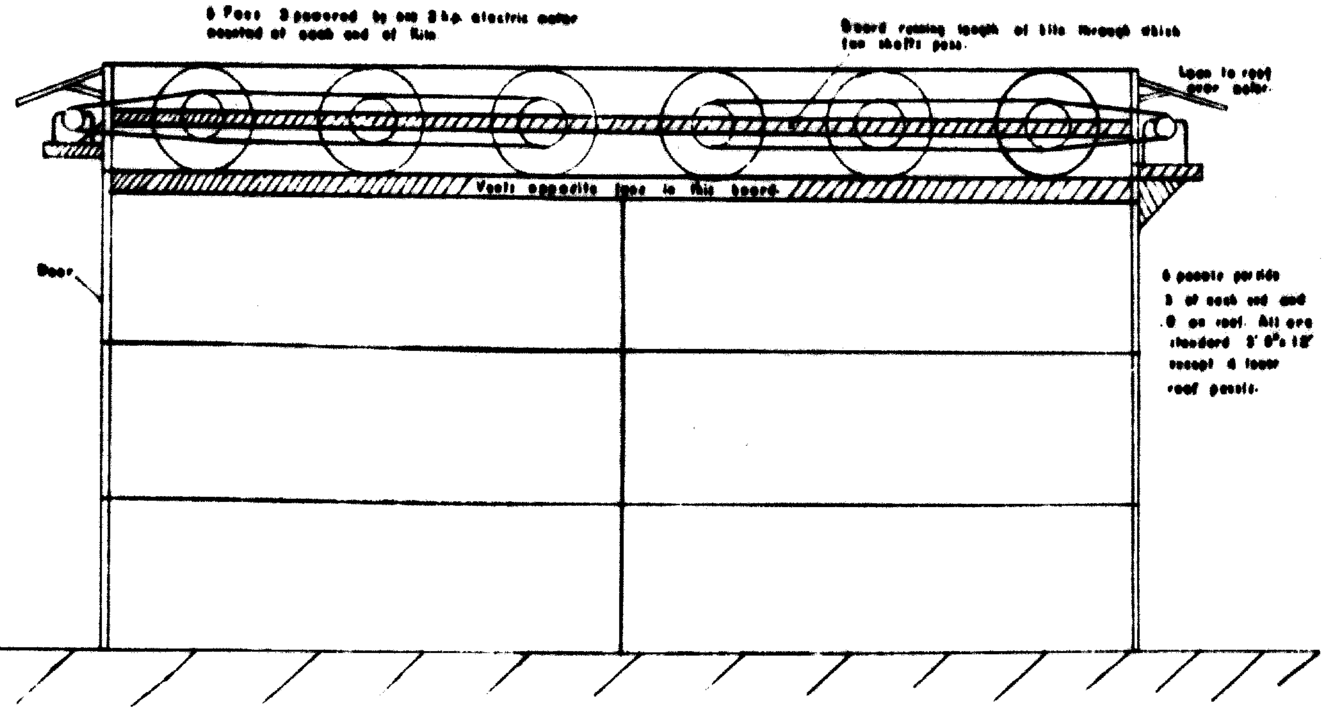
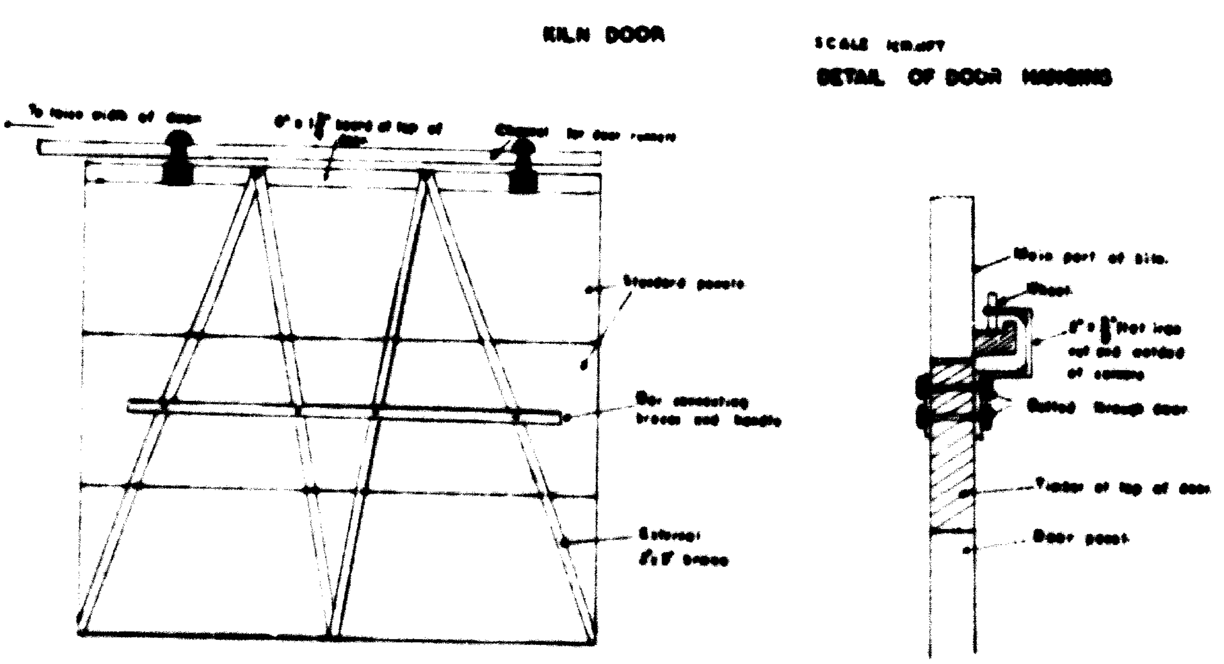
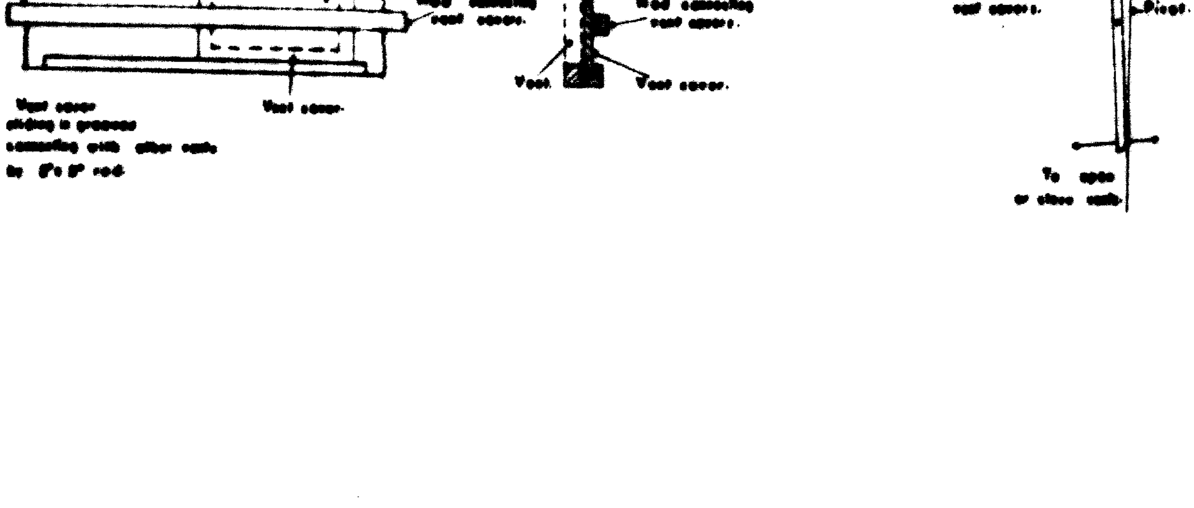


FIGURE 5

Details of Kiln Door and Vents for Kiln No.3





Key to Figure 1

A - Fan
B - Fan shaft
C - Fan shaft bearings
D - Vee pulley on fan shaft
E - Cap over fan shaft at exit through roof
F - Roof truss
G - Roof panels
H - Wall panels
I - Vents
J - Vent control
K - Black painted aluminium absorber
L - Baffle to change air flow direction
M - Channel iron bearers for kiln charge
N - R.S.J.'s forming main bearers of trolley
O - Trolley wheel shaft
P - Wooden bearings round shaft
Q - Trolley wheel
R - Trolley rail set in concrete

Key to Figure 2

Details of Fan

A - Fan blades

B - Black painted aluminium baffle

Details of Vents

A - Vent flap

B - Hinges

C - 1" pipe connecting vents

D - Bevelled bottom edge of vent

Details of Trolley

A - Channel iron cross bearers

B - R.S.J. longitudinal bearers

C - Flat iron cross bracing

D - Wooden wheel bearings

E - Wheels (old sugar trolley wheels)

Details of Reflector and Stand

Reflector Frame

A - Polished aluminium sheet

B - Longitudinal timber braces

C - Pivot

Stand and Reflector

A - Pivot for reflector

B - Stand side legs

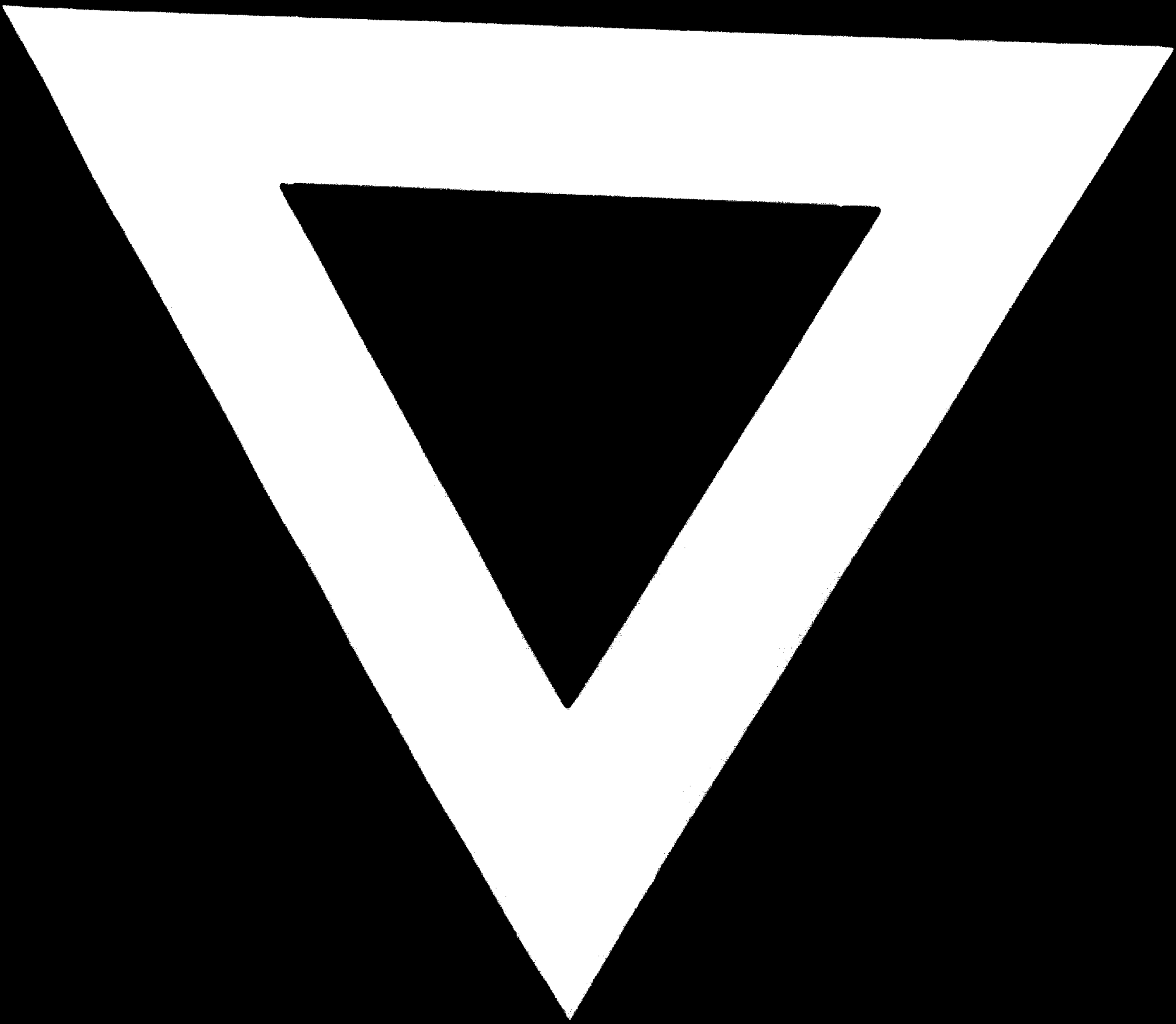
C - Half moon for setting angle of reflector

D - Cross brace for legs

E - Strut

F - Longitudinal brace joining two stands

G - Pin for fixing angle of reflector



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