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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

16027

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DP/ID/SER.B/544
7 January 1987
ENGLISH

# CONSTRUCTION OF A PROTOTYPE SOLAR TIMBER DRYING KILN

SI/GUY/84/802/11-01

GUYANA

Terminal report*

Prepared for the Government of Guyana
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of R. A. Plumptre, Consultant on timber drying and solar kiln design

Backstopping officer: A. V. Bassili, Agro-based Industries Branch

United Nations Industrial Development Organization
Vienna

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## Explanatory Notes

The following abbreviations have been used in the text of the report.

| | | | |
|---|---|---|---|
| square metres | - $m^2$ | feet | - ft |
| cubic metres | - $m^3$ | inches | - in |
| hectares | - ha | board feet | - b.f. |
| centimetres | - cm | cubic feet | - $ft^3$ |
| moisture content | - m.c. | equilibrium moisture content | - e.m.c |
| Guyana dollars | - G$ | fibre saturation point | - f.s.p |
| United States Dollars | - US$ | United Nations Development Programme | - UNDP |
| Forest Industries Development Unit | - FIDU | | |

## Abstract

In a two phase study of the timber drying industry in Guyana it was found that kiln drying is essential in the prevailing conditions of temperature and humidity to reach emcs low enough for interior use in housing in Guyana or for even more demanding conditions overseas. Only one kiln at FIDU of 17 $m^3$ is currently operating regularly other than three solar kilns now operating one at FIDU and two at a firm making joinery.

In phase 1 of the project a "Jakrap" solar kiln was erected and put into operation at FIDU in early 1985.

A new Aluminium framed and "Melinex" glazed kiln was constructed at FIDU in phase 2 of the project and a new design of solar kiln of 21 $m^3$ capacity was also erected.

Two local firms have constructed solar kilns similar to the "Jakrap" kiln to dry timber for furniture and joinery and there appears to be a general understanding of the need for kiln drying and the potential of small solar kilns for providing a low cost method of drying.

In view of the difficulties of obtaining foreign exchange for purchases overseas it is important for the success of solar drying that imports of a good glazing material and fans, motors, switchgear and spare parts for solar kilns are facilitated to provide easy local purchase of the necessary equipment.

Acknowledgements

The writer is indebted in particular to Mr R Field-Ridley who worked with him on phase 2 of the project in designing the 21 $m^3$ timber and Melinex kiln. Much of the design work and the drawings in Appendix 6 are the work of Mr Field-Ridley as is the completion of the work of building the kiln after the departure of the writer from Guyana.

He is also indebted to Mr C Hall, head of FIDU in 1986 without whose help and encouragement the project would have failed to construct the kilns or to interest the industry in timber drying. The help of Mr J Douglas, head of FIDU in 1985, is also gratefully acknowledged.

The interest and assistance of Miss C Davies Resident Representative of UNDP was also appreciated and Mr Appiateng, JPO UNIDO, Georgetown who took a keen interest in the project was of great assistance in sorting out administration problems.

The writer is keenly aware that without the help of these people and many others working at FIDU, particularly the carpenters and electricians, he would have got nowhere and, accordingly, that any achievements of the project are largely due to their interest and efforts.

# CONTENTS

APPENDICES

## INTRODUCTION

This report covers a consultancy by R. A. Plumptre, consultant in timber drying and solar kiln design split into two weeks during February 1985 and a further three weeks in July/August 1986. A copy of the job description is contained in Appendix 1. An interim report was prepared after the first two weeks and this report is complementary to the interim report but includes some of the information contained in it in order to make this a comprehensive report of the whole consultancy.

Guyana's forests cover some 18 million hectares; with a population of about 800,000 the domestic consumption of wood products is only about 180,000 $m^3$ per annum of logs and 9000 $m^3$ of sawnwood. Exports of sawn products, logs, plywood, posts, poles and piles were about 19,000 $m^3$ in 1985 worth US $3.5 million. This excludes joinery and furniture but includes dressed timber. Approximately 5 $m^3$ of logs are felled per hectare of forest cut over and some 40 species are known and sometimes used, but normally any individual sawmill only cuts a smaller number of species and 70% of exports are a single species, Greenheart (<u>Ocotea rodiaei</u>). Some 15-20 species are used for furniture manufacture.

Production which could be sustained indefinitely from the forest is probably around 9 million $m^3$ of species currently used and probably 18-20 million $m^3$ of potentially usable species. Many of the species are hard, heavy and durable but many are also very decorative and have good potential for export as furniture, flooring, joinery or prefabricated housing components. These species, therefore, offer an opportunity for a very valuable export trade and a large potential for foreign exchange earning provided the quality of the products is high enough to compete on world markets. Up till the present time the export potential has not been realised largely because of a failure to reach the standard of quality required and much of this failure has been due to a lack of good seasoning practice. Cody (1985) has reported on the furniture industry and corroborates this view. There are many examples in Guyana of furniture split or warped because it was made with inadequately dried timber and after manufacture further shrinkage occurred as it dried out. If this occurs in Guyana's climate exports to drier climates would suffer worse. Improvement of product quality is, therefore, very closely connected with improvement of wood drying practice in the country and without the latter the former is not possible.

# I WOOD DRYING IN THE TIMBER INDUSTRIES

Wood drying is carried out by both the sawmill and the wood using industries such as joinery and furniture makers and firms making pre-fab housing. A list of wood processing plants and their drying facilities is given in Appendix 2.

## A Kiln Seasoning

The only conventional kiln in commercial operation is a 17 $m^3$ kiln at the Forestry Commission's Forest Industries Development Unit at Kingston Georgetown. Three sawmills have new kilns none of which are yet functioning, one sawmill which used to operate kilns has closed down and one furniture manufacturer who has a dehumidifier kiln is not currently using it because of the cost of electricity. One other furniture manufacturer has said he is ordering a conventional kiln. FIDU is currently constructing another kiln and repairing a third, only a timer is required for the control of fans in the kiln being repaired and a door is required for the new kiln. The type of door previously fitted to the new kiln was a door which rolled up and across the top of the kiln. A door of similar design would be useful and easy to fit. These kilns are both well advanced and when completed will give a total capacity for FIDU of 142 $m^3$. The sawmills which had kilns nearing completion in February 1985 have still (July 1986), for various reasons, not managed to get them into operation.

## B Solar Kiln Seasoning

The prototype 7 $m^3$ solar kiln (the "Jakrap" kiln) constructed in the FIDU yard in phase 1 of the project has operated continuously since then and its performance will be described below. The horticultural polythene cover is now at the end of its useful life and needs renewing.

One firm which is starting a joinery and furniture business has built two kilns of similar design to the FIDU "Jakrap" kiln but modified to take ordinary polythene as a glazing material. The polythene is fixed over a frame in such a way as to enable quick and easy replacement which will be necessary as normal polythene will only last about 3 months in the tropical sun. One of these kilns is already operating using locally obtained fans. A further four kilns of a similar design have been built by a second firm but glazing material has been found difficult to procure and they are not glazed yet. A number of other firms have shown an interest in solar drying.

## C Air Drying

### In Sawmills

Most sawmills have stacking sheds except in the Corentyne area where sawmills appear to be able to market timber straight off the saw. The sheds are sometimes adequate but stacking is often poor with stickers badly placed and long overhanging unsupported ends. Block stacking in even-ended stacks is a technique which appears either not to be known or, if known, not applied. One sawmill only was seen to be end coating wood with paint to reduce end split.

Much timber is left for long periods lying in heaps in the sun before it is stacked. This is particularly destructive of quality where the timbers are hard and heavy and distortions that occur through uneven drying of one side and not the other become permanently set into the timber and very difficult to remove. The loss of quality in the form of warping and cracking due to this cause alone must be huge and carries with it a corresponding financial loss in timber that is virtually unsaleable.

In furniture and joinery workshops

Many workshops particularly in Georgetown are limited in the space they have for storing and drying wood. Sheds tend to be close together, open on only one side or badly oriented in relation to the movement of the sun. As a result airflow is often restricted or the sun shines on the ends of the timber and end splitting results. End coating of timber to slow drying of the ends is very seldom practised. Some timber is stored inside closed sheds during the later stages of drying by a small number of firms.

### D General

There appears however to be a widespread realisation now of the need for good timber seasoning practice amongst the more progressive furniture and joinery manufacturers but lack of kiln capacity and lack of an understanding of the construction and operation of kilns combined with the difficulty of obtaining foreign exchange have held back development. Methods of measuring wood moisture content are not known or not practised in most joinery and furniture workshops. Ovens for oven drying wood to determine content and electric moisture meters are only known to be used at FIDU. At FIDU most moisture content determination has been by the oven drying method because electric moisture meters have not been calibrated for local timbers and manufacturers' calibration charts do not include any Guyanese timbers.

## II WOOD DRYING IN THE GUYANA CLIMATE

Figure 1 gives histograms of humidity at Timehri Airport and figure 2 shows equilibrium moisture content of wood for given conditions of temperature and humidity. It can be seen that the equilibrium moisture content of timber in the coastal climate in Guyana is around 17-18% moisture content. Whatever length of time timber is stacked in open sheds or covered stacks it will never go much below this moisture content.

Inside closed buildings moisture content will vary but will probably be around 12% moisture content because of higher temperature or lower humidities (air conditioners lower humidities by about 1-2%). Timber to be used in furniture or joinery for the Caribbean area needs to be dried to 10-12% mc to ensure its performance will be adequate. Timber to be used in temperate climates with centrally heated buildings needs to be dried to 8-9% mc. This can only be done in some form of kiln, whether conventional or solar.

## III DRYING CHARACTERISTICS OF TIMBERS CURRENTLY USED FOR JOINERY, FURNITURE AND PREFAB. HOUSING

Appendix 3 gives a list of timbers stated to be used in the survey of the furniture industry giving their density, recommended kiln drying schedules and notes on drying characteristics. They vary in density from 0.48 $g/cm^3$ to 1.06 $g/cm^3$. The schedules recommended are also given in the same appendix. It can be seen that schedules B & C are slow schedules for slow drying woods while E, F & G are moderate schedules and J is a fast schedule.

Of the species used six require B & C and of the untested species one probably requires these schedules given in Annex 1. Six, plus probably three untested species, require E, F and G and one requires J. Seven, therefore have to be dried very slowly, nine at a medium speed and one can be dried fast. The latter is only used in very small quantities.

## IV QUANTITIES OF TIMBER REQUIRING KILN DRYING

Appendix 4 gives the quantities of timber used annually by the thirteen firms replying to Cody's questionnaire (Cody, 1985). It is estimated (Hall, 1985) that there are some forty more small joinery and furniture workshops using woodworking machinery in the neighbourhood of Georgetown, and many small carpenters. The major manufacturers of timber frame housing are not included in the total but most are equipped with their own air drying facilities except possibly some of the building contractors who are relatively small producers of prefab. timber housing.

It can be seen from the appendix that four firms use over 500 $m^3$, two 200-500 $m^3$, four 100-200 $m^3$ and three less than 100 $m^3$ per year. The four largest consumers either manufacture considerable quantities of joinery items as well as furniture or make prefab. housing.

## V CHARACTERISTICS OF CONVENTIONAL AND SOLAR KILN DRYING

The conventional kiln controls both humidity and temperature according to schedules prescribed for different timbers; the severity of drying possible, in terms of height of temperature and lowness of humidity, varies according to the timber being dried. Two processes are taking place; the first being the removal of water from the surface of the wood and the second the movement of water or vapour from the interior of the wood to the surface. In all slow-drying woods the latter is limiting and rate of drying depends on rate of movement through the wood. Given an adequate moisture gradient this is very largely temperature-dependent provided case-hardening and collapse do not occur. Kiln schedules are designed to keep these defects to a minimum and final steam treatments are designed to relieve stresses at the end of drying.

With solar drying it is not possible to control temperature other than by raising it above ambient by 10-20°C in the middle of the day. Humidity can be very considerably controlled by opening or closing vents to remove or retain humid air produced by evaporation of water from the wood. Typically, the simple greenhouse-type solar kiln in the tropics reaches a temperature of about 40°C, in the middle of the day, in the early stages of drying dropping to about 3-4°C above ambient at night. Midday humidities are around 80-90% provided vents are not opened too far and rise to nearly 100% at night if fans are shut off at night. As drying proceeds midday temperatures rise to as much as 50-55°C on clear days with humidities as low as 40-50% in the later stages of drying while night temperatures drop to 2-3°C above ambient and humidities rise to 60-80%. Day temperatures, therefore, follow fairly closely the slower conventional kiln schedules while at night temperature gradients in the timber may help to speed vapour diffusion from the centre to the surface of the wood. Solar kilns, therefore, become more competitive, compared with conventional kilns, when drying slow-drying, hard, heavy timbers. All kiln drying is best done after a preliminary period of air drying except for very fast drying woods where fast schedules can be used or for timbers which deteriorate if not kiln dried from green.

Very refractory woods may require careful air drying with end sealing and shading to prevent too rapid air drying and checking and splitting. The higher humidities in a solar kiln may often be less severe on the timber than air drying.

## A Different Designs of Solar Kilns

Solar kilns can be divided into the following three main design types:

- Greenhouse kilns
- Kilns with integral box collectors
- Kilns with external collectors

### Greenhouse Kilns

This is the simplest and cheapest type of kiln, where the kiln is a single structure containing the timber stack and heat absorbing surfaces in the same chamber. It can be single or double glazed. It has a size limit and unless very "stretched" beyond the dimensions of the stack alone it is probably not efficient over a 12-15 $m^3$ capacity.

### Kilns with integral box collectors

Box collectors, normally of prismatic shape with one side glazed, are more efficient than flat plate collectors if painted black on internal surfaces. A kiln built up of a series of boxes of this type can be built to dry efficiently 20-25 $m^3$ of timber at a time for a stack of 8-10 metres long. For longer stacks a greater volume is possible. The cost of this type of kiln is greater, but not very much greater, than for the greenhouse kiln.

### External Collector Kilns

These kilns are less limited in size since efficient, well insulated external air or water filled collectors can be manufactured of any size and the hot air or water pumped into the kiln chamber which is also efficiently insulated. These kilns are very much more costly, they are more difficult to control and operate and in the writer's opinion they are not worth considering for Guyana.

## B Advantages and Disadvantages of Solar Kilns

The advantages of solar kilns over conventional kilns are as follows:

- lower capital cost (by a factor of 5-10 for greenhouse types)
- lower running cost for power and labour
- less skill required to operate them adequately
- ease of construction and maintenance
- continuous supervision not needed (no boiler man)
- high quality of drying because it is slow
- little maintenance required other than replacement of glazing material.

The disadvantages are:

- small capacity
- slower drying (by a factor of 1½-3 times depending on timber species and thickness)
- glazing materials have relatively short life (1 year in tropics for horitcultural polythene and 2-3 years for Melinex)
- glazing materials are fragile but can be repaired.

## C Performance of the "Jakrap" kiln at FIDU

The "Jakrap" solar kiln erected in February 1985 has operated more or less continuously since then. During that period the roof was renewed after about 10 months service and the sides are now at the stage where they need renewal and have got beyond repair. A number of timbers have been dried in the kiln to 8-10% mc from different initial moisture contents. Details of those species are given in Appendix 5. Some 15 charges have been put through the kiln in the course of the 16 months it has been operating. Humidity and temperature within the kiln were much as expected and the rate of drying was similar to the estimates made for the Aluminium/Melinex kiln in the Interim report. The highest temperature recorded in the kiln was 52°C which is similar to the 53°C temperature recorded for the Aluminium/Melinex kiln in its first few days of operation; the latter should be more efficient because of the greater transparency to shortwave radiation and greater opaqueness to longwave radiation of the Melinex. Fans, motors and switchgear operated without any problems for the period of 16 months the kiln has been operating. In order to enable the kiln to continue operating a supply of horticultural polythene, 50 mm wide PVC adhesive tape, "Velchro" and eyelets are required to make up a new cover. The tools for doing the job are still available at FIDU. Drying curves, for five charges put through the kiln are given in Figure 3 while graphs of mean daily humidity and temperature in the kiln from 0800 hrs till 1600 hrs, inclusive, during the drying period are given in Figure 4. Figure 4 illustrates how humidities dropped and temperatures rose during drying to achieve the moisture contents of 8-10% mc required. Figure 5 shows typical daily movement of humidity and temperature from 0800 hrs till 1600 hrs for two charges at three different moisture contents and for one wet day and for one fine day mid way through the drying cycle. It is interesting to note that humidities as opposed to temperature do not vary as greatly during the day as might be expected from temperature variation and humidities, as in a conventional kiln, are slowly lowered throughout the drying cycle.

## D Construction of the Aluminium/Melinex Kiln

The kiln was completed in just over seven working days. Although the crate in which it was packed was damaged badly on arrival only one small part was missing and it was replaced. There were no major difficulties in assembling the kiln. It was assembled around a stack of timber which had been air dried for a long period of time and required drying from air dry to 8-10%. It has been found from trials of this kiln in Sri Lanka that the Melinex on the roof of the kiln only lasted 2 years but on the sides of the kiln it is likely to last three years. This makes very little difference to the viability of the kiln provided it is possible to obtain the Melinex which is relatively cheap compared with the rest of the kiln but in Guyana the problem of obtaining spare Melinex needs to be overcome.

## E Construction of the Larger Timber and Melinex Kiln

The construction of the new design of larger kiln was started with the help of Mr R Field-Ridley who had prepared some rough drawings before the writer's arrival in Guyana and who, with the help of Mr Clayton Hall, had collected most of the necessary building materials. Discussions were held on methods of constructing the main trusses, methods of bracing the structure and methods of glazing the kiln to get water-tight and airtight joints and to stretch the Melinex taut. It was decided to glaze the roof with Melinex but clad the sides under the eaves with plywood into which vents could be cut.

When the writer left Guyana the sides and five of the eight main trusses of the kiln were in place and the method of glazing had been tested and found to work satisfactorily. There remained the glazing of the rest of the structure, the fitting of fans, motors and switchgear, the fitting of the doors and the completion of the timber trolley and rails which were all on site. In addition the false ceiling and longitudinal central plywood partition above the false ceiling needed fitting to the trusses. It is unfortunate that it was not possible in the time available, to complete the kiln but FIDU should not have any great difficulty in completing the job. All the necessary materials are on site and the workshop staff were briefed on what needed to be done. Mr Field-Ridley will supervise the completion of the job.

Preliminary drawings of the new kiln are attached as Appendix 6 .

## F Operation and Recording of Performance of Kilns

Operating instructions for the Aluminium/Melinex kiln and suggested methods of recording performance of the kilns are given in Appendix 7. A half day seminar was given to FIDU staff, Forestry Commission training school trainees and one member of private industry, near the end of the consultancy, on the potential value of forest products to Guyana, the need to maintain high standards of quality for exported products, the importance of wood drying in maintaining quality, the need for kiln drying, methods of operating solar kilns and methods of monitoring performance and measuring moisture content of wood. The staff of FIDU have copies of Appendix 7 and a list of minor works needing doing to improve the performance of the Aluminium/Melinex kiln was left with the staff.

## G Maintenance Schedule for the Aluminium/Melinex Kiln

A schedule of daily and weekly maintenance and maintenance required every time a kiln charge is changed was handed to FIDU staff and is given in Appendix 8.

## H Costs of Operation of Aluminium/Melinex Kiln

Costings prepared for the interim report have been updated and revised in the light of experience with the "Jakrap" kiln and are given in Appendix 9. They assume that the Aluminium/Melinex kiln will perform at least as well as the "Jakrap" kiln. It is clear that, although costs of some items have had to be revised upwards quite considerably since March 1985 because of a rise in the cost of materials, electricity and an underestimation of some costs in the interim report, the rise from G $0.5 to G $0.6 (US $0.14) per bf in the charge for drying timber more or less compensates for the cost rises. It appears, therefore, that the kiln is viable to operate even on 8 charges per year and it can dry down to 8% mc and still be profitable.

### I Costs of Operation of the New Timber/Melinex Kiln

The costs of operating the new kiln are unknown. It is likely to be slightly slower operating than the Aluminium kiln having a slightly lower absorber area to timber volume ratio than the latter but the rather faster air flow and the box shape of the collectors may compensate for this. It is not considered worth attempting here to cost the kiln until it has proved to work well but as the capital cost of the kiln per unit of volume of kiln capacity is low it is likely to be viable unless it is very considerably slower than the Aluminium kiln.

Kits for the "Jakrap" kiln are no longer obtainable and, therefore, cost and revenue have not been calculated for it. It is certain, however, that the kiln would be profitable to operate at a charge of G $0.6 per bf seasoned provided horticultural polythene and other materials to make new covers could be obtained in Guyana.

## VI KILN DRYING REQUIREMENTS FOR THE GUYANA TIMBER INDUSTRY

### A Existing kiln capacity and drying practice

The large sawmills at Demerara Woods Ltd, Interior Forest Industries Ltd and Guyana Timbers (currently not operational) already have adequate kiln seasoning capacity of their own provided it is put into working order. At Kingston, the Forestry Commission's Forest Industries Development Unit has one 17 $m^3$ capacity kiln operating, spares for a 95 $m^3$ kiln have been ordered to put it back into working order and a 30 $m^3$ kiln and boiler have been purchased and are partially erected; only the door remains to be put in place. Assuming the three kilns at Kingston are put in working order and kiln drying of timber for the trade is done from green to 12% mc it is likely that 20 days will be required in the kilns per load. 17 charges of 142 $m^3$ could be put through the kilns per year, once they are operating or a total of 2414 $m^3$.

The requirement for the thirteen largest firms in Georgetown are 5835 $m^3$ (see Appendix 4) so the Commission at full production could meet about 40% of the requirements of these firms. There is, however, a sizeable sawmill industry in the Corentyne area making little or no attempt to dry timber at all and several millers mould profiles for timber housing straight off the saw with water running out of the wood. The resulting surface finish is extremely poor and purchasers even if they then dried out the timber would encounter great difficulties in putting it together and obtaining a reasonable surface finish.

At present the only kiln in the country which is being properly operated is the 17 $m^3$ kiln at Kingston. Elsewhere drying practice varies from being non-existent to being seriously attempted but very imprecise. In spite of this Guyana has a heritage of beautiful wooden buildings, both public and private, which is surpassed by very few. This is a tribute either to better seasoning practice in former times or the very forgiving nature of the country's timbers.

There is little hope, however, of successful and trouble free entry into Caribbean furniture or joinery markets and even less into North American or European markets without competent kiln drying to 12% for the Caribbean and 8-10% for temperate regions. Prefabricated housing components for the Caribbean area should be dried preferably to 12% mc, but drying to 20% for most components except windows, doors and flooring is probably acceptable because equilibrium moisture content for the external parts of a house is 17 to 18%.

## B Advantages and Disadvantages of a Central Kiln Drying Facility at Kingston

The Kingston yard provides the only reliable kiln drying in the country at present and it is also recognised as a centre where training can be obtained; it is gaining a reputation for good quality drying. This reputation suggests that joinery and furniture manufacturers would be keen to use this facility to have their own timber dried or would be willing to buy dried timber from the Commission. This is becoming the case and growing numbers are requesting this service, although with only the 17 $m^3$ kiln operating at present the quantity of timber which can be dried is very limited; as the full 142 $m^3$ capacity becomes available the ability to dry timber for the trade will increase. There are, however, several factors to be taken into account in the provision of a central drying facility to custom dry timber for the trade as follows:

1. The trade becomes very dependent upon the efficient functioning and operation of a small number of kilns.

2. Some 18 species in some 5 different thicknesses are currently used which would require sorting and drying on different schedules or drying on the schedule suitable for the slowest drying timber in the charge. This could become very wasteful of energy and time with a large kiln containing different species and sizes

3. Customer's timber will have to be carefully labelled and sorted after drying and customers with fast drying species and sizes will not want to wait for the slower timbers owned by others to dry.

4. There will be a tendency for some timber to be over-dried and there will be temptation to under-dry the slowest drying woods.

Similarly, the following factors need to be taken into account in building up stocks of dried timber at the Kingston yard from which the trade can purchase ready-dried timber:

1. The different members of the trade tend to specialise on particular timbers and these are different for different firms.

2. The trade reacts to its customer's preferences for timber for furniture ordered by them. There are therefore, likely to be changes in patterns of demand.

3. It is unlikely that the Forestry Commission will be able to hold stocks of all the species and sizes required. If they do, they will find some are very slow moving and this leads to problems of storage and tying up capital for too long a time.

4. One aim of the Commission is to get more species on the market and undoubtedly more species than are currently used for furniture, joinery or flooring could be used. Promotion of the use of more species is very important to the rational and economic use of the forest, since 5 $m^3$/ha is a very low volume to be taking out of the forest and leads to uneconomic logging and sawmilling. Promotion of more species would, however, complicate further the problem of kiln drying and stock holding.

### C Balance Between Forestry Commission and Private Drying

The Commission is providing a very valuable service which should be expanded as planned, but it cannot dry timber for the whole trade as indicated above nor can it cope with the complexities of large numbers of species and sizes.

Similarly, the provision of a small number of large kilns is almost certainly not what is needed by the trade except for prefab. housing, where large quantities of a small number of sizes of, at present, a limited number of species are required. Preservation to treat non-durable woods for housing is urgently required and would increase the range of species which could be used for this purpose.

The aim, therefore, should be to equip as many private firms as possible which are attempting to produce high quality furniture and joinery, with kilns which are suitable to their size of operation and to train them to use them efficiently. This requires the right size of kiln with the right capital and running costs for the size of operation concerned.

Several small kilns are probably more suitable than one large one provided economies of scale are not too great. The dehumidifier type kiln is economic on labour and energy but is expensive on electricity while steam heated kilns are cheap on electricity but high on capital and labour costs.

### D The Suitability of Solar Kilns for Guyana Industries

The performance of the "Jakrap" kiln and the interest of a number of furniture and joinery industries suggest that, for these industries, solar kilns may have considerable attraction. They are much cheaper to purchase than conventional kilns and the indications are that they are cheaper to operate. Temperatures of 50°C in the "Jakrap" kiln towards the end of the drying period approach the temperatures used in the slower conventional kiln schedules and the temperature of 53°C recorded in the Aluminium/Melinex kiln in its first week of operation suggests that solar drying can approach quite closely to conventional kiln drying. Figures 3-5 show the gradual reduction of humidities and the corresponding increase of temperatures as solar kiln drying proceeds. These are similar to slow conventional kiln schedules and the resulting quality of drying has been proved by the "Jakrap" kiln to be as good as the drying obtained in the conventional kiln. Very little seasoning degrade has been reported by FIDU Seasoning staff from the "Jakrap" kiln. Two boards were shown to the writer exhibiting collapse but this was associated with bands of tension wood. The quality of drying, therefore, seems to be adequate for a range of species from heavy, hard and slow drying to soft, light and fast drying. For the smaller firms, therefore, solar drying appears to be a promising method of seasoning timber. For the larger firms, and particularly firms requiring large quantities of timber for wooden housing, conventional kilns may be more appropriate. The alternative is a fairly large number of solar kilns. The latter are better operated in conjunction with air drying, the stack being air dried and then kiln dried after placing the portable kiln around it. A considerable area of land is required for this and some firms do not have it: even with conventional kilns, however, it is more economic to air dry first and then finish the drying process in the kiln.

## VII TRAINING

A half day seminar was held at FIDU on the necessity for wood drying in producing quality wood products, the causes of wood movement and shrinkage, the measurement of moisture content, and methods of operating and controlling drying in kilns. The seminar covered most of the operating instructions in Appendix 7. The seminar was attended by FIDU staff, Forest School students and one manager in a private industry.

## VIII PUBLICITY

The "Jakrap" kiln has generated a certain amount of interest amongst furniture makers as evidenced by the fact that two are building their own solar kilns of similar design. Some 8-10 people from industry made enquiries about kiln design and construction during the second stage of the project. It appears that more would build kilns if a durable plastic were readily available to glaze them.

The kilns were visited by the Minister of State for Forestry Mr Dharamdeo Sawh and the necessity for the importation of horticultural polythene, Melinex and necessary materials for repairing and replacing the glazing was emphasised to him. He said that he would ensure that methods of doing this were set up.

The press in the form of a reporter and photographer from the "Chronicle" newspaper came to see the kilns and were briefed on them.

## IX CONCLUSIONS AND RECOMMENDATIONS

### A Conclusions

The following conclusions can be drawn from the project:

1. The climate of Guyana is such that air drying will not dry timber in most parts of the country below 17-18% mc.

2. Kilns of some kind are, therefore, essential to dry timber for joinery and furniture to 12% mc for the Caribbean area and 8-9% for temperate climates. For pre-fabricated housing for the Caribbean 12% is necessary for internal joinery and 18-20% for framing and external cladding. The latter is attainable with prolonged air drying but faster in a kiln.

3. The 17 $m^3$ capacity kiln at the FIDU yard is currently the only conventional kiln operating in the country although the two larger kilns at FIDU are almost completed.

4. The "Jakrap" solar kiln at FIDU has operated for 17 months and is capable of drying timber to 8% in an acceptable period of time.

5. The Aluminium/Melinex kiln constructed in the second stage of the project, is operating and recorded a figure of 53°C soon after construction. It is, therefore, likely to be slightly faster than the "Jakrap" kiln.

6. The larger experimental kiln was only half completed during the writer's stay in Guyana but will be completed by Mr R Field-Ridley and FIDU staff. It is not anticipated that any serious difficulties will be encountered in doing this. No measure of its efficiency can be made until it is operating.

7. Six solar kilns have been built by two joinery/furniture makers, one was operating using ordinary polythene sheet which will deteriorate within three months but can be quickly replaced.

8. There is a widespread awareness now of the need for proper timber drying and a likelihood of more solar kilns being built by the joinery/furniture trade if supplies of glazing material and fans and motors with high temperature windings can be made available for purchase in Guyana.

9. Methods of measuring wood moisture content are not well known and very infrequently used in the timber trade. There is a need for equipment and training in monitoring kiln and air drying and in the control and maintenance of kilns.

10. There is a need to calibrate electrical resistance moisture meters for Guyana timbers for each different type of moisture meter. Preliminary instructions issued to staff at FIDU on how to do this by comparing meter readings with oven drying and weighing is given in Appendix 10. Some refining of the method may be necessary to give a representative range of moisture contents to compare with the two methods.

## B Recommendations

Inadequate wood drying is a major factor in preventing the manufacture of high quality wood products in Guyana and there is now a realisation of this fact by most furniture and joinery manufacturers. Failure to remedy the situation is due partly to the lack of knowledge of the fundamentals of wood drying and how to measure accurately wood moisture content, partly to the lack of knowledge of seasoning kilns, both solar and conventional, and how to construct and operate them and partly to a reluctance to spend large sums of foreign exchange on drying equipment which is not well understood. The conventional kiln equipment comes in a wide range of makes, employing different methods of drying, whose relative merits are also poorly understood and many of which are of too large a capacity and of too high a price to be acceptable for their size of operation. An important extra factor preventing development is the difficulty of obtaining foreign exchange for the original purchase of the equipment or for spare parts and accessories necessary to keep the equipment operating.

Solar kilns have proved to operate quite successfully in Guyana and offer the chance of bringing kiln drying within the range of possibility for the smaller firms.

If they are to be widely accepted and used the main constraints preventing the use of kilns need to be addressed which are lack of ability to get the necessary materials and spare parts when required and the lack of knowledge of how to monitor and control kiln operation and the measurement of moisture content of timber. With these in mind the following recommendations are made:

1. The offer of the Minister of State (made on 4 August 1986) to facilitate the import and holding of materials for the manufacture and repair and maintenance of solar kilns and for the monitoring and control of all kiln drying should be taken up by UNIDO and by FIDU with speed and energy.

   The major materials required are as follows:

   (a) Glazing materials for kilns:-
   - Melinex 071 (from ICI or Cambridge Glasshouse Co Ltd) or similar, durable glazing material for the Aluminium kiln and the new kiln. It would be equally suitable for kilns purchased or home-built by Guyanese firms. "Tedlar" from Du Pont Co Ltd is a more durable but more costly alternative.
   - Horticultural polythene for the repair of the "Jakrap" kiln cover and Commerical kilns using this as a glazing material.
   - PVC repair tape and "Velchro" for doors and vents of "Jakrap" and similar kilns and eyelets for making up covers for this kiln.

   (b) Motors, fans and switchgear
   Suitable for all the solar kilns built so far in Guyana. (All fans used are a standard 24 inch fan with ¼hp rated, single phase, high temperature wound motor).

   (c) Kiln Monitoring Equipment
   - Single, small, thermostatically controlled electric ovens for oven-drying wood samples at just over 100°C.
   - Simple scales for weighing wood.
   - Moisture meters, preferably of a standard make which can be calibrated for Guyanese timbers.
   - Simple wet and dry bulb thermometers for use in checking temperature and humidity in kilns and in wood stores and stacking sheds.
   - Spare batteries and probes for moisture meters.

2. The lack of knowledge of methods of measuring moisture content by oven-drying and the use of moisture meters recording temperatures and humidity, sampling of kiln charges for moisture content and calibrating electrical resistance moisture meters needs to be remedied.

   It is recommended that one or more courses be run, lasting one week, on moisture in wood and kiln operation and monitoring. It should, preferably, be run using equipment available for purchase in Guyana through recommendation 1 above. This would enable participants to be trained on equipment they or their employers could buy. The consultant selected to run the course should be given a week to visit industry and prepare teaching material for the course.

3. Monitoring of the durability and performance of the new solar kiln plus suggestions for improvement in design and construction are desirable. This evaluation could be done by a consultant at the same time as recommendation 2 above.

4. Training of a Staff Member of FIDU in Wood Technology is needed. With the transfer of Mr J Douglas from FIDU to Demerera Wood Ltd there is now no one at FIDU with a Wood Technology Qualification. A young member of the staff will be going for five years to Russia to do a first degree and an MSc in Wood Technology but will not return for five years. The postgraduate, one year diploma course in Wood Technology at the Buckinghamshire College of Higher Education would be suitable or a similar course elsewhere.

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**Table 1 Relative humidity-equilibrium moisture content table and saturated vapor pressure for use with dry-bulb temperature and wet-bulb depression —°C**

**Difference between wet- and dry-bulb temperatures in degrees Celsius**

| Temp dry bulb (°C) | V.P kPa | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 6.0 | 7.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.6 | 91 / 20.5 | 82 / 17.0 | 73 / 14.3 | 64 / 12.2 | 56 / 10.5 | 47 / 9.0 | 39 / 7.6 | 31 / 6.3 | 22 / 4.9 | 14 / 3.5 | | |
| 5 | 0.9 | 93 / 21.6 | 86 / 18.4 | 79 / 15.9 | 72 / 14.0 | 65 / 12.3 | 58 / 10.9 | 51 / 9.7 | 45 / 8.5 | 38 / 7.5 | 32 / 6.5 | 19 / 4.4 | 6 / 1.9 |
| 10 | 1.2 | 94 / 22.4 | 88 / 19.5 | 82 / 17.2 | 76 / 15.3 | 71 / 13.7 | 65 / 12.4 | 60 / 11.2 | 54 / 10.2 | 49 / 9.3 | 44 / 8.4 | 33 / 6.8 | 23 / 5.2 |
| 15 | 1.7 | 95 / 23.0 | 90 / 20.3 | 85 / 18.1 | 80 / 16.3 | 75 / 14.8 | 70 / 13.6 | 66 / 12.4 | 61 / 11.5 | 57 / 10.6 | 52 / 9.8 | 44 / 8.3 | 35 / 7.0 |
| 20 | 2.3 | 96 / 23.4 | 91 / 20.9 | 87 / 18.8 | 83 / 17.1 | 78 / 15.7 | 74 / 14.4 | 70 / 13.4 | 56 / 12.4 | 62 / 11.5 | 59 / 10.8 | 51 / 9.4 | 44 / 8.2 |
| 25 | 3.2 | 96 / 23.6 | 92 / 21.2 | 88 / 19.3 | 84 / 17.7 | 81 / 16.3 | 77 / 15.1 | 74 / 14.0 | 70 / 13.1 | 67 / 12.3 | 63 / 11.5 | 57 / 10.2 | 50 / 9.1 |
| 30 | 4.2 | 96 / 23.7 | 93 / 21.5 | 89 / 19.6 | 86 / 18.0 | 83 / 16.7 | 79 / 15.5 | 76 / 14.5 | 83 / 13.6 | 70 / 12.8 | 67 / 12.1 | 61 / 10.8 | 55 / 9.7 |
| 35 | 5.6 | 97 / 23.7 | 93 / 21.5 | 90 / 19.8 | 87 / 18.2 | 84 / 16.9 | 81 / 15.8 | 78 / 14.8 | 75 / 13.9 | 72 / 13.1 | 69 / 12.5 | 64 / 11.2 | 59 / 10.2 |
| 40 | 7.4 | 97 / 23.6 | 94 / 21.5 | 91 / 19.8 | 88 / 18.3 | 85 / 17.1 | 82 / 16.0 | 80 / 15.0 | 77 / 14.1 | 74 / 13.4 | 72 / 12.7 | 67 / 11.5 | 62 / 10.5 |
| 45 | 9.6 | 97 / 23.4 | 94 / 21.4 | 91 / 19.7 | 89 / 18.3 | 86 / 19.1 | 83 / 16.0 | 81 / 15.1 | 78 / 14.2 | 76 / 13.5 | 73 / 12.8 | 69 / 11.6 | 64 / 10.6 |
| 50 | 12.3 | 97 / 23.1 | 95 / 21.2 | 92 / 19.6 | 89 / 18.2 | 87 / 17.0 | 84 / 16.0 | 82 / 15.0 | 80 / 14.2 | 77 / 13.5 | 75 / 12.8 | 71 / 11.7 | 66 / 10.7 |
| 55 | 15.8 | 97 / 22.9 | 95 / 20.9 | 92 / 19.4 | 90 / 18.0 | 88 / 16.9 | 85 / 15.8 | 83 / 15.0 | 81 / 14.2 | 78 / 13.4 | 76 / 12.8 | 72 / 11.7 | 68 / 10.7 |
| 60 | 19.9 | 98 / 22.4 | 95 / 20.6 | 93 / 19.1 | 90 / 17.8 | 88 / 16.7 | 86 / 15.7 | 84 / 14.8 | 82 / 14.0 | 79 / 13.3 | 77 / 12.7 | 73 / 11.6 | 69 / 10.7 |
| 65 | 25.0 | 98 / 22.0 | 95 / 20.1 | 93 / 18.8 | 91 / 17.5 | 89 / 16.4 | 87 / 15.5 | 84 / 14.6 | 82 / 13.9 | 80 / 13.2 | 78 / 12.6 | 74 / 11.5 | 71 / 10.6 |
| 70 | 31.2 | 98 / 21.6 | 96 / 19.9 | 93 / 18.5 | 91 / 17.2 | 89 / 16.2 | 87 / 15.2 | 85 / 14.4 | 83 / 13.6 | 81 / 13.0 | 79 / 12.4 | 75 / 11.3 | 72 / 10.4 |
| 75 | 38.6 | 98 / 21.1 | 96 / 19.5 | 94 / 18.1 | 92 / 16.9 | 90 / 15.9 | 88 / 15.0 | 86 / 14.1 | 84 / 13.4 | 82 / 12.9 | 80 / 12.2 | 76 / 11.1 | 73 / 10.3 |
| 80 | 47.4 | 98 / 20.6 | 96 / [illegible] | 94 / [illegible] | 92 / 16.6 | 90 / 15.5 | 88 / 14.7 | 86 / 13.9 | 84 / 13.2 | 82 / 12.5 | 82 / 11.9 | 77 / 10.9 | 74 / 10.1 |
| 85 | 57.8 | 98 / [illegible] | 96 / 15.6 | 94 / [illegible] | 92 / 16.2 | 90 / 15.2 | 88 / 14.3 | 87 / 13.6 | 85 / 12.9 | 83 / 12.3 | 81 / 11.7 | 78 / 10.7 | 75 / 9.9 |
| 90 | 70.1 | 98 / 13.6 | 96 / [illegible] | 94 / 16.9 | 92 / 15.8 | 91 / 14.8 | 89 / 14.0 | 87 / 13.3 | 85 / 12.6 | 84 / 12.0 | 82 / 11.4 | 79 / 10.5 | 76 / 9.7 |
| 95 | 84.5 | 98 / 19.1 | 96 / [illegible] | 94 / 16.4 | 93 / 15.4 | 91 / 14.5 | 89 / 13.7 | 99 / 12.9 | 86 / 12.3 | 84 / 11.7 | 83 / 11.2 | 79 / 10.3 | 76 / 9.5 |
| 100 | 101.3 | 98 / 18.[illegible] | 96 / 17.2 | 95 / [illegible] | 93 / 15.0 | 91 / 14.1 | 90 / 13.3 | 88 / 12.6 | 86 / 12.0 | 85 / 11.4 | 83 / 10.9 | 80 / 10.0 | 77 / 9.2 |
| 105 | 120.8 | 98 / 18.0 | 97 / [illegible] | 55 / [illegible] | 93 / 14.6 | 92 / 13.7 | 90 / [illegible] | 88 / 12.3 | 87 / [illegible] | 84 / 11.1 | 84 / 10.6 | 81 / 9.7 | 78 / 9.0 |
| 110 | 143.2 | 98 / [illegible] | 97 / [illegible] | 95 / [illegible] | 93 / 14.1 | 92 / 13.3 | 90 / 12.6 | 89 / 11.9 | 87 / 11.3 | 86 / 10.8 | 84 / 10.3 | 81 / 9.5 | 78 / 8.7 |
| 115 | 169.0 | 98 / [illegible] | 97 / [illegible] | 95 / [illegible] | 94 / 13.7 | 92 / 12.9 | 90 / 12.2 | 89 / 11.6 | [illegible] / 11.0 | 86 / 10.5 | 85 / 10.0 | 82 / 9.2 | 79 / 8.0 |

| Temp dry bulb (°C) | V.P kPa | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 22.0 | 24.0 | 26.0 | 28.0 | 30.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.6 | | | | | | | | | | | | | | | | | | |
| 5 | 0.9 | | | | | | | | | | | | | | | | | | |
| 10 | 1.2 | 14 / 3.5 | 4 / 1.3 | | | | | | | | | | | | | | | | |
| 15 | 1.7 | 27 / 5.8 | 19 / 4.5 | 12 / 3.0 | 4 / 1.3 | | | | | | | | | | | | | | |
| 20 | 2.3 | 37 / 7.2 | 30 / 6.2 | 24 / 5.2 | 17 / 4.1 | 11 / 2.9 | 5 / 1.6 | | | | | | | | | | | | |
| 25 | 3.2 | 44 / 8.1 | 38 / 7.2 | 33 / 6.4 | 27 / 5.6 | 22 / 4.8 | 16 / 3.5 | 11 / 3.0 | 7 / 1.9 | | | | | | | | | | |
| 30 | 4.2 | 50 / 8.8 | 44 / 8.0 | 39 / 7.2 | 34 / 6.5 | 29 / 5.8 | 25 / 5.2 | 16 / 4.5 | 12 / 3.8 | 12 / 3.0 | 8 / 2.2 | 4 / 1.3 | | | | | | | |
| 35 | 5.6 | 54 / 9.3 | 49 / 8.5 | 44 / 7.8 | 40 / 7.1 | 36 / 6.5 | 31 / 5.9 | 27 / 5.4 | 23 / 4.8 | 20 / 4.3 | 16 / 3.7 | 13 / 3.1 | 9 / 2.4 | 6 / 1.7 | | | | | |
| 40 | 7.4 | 57 / 9.6 | 53 / 8.8 | 48 / 8.1 | 44 / 7.5 | 40 / 7.0 | 36 / 6.4 | 33 / 5.9 | 29 / 5.5 | 26 / 5.0 | 22 / 4.5 | 19 / 4.1 | 16 / 3.6 | 13 / 3.1 | 8 / 2.0 | 2 / 0.7 | | | |
| 45 | 9.6 | 60 / 9.8 | 56 / 9.0 | 52 / 8.4 | 48 / 7.8 | 44 / 7.3 | 40 / 6.8 | 37 / 6.3 | 34 / 5.9 | 30 / 5.5 | 27 / 5.1 | 24 / 4.7 | 22 / 4.3 | 19 / 3.9 | 14 / 3.1 | 9 / 2.2 | 4 / 1.2 | | |
| 50 | 12.3 | 62 / 9.9 | 58 / 9.2 | 54 / 8.5 | 51 / 8.0 | 47 / 7.5 | 44 / 7.0 | 40 / 6.5 | 37 / 6.1 | 34 / 5.8 | 31 / 5.4 | 29 / 5.0 | 26 / 4.7 | 23 / 4.4 | 18 / 3.7 | 14 / 3.0 | 10 / 2.3 | 6 / 1.5 | 2 / 0.6 |
| 55 | 15.8 | 64 / 9.9 | 60 / 9.2 | 57 / 8.6 | 53 / 8.0 | 50 / 7.5 | 47 / 7.1 | 43 / 6.7 | 40 / 6.3 | 38 / 5.9 | 35 / 5.6 | 32 / 5.3 | 30 / 5.0 | 27 / 4.7 | 22 / 4.1 | 18 / 3.5 | 14 / 2.9 | 19 / 2.3 | 7 / 1.7 |
| 60 | 19.9 | 66 / 9.9 | 62 / 9.2 | 59 / 8.6 | 55 / 8.1 | 52 / 7.6 | 49 / 7.0 | 46 / 6.7 | 43 / 6.4 | 40 / 6.0 | 38 / 5.7 | 35 / 5.4 | 33 / 5.1 | 30 / 4.8 | 26 / 4.3 | 22 / 3.8 | 18 / 3.3 | 14 / 2.8 | 11 / 2.3 |
| 65 | 25.0 | 67 / 9.6 | 64 / 9.1 | 60 / 8.5 | 57 / 8.0 | 54 / 7.6 | 51 / 7.1 | 48 / 6.8 | 45 / 6.4 | 43 / 6.1 | 40 / 5.8 | 38 / 5.5 | 35 / 5.2 | 33 / 4.9 | 29 / 4.4 | 25 / 4.0 | 21 / 3.5 | 17 / 3.1 | 14 / 2.7 |
| 70 | 31.2 | 68 / 9.7 | 65 / 9.0 | 62 / 8.5 | 59 / 8.0 | 56 / 7.5 | 53 / 7.1 | 50 / 6.7 | 47 / 6.4 | 45 / 6.1 | 42 / 5.8 | 40 / 5.5 | 37 / 5.2 | 35 / 5.0 | 31 / 4.5 | 27 / 4.1 | 23 / 3.7 | 20 / 3.3 | 17 / 2.9 |
| 75 | 38.6 | 70 / 9.5 | 66 / 8.9 | 63 / 8.4 | 60 / 7.9 | 57 / 7.4 | 54 / 7.0 | 52 / 6.6 | 49 / 6.3 | 47 / 6.0 | 44 / 5.7 | 42 / 5.5 | 39 / 5.2 | 37 / 5.0 | 33 / 4.5 | 29 / 4.1 | 26 / 3.8 | 23 / 3.4 | 19 / 3.1 |
| 80 | 47.4 | 71 / 9.4 | 67 / 8.8 | 64 / 8.2 | 61 / 7.7 | 59 / 7.3 | 56 / 6.9 | 53 / 6.6 | 51 / 6.2 | 48 / 5.9 | 46 / 5.7 | 44 / 5.4 | 41 / 5.2 | 39 / 4.9 | 35 / 4.5 | [illegible] / 4.1 | 28 / 3.8 | 25 / 3.5 | 22 / 3.1 |
| 85 | 57.8 | 72 / 9.2 | 68 / 8.6 | 66 / 8.1 | 63 / 7.6 | 60 / 7.2 | 57 / 6.8 | 55 / 6.4 | 52 / 6.1 | 50 / 5.8 | 47 / 5.6 | 45 / 5.3 | 43 / 5.1 | 41 / 4.9 | 37 / 4.5 | 33 / 4.1 | 30 / 3.8 | 27 / 3.5 | 24 / 3.2 |
| 90 | 70.1 | 72 / 9.0 | 69 / 8.4 | 67 / 7.9 | 64 / 7.4 | 61 / 7.0 | 59 / 6.7 | 56 / 6.3 | 54 / 6.0 | 51 / 5.7 | 49 / 5.5 | 47 / 5.2 | 45 / 5.0 | 43 / 4.8 | 39 / 4.4 | 35 / 4.1 | 32 / 3.7 | 28 / 3.4 | 25 / 3.2 |
| 95 | 84.5 | 73 / 8.8 | 70 / 8.2 | 68 / 7.7 | 65 / 7.3 | 62 / 6.9 | 60 / 6.5 | 57 / 6.2 | 55 / 5.9 | 53 / 5.6 | 50 / 5.4 | 48 / 5.1 | 46 / 4.9 | 44 / 4.7 | 40 / 4.3 | 37 / 4.0 | 33 / 3.7 | 30 / 3.4 | 27 / 3.1 |
| 100 | 101.3 | 74 / 8.6 | 71 / 8.0 | 69 / 7.5 | 66 / 7.1 | 63 / 6.7 | 61 / 6.3 | 58 / 6.0 | 56 / 5.7 | 54 / 5.5 | 52 / 5.2 | 49 / 5.0 | 47 / 4.8 | 45 / 4.6 | 42 / 4.3 | 38 / 3.9 | 35 / 3.6 | 32 / 3.3 | 29 / 3.1 |
| 105 | 120.8 | 75 / 8.4 | 72 / 7.8 | 69 / 7.3 | 67 / 6.9 | 64 / 6.5 | 62 / 6.2 | 60 / 5.9 | 57 / 5.6 | 55 / 5.3 | 53 / 5.1 | 51 / 4.9 | 49 / 4.7 | 47 / 4.5 | 43 / 4.1 | 39 / 3.5 | 36 / 3.5 | 33 / 3.3 | 30 / 3.0 |
| 110 | 143.2 | 76 / 8.1 | 73 / 7.6 | 70 / 7.1 | 68 / 6.7 | 65 / 6.3 | 63 / 6.0 | 61 / 5.7 | 58 / 5.4 | 56 / 5.2 | 54 / 4.9 | 52 / 4.7 | 50 / 4.5 | 48 / 4.3 | 44 / 4.0 | 41 / [illegible] | 38 / 3.4 | 34 / 3.2 | 32 / 3.0 |
| 115 | 169.0 | 76 / [illegible] | 74 / [illegible] | 71 / 6.9 | 69 / 6.5 | 66 / 6.2 | 64 / 5.8 | 62 / 5.5 | 59 / 5.3 | 57 / 5.0 | 55 / 4.8 | 53 / 4.7 | 51 / 4.4 | 49 / [illegible] | 46 / [illegible] | 42 / [illegible] | 39 / [illegible] | 36 / [illegible] | 33 / 2.9 |

Calculated from Hailwood-Horrobin single hydrate equation using parameters determined by Simpson (1973).

From Kiln Drying of Western Canadian Lumber by G Bramhall and R W Wellwood

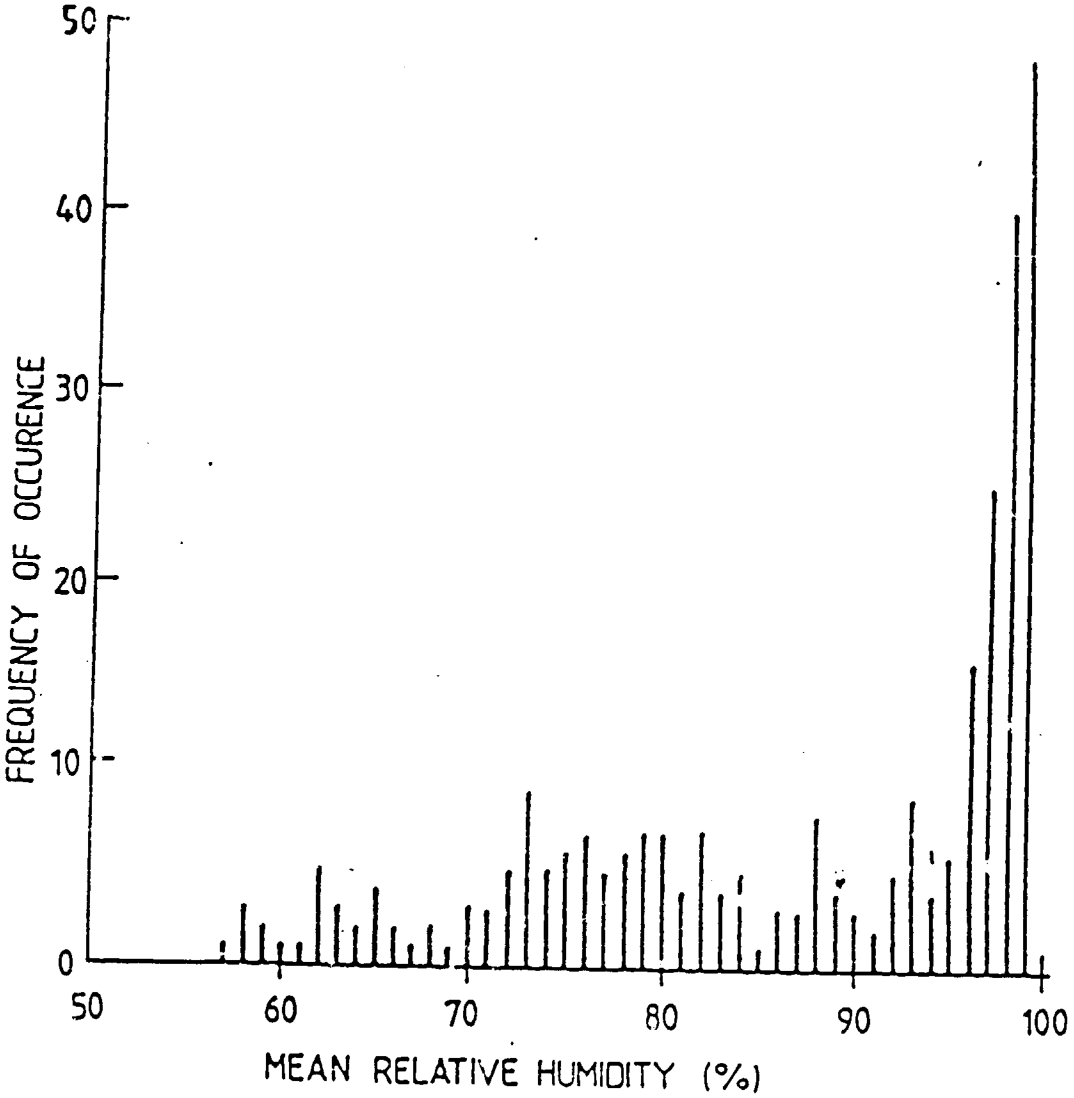



Figure 1 Relative humidity at Timehri airport in 1973, after Bonar [2]

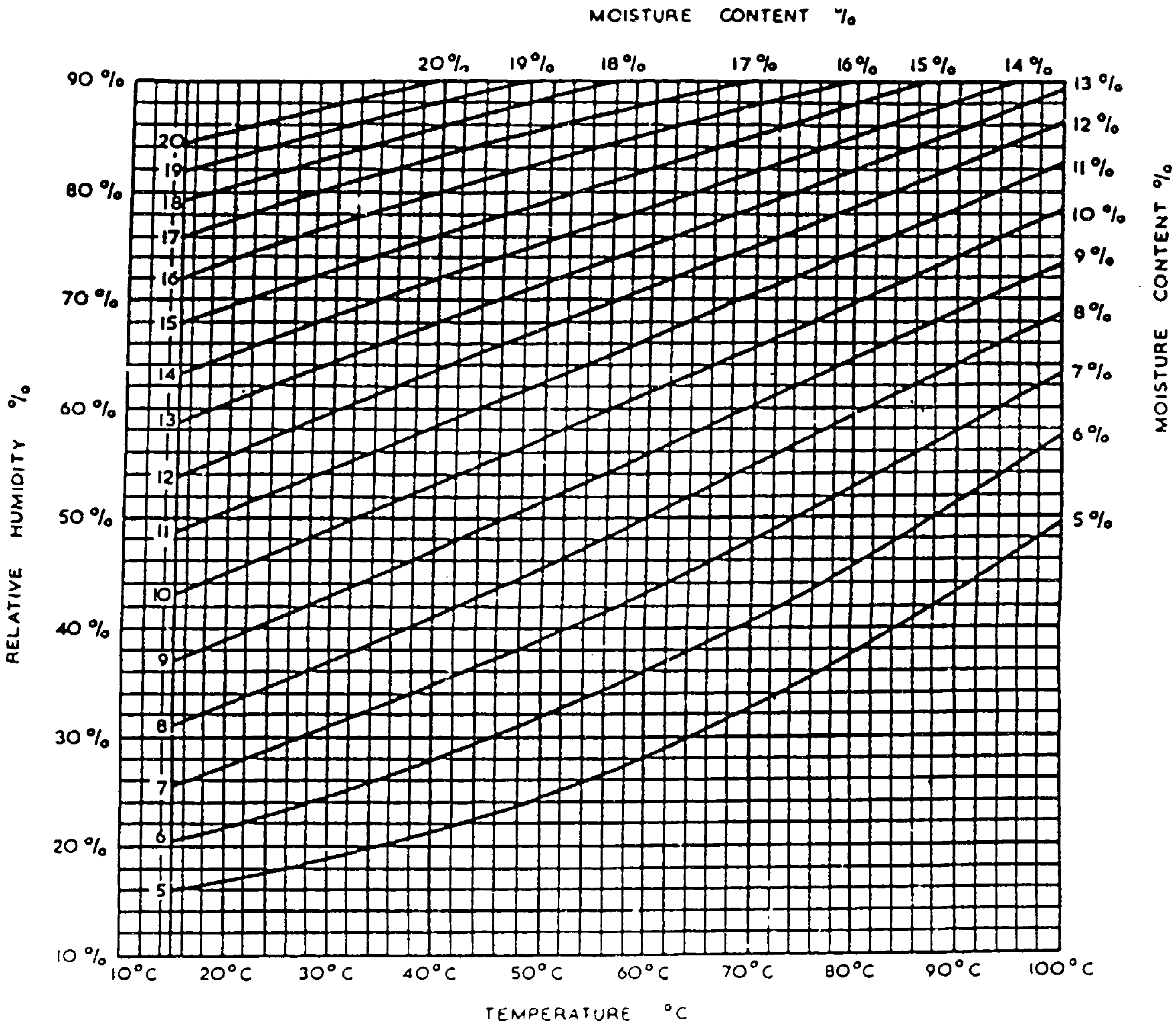



Figure 2. Relationships between humidity temperature and equilibrium moisture content of timber.

FIGURE 3. JAKRAP KILN DRYING CURVES, GUYANA
Figures in brackets are wood density in g/cm³

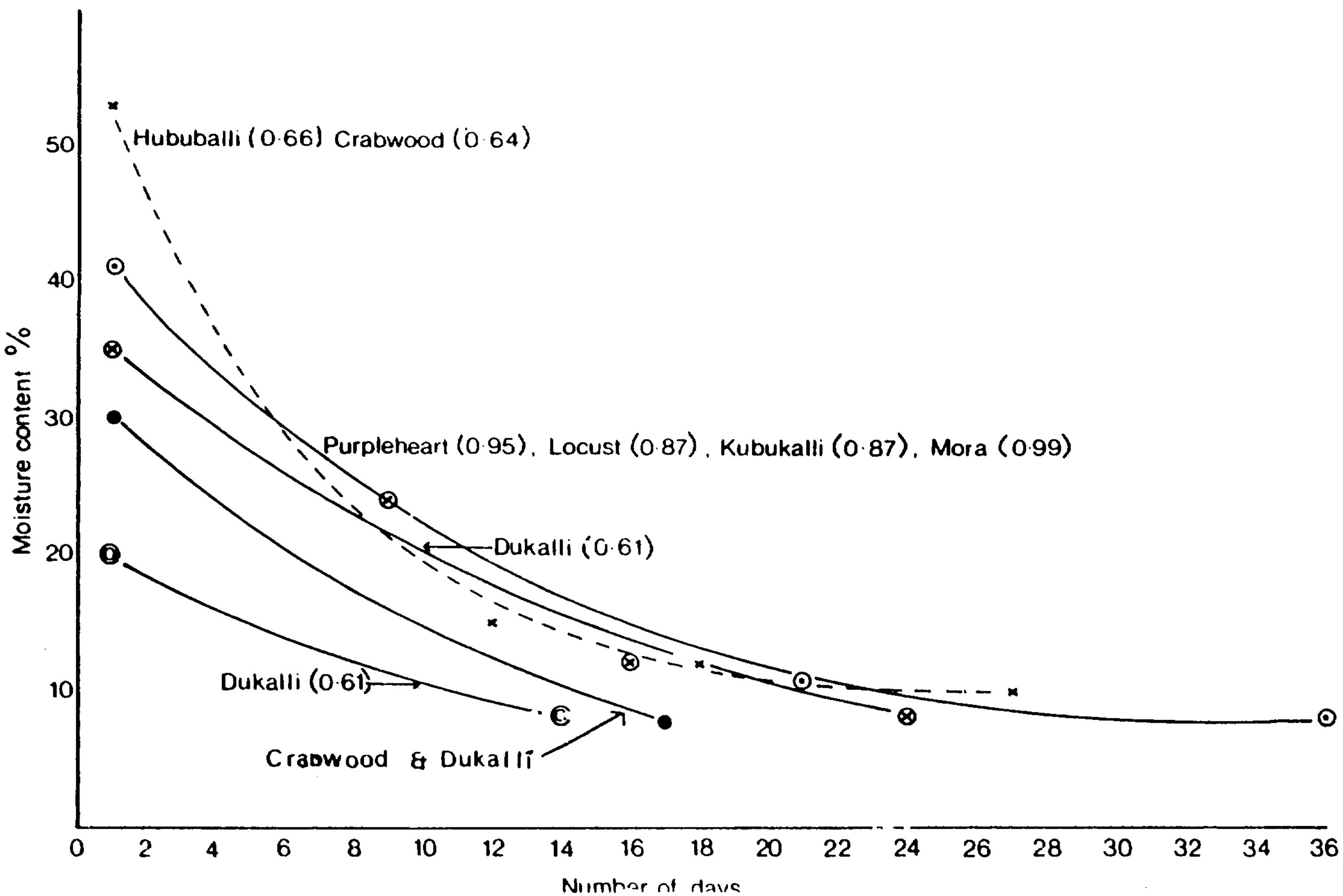


FIGURE 4. MEAN DAILY HUMIDITY AND TEMPERATURES DURING DRYING OF TWO CHARGES

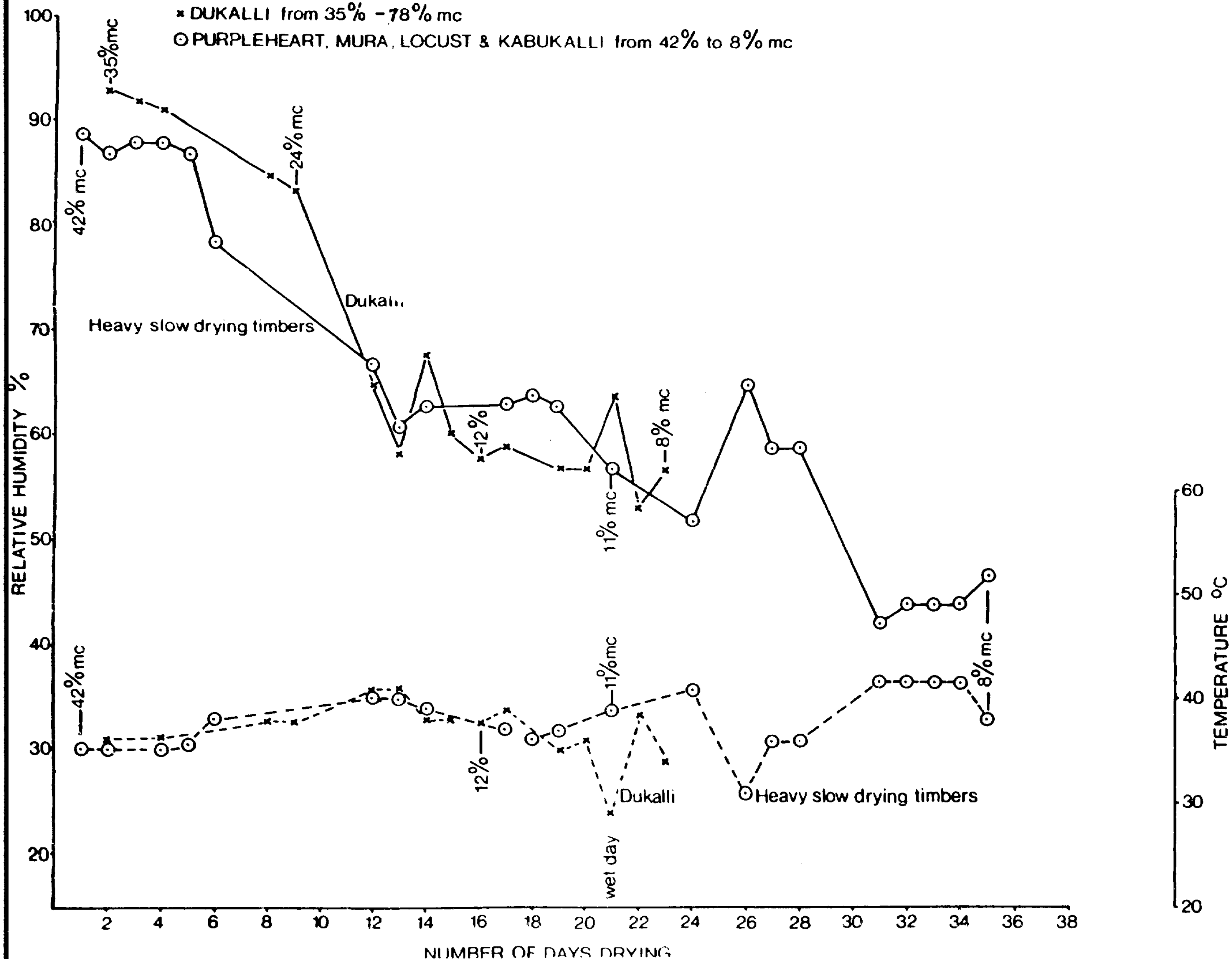
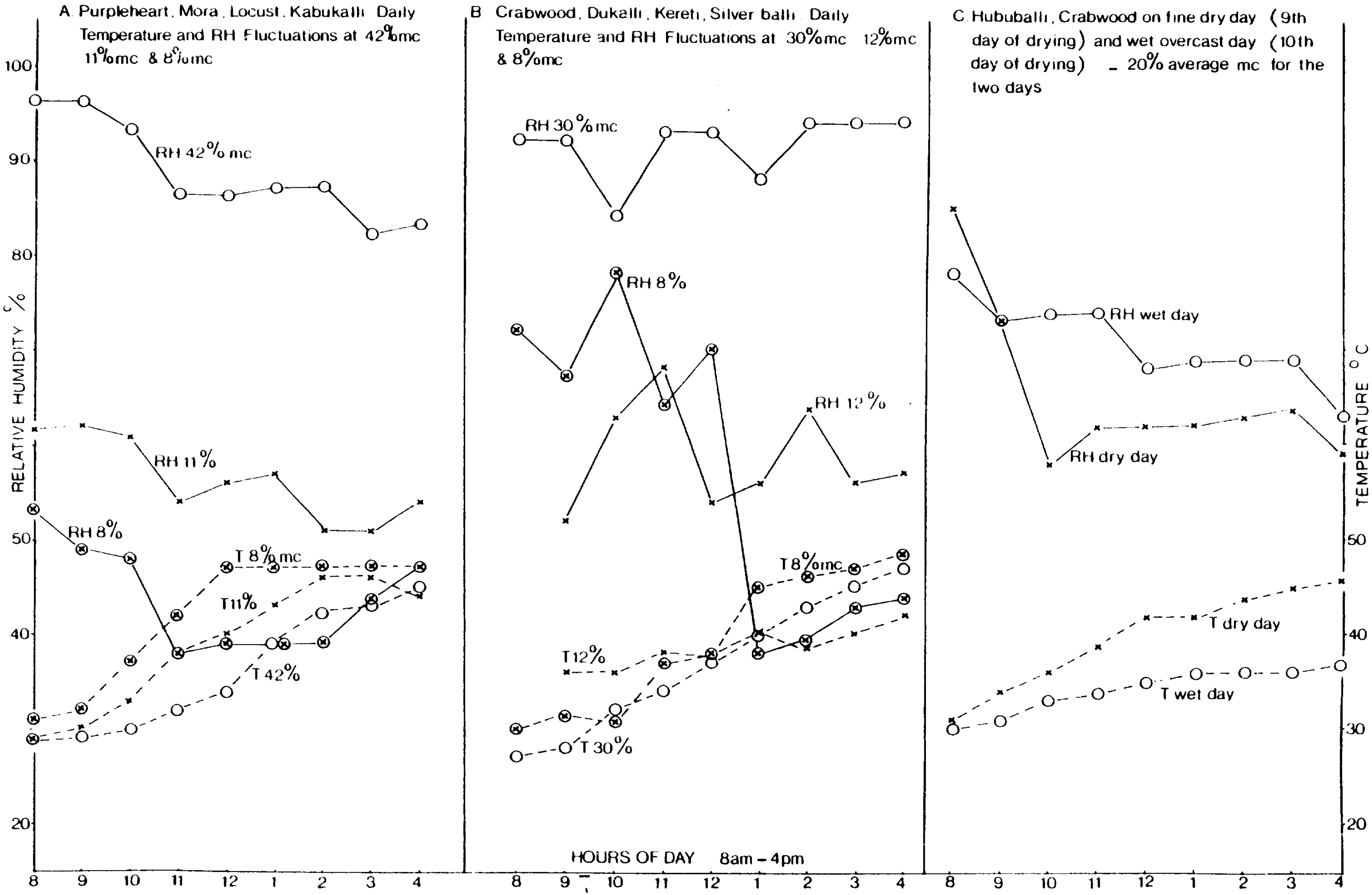


FIGURE 5 EXAMPLES OF HOURLY HUMIDITY AND TEMPERATURE FLUCTUATIONS AT DIFFERENT STAGES IN DRYING (A & B) AND ON WET/OVERCAST AND SUNNY DAYS (C)



## APPENDIX 1

## JOB DESCRIPTION

Post title: Consultant in solar drying of timber and solar kiln construction.

Duration: Two months (split mission).

Date required: As soon as possible.

Duty station: Georgetown.

Purpose of project: To determine the economic and technical parameters of timber drying in Guyana using solar kilns and develop a prototype (greenhouse type) solar timber drying kiln.

Duties: During the two phases of his split mission, the consultant will, in collaboration with the counterpart agency (Institute of Applied Science and Technology) undertake the following activities:

First phase - exploratory mission:

1 Survey of the needs of small entrepreneurs for kiln-dried timber.
2 Finalization, based on the above, of the technical specifications of the kiln to be developed (size, type and detailed design).
3 Drawing up of the list of equipment and materials to be provided by the project and that of those items which could be purchased locally (the local versus imported components will be clearly shown).
4 Selection of the species to be test-dried in the kiln.
5 Prepare an interim report outlining in detail the tasks to be completed by the counterpart agency prior to his return.

Second phase - implementation

1 Erection of the kiln.
2 Starting of its operation.
3 Testing of the kiln by operating it with the selected species.

The consultant will present the results of his mission in a final report, which will contain detailed information on the design of the kiln, its operation procedures, its actual costs, etc.

Qualifications: Wood technologist specialized in wood drying and experienced in solar kiln construction and operation.

## APPENDIX 2

### Wood Processing Plants Visited and their Drying Facilities

| Name of Firm | People Consulted | Operation Performed | Wood Drying Facilities | Current State of Wood Drying |
|---|---|---|---|---|
| Forestry Commission Forest Industries Development Unit, Kingston. | J. Douglas<br>C. Hall | Joinery & Furniture manufacture, wood products research. | Three kilns (conventional)<br>- one small experimental<br>- one 17 $m^3$ (7000 bf) kiln<br>- one 95 $m^3$ (4000 bf) kiln<br>All steam heated.<br>One solar kiln kit.<br>Air drying in open sheds and some stacks outside sheds. | The 7 $m^3$ kiln is in operation drying timber for the Unit's own use and a limited quantity for customers. Spare parts for the 95 $m^3$ kiln have been ordered. Have own drying facilities and 2-3 operational electrical moisture meters. |
| Guyana Timbers Ltd. | C. Peters<br>C. Anderson | Large sawmill with Prefab. housing operation. | One battery of high temperature 85°C (max.). Kilns of 24 $m^3$ (10,000 bf) capacity. One battery of low temperature (75°C), 155 $m^3$ (65,000 bf) capacity. Air drying in sheds and some stacks in open. | Boiler operating and the 155 $m^3$ kilns contained a half charge of timber. Temperature low and vents and control for humidity and temperature were not operating. Not much control of drying or control of final moisture content. |
| Walvis & Sons Woodworking Establishment | W. Davis<br>R. Field-Ridley | Joinery & Furniture manufacture | One Dehumidifier kiln 5.3 $m^3$ (2600 bh). Air drying in racks in a shed. | Kiln has been used but is not currently being used. Cost of electricity given as a reason for not using it. |
| Guyana Wood Products Ltd. | B. Gittens<br>P. Gittens<br>B. Harper | Joinery, Furniture, toys and prefab. housing. | Currently only air drying sheds. Proposal for a 50 $m^3$ (21000 bf) drying kiln. | Air dried timber currently used and no facilities for testing moisture content. |
| G. Singh & Sons | G. Singh | Furniture Manufacture | Limited air drying facilities in shed. | Air dried timber used. Is considering purchase of dehumidifier. |
| Precision Woodworking Ltd. | H. Bulkhan | Furniture | Air drying only. | Air dried wood used. |
| Fries Furniture | Wong | Furniture | Open yard and closed shed for air drying. | Air drying only. |
| Persaud's Furniture | B. Persaud | Furniture, much of it upholstered. | Air drying in sheds. | Air drying but considering installation of kilns. |
| TWIGA Construction Company Ltd. | - | Joinery and prefab. housing, broom handles. | Air drying sheds. | Air drying only with limited shed capacity. |
| Interior Forest Industries Ltd. | T. Persaud | Large Sawmill. | Batteries of three large kilns 380 $m^3$ (160000 bf) capacity. Air drying sheds. | Installation of kilns not yet complete. |
| Amarali Sawmill | M Amarali | Medium Sawmill | Air drying shed. No kilns. | Very little drying. Timber sold green. |
| Haroon Fazal Sawmill | H. Fazal | Medium Sawmill | No drying facilities. | No drying carried out. |
| Baijnauth & Sons | C.B. Baijnauth | Medium Sawmill | No drying facilities. | No drying carried out. |
| J & Z Sawh | J. Sawh | Large/medium sawmill. | No drying facilities. | No drying carried out. |

# APPENDIX 3

## Timbers used by Joinery and Furniture Manufacturers and their Drying Properties and Guyana kiln schedules

| Common Name | Botanical Name | Density 12% m.c. g/cm³ | Recommended kiln schedule | Drying Characteristics |
|---|---|---|---|---|
| Red Cedar | *Cedrela odorata* | 0.48 | J | Dries rapidly without marked distortion. |
| Crabwood | *Carapa guianensis* | 0.64 | C | Dries slowly with tendency to split in early stages. |
| Determa | *Ocotea rubra* | 0.66 | E | Slow diffusion of moisture in wood: difficult to dry. |
| Dukali | *Parahancornia amapa* | 0.61 | - | Air dried easily with little degrade. |
| Greenheart | *Ocotea rodiaei* | 0.99 | B | Dries slowly with minor degrade: checking and splitting may occur but distortion not severe. |
| Hububalli | *Loxopterygium sagotii* | 0.66 | - | Low movement, dries readily with little degrade. |
| Kabukalli | *Goupia glabra* | 0.87 | F | Kiln dries easily without degrade if dried slowly. |
| Kirikau | *Iryanthera lancifolia* | 0.56 | - | Air dries easily with little degrade. |
| Locust | *Hymenaea courbaril* | 0.87 | C | Dries readily without distorting or splitting. |
| Mora | *Mora excelsa* | 0.99 | B | Slow drying required to prevent checking and distortion. |
| Purpleheart | *Peltogyne pubescens* | 0.95 | F | Dries well and fairly rapidly with little degrade. |

APPENDIX 3 (Continued)

| Common Name | Botanical Name | Density 12% m.c. g/cm³ | Recommended kiln schedule | Drying Characteristics |
|---|---|---|---|---|
| Shibadan | Aspidosperma album | 0.91 | E | Dries without difficulty. |
| Silverballi (brown) | Licaria canella (part of group of species) | 0.80 | G | Dries well with little degrade. |
| Silverballi (kereti) | Ocotea spp. (part of group of species) | 0.75 | G | Dries well, slight surface checking may occur. |
| Tatabu | Diplotropis purpurea | 0.92 | C | Dries slowly but without distortion or splitting. |
| Tauroniro | Himiria balsamifera | 0.80 | - | Dries fairly well without degrade. |
| Wamara | Swartzia leiocalycina | 1.06 | B | Dries slowly with considerable surface checking & end splitting but distortion not serious. |

## APPENDIX 4

**Quantities of Timber used per Annum by Joinery and Furniture Manufacturers**

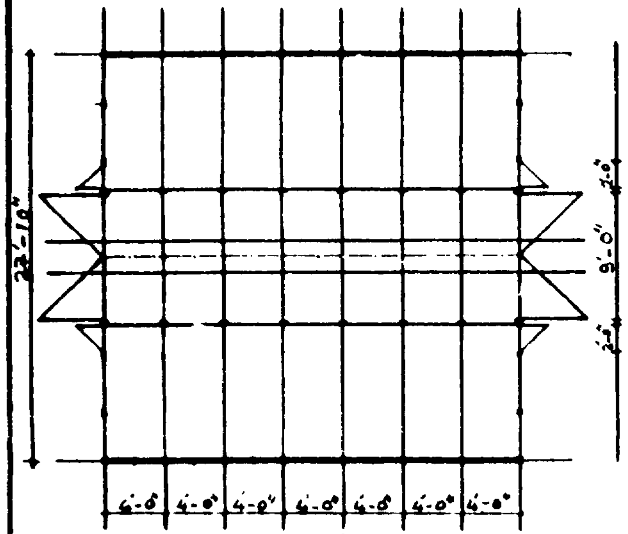
| Company's Number | Timber used b.f | Timber used $m^3$ |
|---|---|---|
| 1 | 42,500 | 101 |
| 2 | 40,000 | 95 |
| 3 | 124,000 | 295 |
| 4 | 25,000 | 60 |
| 5 | 364,000 | 867 |
| 6 | 400,000 | 952 |
| 7 | 832,000 | 1981 |
| 8 | 30,000 | 71 |
| 9 | 64,000 | 152 |
| 10 | 260,000 | 619 |
| 11 | 53,000 | 126 |
| 12 | 156,000 | 371 |
| 13 | 61,000 | 145 |
| Total | 2,451,500 | 5,835 |

## APPENDIX 5

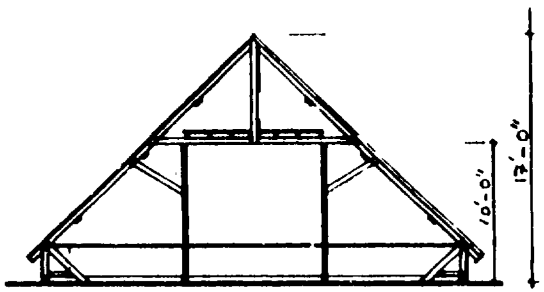
### Drying Rates of Different Timbers in "Jakrap" Kiln

| Local Name taken | Botanical Name | Timber Size | Density 12 % mc | Initial mc % | Final mc % | Time days |
|---|---|---|---|---|---|---|
| Dukali | Parahancornia amapa | 4" x 1" | 0.48 | 20 | 8 | 15 |
| Dukali | Parahancornia amapa | 6" x 1" | 0.48 | 35 | 8 | 24 |
| Crabwood | Carapa guianensis ) | ) | ( 0.64 ) | | | |
| Kereti silverballi | Ocotea spp. (puberula, wachenheimii, oblonga) ) | ) 6" x 1" | (0.5-0.75) | 30 | 8 | 16 |
| Hububalli | Loxopterygium sagotii | 6" x 1" | 0.66 | 53.5 | 10 | 31 |
| Purpleheart | Peltogyne pubescens) | ) | ( 0.95 ) | | | |
| Locust | Hymenaea courbaril ) | ) 3" x 1" | ( 0.87 ) | 42 | 10 | 36 |
| Kabukalli | Goupia glabra ) | ) | ( 0.87 ) | | | |
| Koreroballi | Hymenolobium spp. ) | ) | ( 0.75 ) | | | |

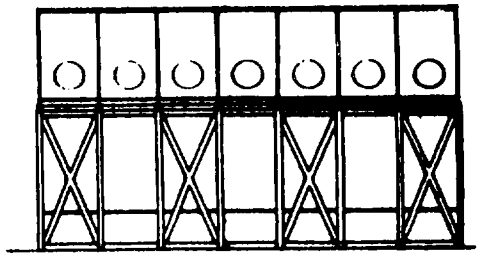
Preliminary Drawings of the New Timber/Melinex Kiln.



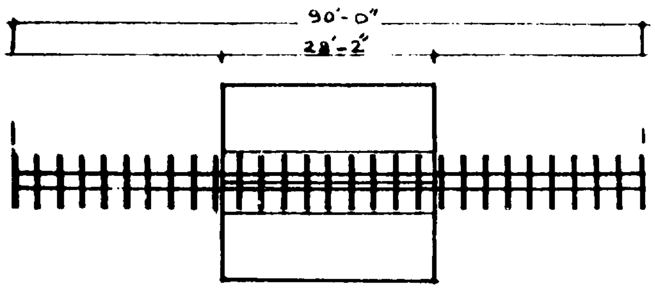

Plan 1/4"=1'-0



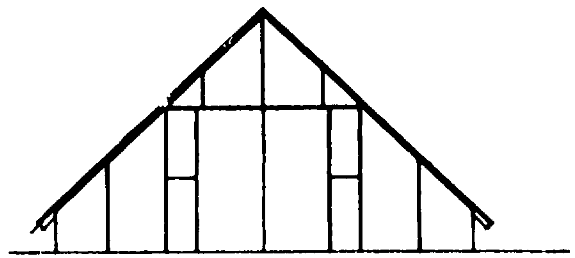

Cross Section 1/4" = 1'-0



Section Thru Ridge 1/4"=1'-0




Plan 1/8" = 1'-0



End Panels 1/4" = 1'-0

# APPENDIX 7

## INSTRUCTIONS FOR OPERATING THE KILN

### GENERAL

The kiln operates in a manner which is part way between the method of operation of conventional kilns and air drying. In the former both temperature and humidity are controlled and, within the limits of the controls, any combination of temperature and humidity is possible. In dehumidifier kilns control is mainly by humidity and the temperature is relatively low. With air drying both temperature and humidity are controlled by the weather and conditions are outside the control of the operator except that stack or shed orientation and protection of stacks from direct sun or rainfall by shed or stack roofs is possible; end sealing of timber and covering of ends of stacks are also possible to prevent too rapid drying and end cracking of the timber.

With solar drying it is not possible to control temperature other than by increasing the temperature over ambient outside temperature using the "greenhouse effect" of the kiln glazing. The temperature inside the kiln will be controlled by the amount of radiation falling on the kiln, by the temperature outside the kiln and by the general efficiency of the kiln in trapping the radiation and converting it to heat.

Unlike air drying, however, the kiln traps air and vents control the quantity of air allowed into and out of it. Humidity, therefore, is much more controllable than temperature and it is relative humidity which controls the final equilibrium moisture content of wood more than temperature.

The following table shows average equilibrium moisture content of wood at different temperatures and humidities.

| TEMPERATURE | 15°C | 30°C | 50°C |
|---|---|---|---|
| | | e.m.c. | |
| Relative Humidities | % | % | % |
| 80 % | 18.25 | 16.8 | 15.25 |
| 60 % | 13.25 | 12.1 | 10.5 |
| 40 % | 9.5 | 8.5 | 7.25 |
| 20 % | 5.9 | 5.25 | 4.3 |

It is clear, therefore, that the relative humidity of the air passing over by the timber very largely controls the e.m.c. of the timber but in a closed kiln a rise in temperature will lower relative humidity and will at the same time speed up the attainment of the equilibrium moisture content by speeding up the rate of movement of water through the wood and its evaporation at the wood surface.

The ability in the solar kiln to control air exchange in the kiln by opening or closing vents, therefore, gives an ability to control humidity particularly since water which is being removed continuously from the wood in the kiln is adding to the humidity in the kiln unless it is vented. The most important factor affecting wood drying is, therefore, to a large extent controllable by the vents; an appreciation of this fact is necessary in operating a solar kiln.

OPERATION OF VENTS IN CONTROL ( DRYING

Air flow through the vents is controlled by air pressure inside and outside the kiln at each vent; air flow through the outlet vents varies considerably but is between 0.25 and 0.5 m/sec.

With an external humidity of 60 % and 21°C temperature and an internal humidity of 60 % and 32°C the net loss of water through the vents, if they are 5 cm open, is approximately 15 - 30 kilograms per 12 hour day assuming that fans are not operated at night and no water is lost then. The actual quantity of water which needs to be removed per charge can be calculated and this degree of opening will allow adequate removal of water from slow drying dense woods. It would allow removal of water from the average charge of timber in about 40 days assuming there were no leaks in the structure and no loss by condensation.

In practice, however, water condenses at night on the outer cover of the kiln and drains to the floor. If this is then allowed to drain out through small perforations in the polythene floor a greater quantity of water can be removed in a given time; the water is removed in a low energy state as a liquid rather than as high energy vapour and the kiln acts as a partial dehumidifier.

At this degree of vent opening 112 - 225 $m^3$ of the air are vented per hour and since the kiln air volume is about 57 $m^3$ the air is changed from 2 - 4 times per hour with a considerable loss of heat in the process. There is, therefore, every reason to remove water as far as possible by condensation rather than by venting.

SCHEDULES FOR DIFFERENT TIMBERS

Selected examples of conventional kiln schedules in Annex 1 are taken from "The Kiln Operator's Handbook" by W C Stevens and G H Pratt to illustrate the operation of normal kilns. Fast drying woods are dried at faster, more severe schedules with higher temperatures and lower humidities than slow drying woods. Those liable to surface checking or warp require high humidities in the early stages of drying when the surface is drying and shrinking while the interior is still wet and swollen. To avoid case hardening it is important with slow-drying woods to avoid low humidities.

With a solar kiln it is not possible to adhere to a strict schedule and the art in operating the kiln is to ensure that the kiln dries the timber as fast as possible with a minimum vent opening to prevent heat loss and reduction of humidity below an acceptable level. In all wood drying most water is lost in the early stages of drying as the easily removed surface water evaporates and the free water within the cell lumens moves to the wood surface. Later in drying the amount of water evaporating from the surface of the wood is reduced since the rate of movement through cell walls is limited.

With fast drying woods it is important to remove sufficient moisture in the early stages of drying and if the timber is green the vents need to be opened fully and then gradually closed as drying proceeds. It is probably more efficient to use the kiln to complete drying after a preliminary period of air drying for these timbers since air drying is almost as fast as the kiln above 30 - 40 % mc. The kiln is designed to be easily moved from stack to stack and if two stack bases are built side by side one can be used for air drying under a stack cover while the other is used for kiln drying and then the kiln is moved to the partially air dried stack while a new stack is built and air dried on the first stack base.

Used in this way the kiln will probably dry one and a half times the quantity of timber it would dry if drying from green in the kiln.

Slow-drying, difficult woods may not stand air drying under stack covers because of low humidities in the middle of the day particularly in dry climates, in tropical dry seasons or in temperate summers. It may, therefore, be necessary to dry these timbers from green in the kiln. This can be done without causing defects even at high temperatures for a solar kiln provided that humidities are kept high in the crucial period when the wood surface starts drying below 25 - 30 % mc. With these woods the vents need to be kept well closed particularly in hot, dry weather; provided this is done humidities will stay high enough. Measurements of humidity show that relative humidity drops in the middle of the day but rises again at night, particularly if fans are switched off at night so that the wood surface has a partial reconditioning every night. This relieves surface stresses in the wood and gives good quality drying of even the most difficult woods.

Later in the drying of both fast and slow drying woods it is possible to keep vents only slightly opened because less water is being removed from the wood surface and the temperature is required to move the water more rapidly through the wood.

## CONTROL OF FANS

There is little benefit to be gained from running fans at night except with charges of fast drying woods when they have high moisture contents and humidities are very high in the kiln. If humidities are over 80 - 90 % during the day it is probably advisable to keep fans going at night, particularly if moulds or blue stain start forming on the wood. With slow drying woods and drier charges of fast drying woods fans should be switched off about an hour before sunset and on an hour after sunrise.

## MONITORING OF KILN PERFORMANCE

Periodic measurements of air temperature and humidity inside the kiln and, preferably also outside the kiln, plus measurements of wood moisture content are necessary to check kiln performance.

Measurements of temperatures and humidities at 8 am, noon and 4 pm are desirable, but not essential, while periodic moisture content measurements are essential.

## TEMPERATURE AND HUMIDITY MEASUREMENTS

Temperature and humidity measurements can be made using a single wet and dry bulb thermometer or a whirling hygrometer which should be swung for at least a minute before readings are taken. Wet and dry bulb chart recorders are expensive but give a continuous record of temperature and humidity.

## MOISTURE CONTENTS OF THE WOOD

Moisture contents of the wood can be measured either by the oven drying and weighing method described in any text book on kiln drying or by moisture meter. Most moisture meters use an electrical resistance method which is accurate up to 30 - 40 % mc but inaccurate at higher moisture contents; a few have scales which measure higher moisture contents more accurately.

## KILN RECORDS

Annex 2 gives methods of keeping records and forms on which they can be kept and it is suggested that they are kept in full at least until the drying characteristics of the timbers and different thicknesses of them are well known. It is always essential to keep records of timber moisture content in order to know when drying is complete.

## FIGURES

Figure 1 of this appendix shows moisture content required for different uses in Britain. Other countries with different climates require timber dried to different moisture contents. For most of the humid tropics 12 % mc is a reasonable average figure required for timber to go into a closed building.

Figure 2 of the main report (page 18) shows how equilibrium moisture content of wood varies with humidity and temperature.

## TABLES

Table 1 of this appendix gives relative humidities in terms of wet and dry bulb temperatures.

## CONCLUSIONS

The solar kiln is easy to operate in an acceptably efficient manner. Provided vents are not opened too much with slow drying refractory woods at the critical time when surface drying and shrinkage starts the quality of drying will be good. Optimum drying speed may be more difficult to achieve without practice but the basic techniques of achieving good quality drying are not difficult to acquire and very little operator time is needed to control the kiln.

## Annex 1

### KILN SCHEDULE A

Suitable for timbers which must not darken in drying and for those which have a pronounced tendency to warp but are not particularly liable to check.

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 95 | 35 | 87 | 30.5 | 70 |
| 60 | 95 | 35 | 83 | 28.5 | 60 |
| 40 | 100 | 38 | 84 | 29 | 50 |
| 30 | 110 | 43.5 | 88 | 31.5 | 40 |
| 20 | 120 | 48.5 | 92 | 34 | 35 |
| 15 | 140 | 60 | 105 | 40.5 | 30 |

### KILN SCHEDULE B

Suitable for timbers that are very prone to check.

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 105 | 40.5 | 101 | 38 | 85 |
| 40 | 105 | 40.5 | 99 | 37 | 80 |
| 30 | 110 | 43.5 | 102 | 39 | 75 |
| 25 | 115 | 46 | 105 | 40.5 | 70 |
| 20 | 130 | 54.5 | 115 | 46 | 60 |
| 15 | 140 | 60 | 118 | 47.5 | 50 |

KILN SCHEDULE C

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 105 | 40.5 | 101 | 38 | 85 |
| 60 | 105 | 40.5 | 99 | 37 | 80 |
| 40 | 110 | 43.5 | 102 | 39 | 75 |
| 35 | 110 | 43.5 | 100 | 38 | 70 |
| 30 | 115 | 46 | 103 | 39.5 | 65 |
| 25 | 125 | 51.5 | 109 | 43 | 60 |
| 20 | 140 | 60 | 118 | 47.5 | 50 |
| 15 | 150 | 65.5 | 121 | 49 | 40 |

KILN SCHEDULE D

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 105 | 40.5 | 101 | 38 | 85 |
| 60 | 105 | 40.5 | 99 | 37 | 80 |
| 40 | 105 | 40.5 | 96 | 35.5 | 70 |
| 35 | 110 | 43.5 | 97 | 36 | 60 |
| 30 | 115 | 46 | 97 | 36 | 50 |
| 25 | 125 | 51.5 | 101 | 38 | 40 |
| 20 | 140 | 60 | 105 | 40.5 | 30 |
| 15 | 150 | 65.5 | 112 | 44.5 | 30 |

KILN SCHEDULE E

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 120 | 48.5 | 115 | 46 | 85 |
| 60 | 120 | 48.5 | 113 | 45 | 80 |
| 40 | 125 | 51.5 | 116 | 46.5 | 75 |
| 30 | 130 | 54.5 | 117 | 47 | 65 |
| 25 | 140 | 60 | 120 | 49 | 55 |
| 20 | 155 | 68 | 127 | 53 | 45 |
| 15 | 170 | 76.5 | 136 | 58 | 40 |

KILN SCHEDULE F

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 120 | 48.5 | 111 | 44 | 75 |
| 60 | 120 | 48.5 | 109 | 43 | 70 |
| 40 | 125 | 51.5 | 109 | 43 | 60 |
| 30 | 130 | 54.5 | 109 | 43 | 50 |
| 25 | 140 | 60 | 115 | 46 | 45 |
| 20 | 155 | 68 | 124 | 51 | 40 |
| 15 | 170 | 76.5 | 136 | 58 | 40 |

## KILN SCHEDULE G

Suitable for timbers which dry very slowly, but which are not particularly prone to warp.

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 120 | 48.5 | 115 | 46 | 85 |
| 60 | 120 | 48.5 | 113 | 45 | 80 |
| 40 | 130 | 54.5 | 123 | 50.5 | 80 |
| 30 | 140 | 60 | 131 | 55 | 75 |
| 25 | 160 | 71 | 146 | 63.5 | 70 |
| 20 | 170 | 76.5 | 147 | 64 | 55 |
| 15 | 180 | 82 | 144 | 62.5 | 40 |

## KILN SCHEDULE H

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 135 | 57 | 127 | 53 | 80 |
| 50 | 135 | 57 | 126 | 52 | 75 |
| 40 | 140 | 60 | 126 | 52 | 65 |
| 30 | 150 | 65.5 | 129 | 54 | 55 |
| 20 | 170 | 76.5 | 136 | 58 | 40 |

KILN SCHEDULE J

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 135 | 57 | 123 | 50.5 | 70 |
| 50 | 135 | 57 | 119 | 48 | 60 |
| 40 | 140 | 60 | 118 | 47.5 | 50 |
| 30 | 150 | 65.5 | 121 | 49 | 40 |
| 20 | 170 | 76.5 | 127 | 53 | 30 |

KILN SCHEDULE K

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 160 | 71 | 151 | 66 | 80 |
| 50 | 170 | 76.5 | 156 | 68.5 | 70 |
| 30 | 180 | 82 | 159 | 70.5 | 60 |
| 20 | 190 | 88 | 153 | 67.5 | 40 |

KILN SCHEDULE L

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 180 | 82 | 165 | 74 | 70 |
| 40 | 200 | 93.5 | 162 | 72 | 40 |

## KILN SCHEDULE M

| Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made | Temperature (Dry bulb) | | Temperature (Wet bulb) | | Relative humidity % (Approx.) |
|---|---|---|---|---|---|
| | °F | °C | °F | °C | |
| Green | 200 | 93.5 | 184 | 84.5 | 70 |
| 50 | 210 | 98 | 179 | 81.5 | 50 |

[From Stevens, M.R. and Pratt, G.H. (1961). Kiln Operators Handbook, HMSO, U.K.]

## Annex 2

## SOLAR KILN RECORDS

These are designed to record the performance of the kiln in relation to the climatic variations and the type and dimensions of timber being dried in it.

There are three record sheets, one recording the temperature and humidity inside and outside the kiln, one recording the moisture content of the wood in the kiln, and one recording seasoning quality. They should be completed as follows:

1 FORM 1 Temperature and humidity measurement sheet

Form 1A is for use where a wet and dry bulb chart recorder is used inside the kiln and a whirling hygrometer outside and Form 1B is for use where the whirling hygrometer or wet and dry bulb thermometer is used for both inside and outside measurements.

In Form 1A wet and dry bulb readings are read off the charts and the temperature and the time of day at which it occurred are recorded for each day. The whirling hygrometer readings are taken at 8 am, noon, and 4 pm or as near as possible to these times. The time must be constant each day and if these times are altered measurements must be consistently at 9 am, or whatever time is chosen.

It is desirable to make the recordings every day but if recordings with the whirling hygrometer are not possible at weekends they can be omitted.

2 FORM 2 Timber moisture content measurement sheet

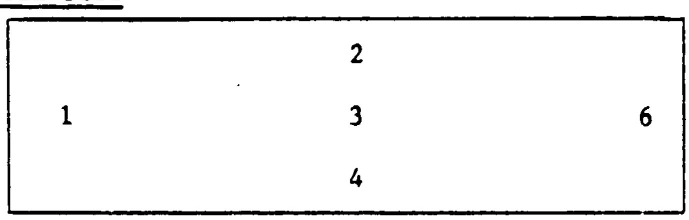
Here measurements should be made every 3 - 5 days (avoiding weekends). With fast drying woods of small thickness drying is faster and measurements should be more frequent than with slower drying thicker timber.

The initial moisture measurement should be made by taking at least 5 samples, weighing, oven-drying and re-weighing to give the moisture content %.

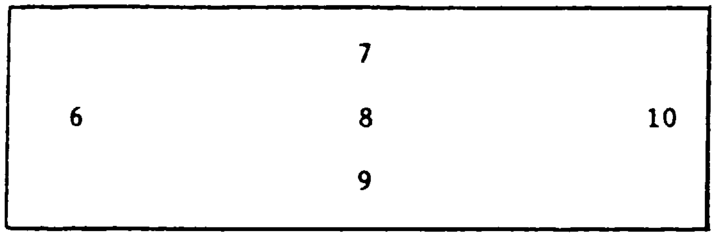
$$(\text{MC \%} = \frac{\text{green weight} - \text{oven dry weight}}{\text{oven dry weight}} \times 100)$$

After this moisture content measurement other measurements should be made with an electrical moisture meter. The measurements should be made at five points at each side of the kiln stack as shown in the following diagrams.

Facing stack from fan side



Facing stack from rear side




Note 6 will be the other side of the stack from 5 and at the same end; 10 & 1, 2 & 7, 3 & 8, and 4 & 9 are opposite each other.

The points should be 1 board from top or bottom of the stack for 2, 4, 7 & 9 and in the centre of the side of the stack for 3 & 8. Points 1, 5, 6 & 10 should be just over 30 cm (1 ft) from the end of the board and 1, 3 & 5 and 6, 8 & 10 should be located in different pieces of timber.

Each measurement should be marked on the wood with its number using pencil or felt pen.

If measurement is made using a moisture meter with a hammer electrode with long probes and an electrode with short probes the internal and external moisture contents of the wood can be measured as follows:

Knock the long probes into the wood at the positions marked using the hammer electrode (without screwing the probes to the electrode) for 2½ cm (1 inch). They should both be knocked into the centre of the edge of the piece of timber so as to measure as far as possible the moisture content of the wood in the middle of the piece of wood one inch from the edge. The probes should be left in that position until the timber is dry when they should be carefully removed using pincers, damaging the insulation on their surface as little as possible. Remeasurement is made by tapping the electrode gently onto these probes, making sure that there is good electrial contact (possible even with rusty probes) and taking a reading.

Surface moisture content readings can be made using the short probes which are pushed into the wood near the long probes every time a measurement is made.

Short and long probe measurements are then recorded on form 2 under position and S or L.

In this way gradients of moisture content between the inside and outside of the wood can be determined at different times during the drying period.

3 FORM 3 Seasoning quality record

Where possible this should be completed by a trained grader. Defects are divided into five categories and after examination of all pieces in the kiln charge the grader should tick the appropriate category column against each defect. Definition of category of defect can vary according to timber dimensions and the general drying properties of woods. The grader should judge whether defect is small or large for the particular species and timber dimensions and mark accordingly. No attempt, therefore, is made here to define categories for each defect but at the bottom of the form space is given to put in an average timber grade for the charge.

Case hardening should be measured using the prong test described in most books on wood seasoning.

FORM 1A

## Temperature & Humidity Measurement Sheet
(Daily Measurement)

Species ............... Charge No. .......... Timber Thickness ................

| Date | Inside Kiln | | | | Outside Kiln | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry bulb | | Wet bulb | | 8 a.m. | | Noon | | 4 p.m. | | |
| | Max & time | Min & time | Max & time | Min & time | dry bulb | wet bulb | dry bulb | wet bulb | dry bulb | wet bulb | |
| | | | | | | | | | | | |

FORM 1B

## Temperature & Humidity Measurement Form
(Daily Measurement)

Species .................. Charge No. ........... Timber Thickness .................

| Date | Inside Kiln | | | | | | Outside Kiln | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 a.m. | | Noon | | 4 p.m. | | 8 a.m. | | Noon | | 4 p.m. | | |
| | dry bulb | wet bulb | dry bulb | wet bulb | dry bulb | wet bulb | dry bulb | wet bulb | dry bulb | wet bulb | dry bulb | wet bulb | |

FORM 2

## Timber Moisture Content (Measurement every 3 - 5 days)

## Measurement Sheet

Species .................. Charge No. ........... Timber thickness ...... Initial Moisture Content (by oven drying)......

| Date | Position | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture Content % | S | L | S | L | S | L | S | L | S | L | S | L | S | L | S | L | S | L | S | L | |

FORM 3

## Seasoning Quality Record

Species .................. Charge No. ......... Thickness ...........

| Defect | Quality Category | | | | | Remarks |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| Surface Checks | | | | | | |
| End split | | | | | | |
| Bow | | | | | | |
| Spring | | | | | | |
| Cup | | | | | | |
| Twist /Warp | | | | | | |
| Collapse | | | | | | |
| Case hardening | | | | | | |
| Blue Stain | | | | | | |
| Mould or other Stain | | | | | | |

Note: Category

1 = Very slight or no defect

2 = Slight

3 = Moderate

4 = Severe

5 = Very severe

## APPENDIX 8

### PREVENTIVE MAINTENANCE ON KILN (Aluminium)

The following checks should be made on the kiln to make sure it is running properly in addition to routine measurements of humidity, temperature and moisture content:

**Daily**

1 Check time clock is showing the correct time.

2 Check for air and water leaks in the kiln structure and close them with selastic or other method of sealing them.

3 Check for damage to the plastic and repair if necessary.

4 Check wet bulbs of wet and dry bulb thermometers have clean water and are damp.

5 Check vent openings are correct for the state of drying of the timber, the weather and humidity in the kiln.

**Weekly**

1 Top up water in wet bulb thermometer reservoirs with distilled or clean rainwater.

2 Check for missing clips on glazing panels and replace.

3 Check with Allen Keys the tightness of the fans on the motor shafts.

**Everytime a Charge is Changed**

1 Check for loose bolts in kiln structure.

2 Check condition of electric cables to the kiln.

3 Check condition of polythene groundsheet, cut vegetation around the kiln and keep area around the kiln clear and tidy.

# APPENDIX 9

## SOLAR KILN COST ESTIMATE FOR ALUMINIUM AND MELINEX 7 $M^3$ KILN

| | US$ |
|---|---|
| **Capital Cost:** | |
| Building Kiln : kit cost in Guyana | 4,450 |
| Erection - 6 men for 10 days at G$ 25/day | 349 |
| Extras (paint, CGI etc) | 300 |
| | 5,099 |
| **Operating Costs:** | |
| Land Rental : 300 $m^2$ (3 weeks air drying and 3 weeks in kiln giving 16 loads per annum allowing for holidays, enough for two (2) stacks at US$ 1/$m^2$/year) | 300 |
| Labour : 2 man days per load for monitoring and 1 load per 3 weeks<br>4 man days stacking per 3 weeks<br>2 man days to move kiln (16 charges/year) at $ 20/man day | 596 |
| Power : 10 hrs x 7 days x 3 weeks x 16 charges x 0.720 kw/hrs x G$ 1.00 per kw | 562 |
| Maintenance 5 % capital cost/year | 255 |
| Annual capital charge : 20 % of capital cost | 1,020 |
| OPERATING COST TOTAL | 2,733 |
| **Working Capital:** | |
| Assuming three loads of 250 $ft^3$ at G$ 42/$ft^3$ | 7,326 |
| 6 weeks rent labour and power | 168 |
| TOTAL WORKING CAPITAL | 7,494 |
| TOTAL ANNUAL COST 20 % annual interest for 6 weeks | 173 |
| TOTAL COST OVERALL | 2,906 |

Unit Cost

| | | |
|---|---|---|
| Cost/$m^3$ | = US$ | 25.66 |
| Cost/$ft^3$ | = US$ | 0.727 |
| Cost/b.f. | = US$ | 0.0606 |
| | G$ | 0.[illegible] |

## Costs at Different Production Rates
## Kiln Loads/Annum

| | | Kiln Loads/Annum | | |
|---|---|---|---|---|
| | | 16 | 12 | 8 |
| Throughput $ft^3$ | | 4,000 | 3,000 | 2,000 |
| Land rent | US$ | 300 | 300 | 300 |
| Labour | US$ | 596 | 447 | 298 |
| Power | US$ | 562 | 421 | 281 |
| Maintenance | US$ | 255 | 255 | 255 |
| Annual capital charge | US$ | 1,020 | 1,020 | 1,020 |
| Total costs | US$ | 2,733 | 2,443 | 2,154 |
| Working capital | US$ | 173 | 173 | 173 |
| | | 2,906 | 2,616 | 2,327 |
| Cost/$ft^3$ + captial | US$ | 0.727 | 0.872 | 1.16 |
| or | G$ | 3.12 | 3.75 | 5.00 |
| Cost/b.f. | G$ | 0.26 | 0.31 | 0.42 |
| Cost/$m^3$ | G$ | 110 | 132 | 177 |

**Revenue**

The mark up per b.f. for kiln seasoning by the Forestry Commission is G$ 0.6 (July 1986). Revenues and net profits, therefore, would be as follows given this mark up:

| Number of loads per year | | Total Revenue G$ | Net profit G$ | Net profit US$ |
|---|---|---|---|---|
| 16 | (4,000 x 12 x 0.6) | 28,800 | 16,304 | 3,792 |
| 12 | (3,000 x 12 x 0.6) | 21,600 | 10,351 | 2,407 |
| 8 | (2,000 x 12 x 0.6) | 14,400 | 5,138 | 1,195 |

(Assuming a price of G$ 0.60/board foot).

# APPENDIX 10

## STANDARDISING MOISTURE METER FOR DIFFERENT TIMBERS (FOR BOLMANN METER)

1 Take 5 samples of each species for test. They should be green timber. (Use 1 inch (25 mm) timber).

2 Record reading of moisture content on surface of the timber ( ¼ cm into wood) with moisture meter for scale 1, 2, 3, & 4 at the temperature of the timber on the °C x 10 scale.

3 Knock the moisture meter probes into the timber for 1 cm (see scale on moisture meter probe depth measure).

4 Repeat measurements in 2 for greater probe depth.

5 Weigh the samples accurately.

6 Oven dry the samples for 1 hour at 104°C (approximately).

7 Repeat 2 - 5 at this new M.C.

8 Oven dry samples for another hour.

9 Repeat 2 - 5 at this new M.C.

10 Oven dry samples for 2 hours.

11 Repeat 2 - 5 at this new M.C.

12 Oven dry the timber for 24 hours or to constant weight ie zero % moisture content and repeat 2 - 5.

This test weight will enable you to calculate Moisture Content green, after 1 hour oven drying, after 2 hours oven drying, after 4 hours oven drying and at 0 % MC and to compare with the moisture meter readings.

Average the two moisture meter readings (surface at ¼ cm and internal at 1.cm) before comparing with oven drying MC method measurements.

Choose the scale for the species which is nearest at all moisture contents to the oven drying moisture contents and make a list of different species and the scale on which they should be measured.