Joint UNDP/World Bank
Energy Sector Management Program

Activity Completion Report
No. 009/83

Country: MALAWI

Activity: TECHNICAL ASSISTANCE PACKAGE TO IMPROVE THE EFFICIENCY OF FUELWOOD USE IN THE TOBACCO INDUSTRY

November 1983
Energy Sector Management Program

The Joint UNDP/World Bank Energy Sector Management Program is designed to provide a rapid and flexible response to governments who request assistance in implementing the policy, planning and institutional recommendations of the Energy Assessment Reports produced under anoter Joint UNDP/World Bank Program, or in carrying out prefeasibility studies for energy investments identified in these reports.

The Energy Sector Management Program can provide the following types of assistance for countries which have had assessments:

- assistance to improve a government's ability to manage its energy sector, for example by defining staffing and work programs, evaluating management information needs, identifying sources of public and private finance, developing a medium-term investment plan;
- prefeasibility work on priority investment plans, especially those which will improve the efficiency of energy use, bring about economic fuel substitution, or provide enough affordable energy to rural areas;
- specific short-term assistance in institutional and manpower development, both at the sectoral and agency levels.

The Program aims to supplement, advance and strengthen the impact of bilateral or multilateral resources already available for technical assistance in the energy sector.

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Funding of the Program

The Program is a major international effort and, while the core finance has been provided jointly by the UNDP and the World Bank, important financial contributions to the Program have been made by the Governments of the United Kingdom, the Netherlands, Denmark, Finland, Norway, Sweden, Australia and New Zealand.
Technical Assistance Package to Improve the Efficiency of Fuelwood Use in the Tobacco Industry.

November, 1983
ACRONYMS

ADD Agriculture Development Division
AHL Auction Holdings Limited
ALO Agricultural Liaison Officer
CBM Commercial Bank of Malawi Limited
DA Development Area
DAD Department of Agricultural Development
EPA Extension Planning Officer
ETA Extension Technical Assistants
ETO Extension Technical Officers
FAO Food and Agricultural Organization of the United States
FCV Flue-Cured Virginia Tobacco
KFCTA Kasungu Flue-Cured Tobacco Authority
MA Ministry of Agriculture
MATSS Ministry of Agriculture Tobacco Sector Study
MDF Malawi Division of Forestry
NBK National Bank of Malawi Limited
NDDF Northern Division Dark Fire-Cured Tobacco
SDDF Southern Division Dark Fire-Cured Tobacco
TPI Tropical Products Institute
TRA Tobacco Research Authority
WEP Wood Energy Project
USAID United States Agency for International Development

WEIGHTS AND MEASUREMENTS

1 kilogram (kg) = 2.204 pounds
1 metric ton = 1000 kg
= 2,204 pounds
= 0.968 long ton
= 1.102 short ton

1 centimeter (cm) = 0.3937 inches
1 meter (m) = 3.28 feet
1 square meter (m²) = 10.76 square feet (ft²)
1 square centimeter (cm²) = 0.155 square inches (in²)
1 liter (l) = 0.2642 US gallons (gal.)
1 cubic centimeter (cm³) = 0.06102 cubic inches (in³)
1 cubic meter (m³) = 35.3 cubic feet (ft³)

degrees Celsius (°C) = Fahrenheit (°F) – 32 × 1.8

EXCHANGE RATE

June - July 1983:
Malawi Kwacha (MK)
Tambola (t)

MK 1 = US$0.8917
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SUMMARY

The purpose of this study was to compile and evaluate the various technical options that may be used to improve the efficiency of fuelwood use in the tobacco industry in Malawi and to recommend an appropriate program of action.

The principal findings of the study are:

(i) A whole range of technical options -- of varying degrees of readiness, sophistication, costs and benefits -- can be used to improve the efficiency of wood use in the tobacco industry in Malawi. In the longer run it is feasible that wood used for tobacco curing (40% of the country's total wood use) could be reduced by as much as one-half.

(ii) The highest returns and quickest paybacks are associated with two relatively low cost measures -- installing doors and grates on furnaces and installing controllable ventilators -- in the least efficient barns at a cost of about MK 400 per barn. These investments would be paid back in less than two years.

(iii) The more efficient barns would require more sophisticated and capital intensive improvements which are also likely to be economically profitable but which require further demonstration and testing.

(iv) The principal constraint to embarking on a large scale program to improve the tobacco industry's energy efficiency is the absence of an effective and adequate extension mechanism to disseminate the potential savings from these improvements. Other constraints include the short horizon of barn managers, the non-availability of long term financing, the unclear demarcation of institutional responsibilities, and uncertainty about the actual existing conditions regarding wood use, efficiency and the cost of wood in different areas.

To tackle these problems, this study recommends a two-phase program to improve the efficiency of energy use in the tobacco industry. The first phase would comprise the following elements:

(i) A pilot project to install doors, grates and ventilators in forty low efficiency barns at five different sites and to monitor and evaluate the savings that accrue from these improvements over a two-year period. The Tobacco Research Authority (TRA) would be the coordinating agency for this project.
(ii) The setting up of an effective extension, monitoring and evaluation capability both for the pilot project and for a larger program in the subsequent phase. This task would involve the Tobacco Research Authority, the Ministry of Agriculture and the Ministry of Forestry and Natural Resources.

(iii) An extensive survey of tobacco curing facilities to define existing conditions and to evaluate the economic attractiveness and investment and human resource requirements of a full-scale program to improve energy efficiency in tobacco curing. The Energy Studies Unit in the Ministry of Forestry and Natural Resources is currently developing such a survey. However, the survey proposal needs to be reviewed and support for its implementation may be required from the TRA and from the extension staff of the Ministry of Agriculture.

(iv) Support for further testing and research by the TRA of the more sophisticated technical improvement packages, some of which could be deployed in Phase II.

This first phase would be implemented over a two-year period and would cost about MK 316,000 as shown below. However, it is important to note that this costing is not based on detailed engineering and therefore should be treated as indicative only.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (MK)</th>
</tr>
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<tbody>
<tr>
<td>Equipment for pilot project barn improvements</td>
<td>36,000</td>
</tr>
<tr>
<td>Technical experts, monitoring and evaluation for pilot project; Development of extension network for subsequent phase</td>
<td>190,000</td>
</tr>
<tr>
<td>Research and Development Program</td>
<td>90,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>316,000</td>
</tr>
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</table>

At the end of the two-year implementation period for the first phase summarized above, a full-scale program of tobacco industry efficiency improvements could be launched. It is difficult at this time to estimate the investments and benefits associated with such a program because the mix of the various measures required still has to be determined. However, such a program is likely to entail investments in excess of MK 10 million and would take five to seven years to implement. The expected benefits are also difficult to quantify with precision but if they result in savings of a quarter of the current wood used for tobacco curing — which is a conservative estimate — then, at an estimated cost of MK 6 per cubic meter of wood (again a conservative estimate) — the annual value of savings would amount to MK 5 million.
Background

Fuelwood is Malawi's main source of energy, supplying some 90% of the country's primary energy requirements. As in most other countries which rely heavily on wood energy, fuelwood consumption in Malawi exceeds the incremental production of this resource and is a contributor to the country's depleting forest cover. The government is concerned about this both for environmental reasons and because the increasing difficulty in obtaining wood -- either purchased or collected -- directly affects the quality of life for Malawi's population, 90% of whom rely almost exclusively on wood for their energy needs. To tackle this problem the Government has embarked upon a reforestation program but its scope is constrained by resource limitations and the need to mobilize community support. A complementary program to improve the efficiency of wood use through better cook stoves in the household sector also has been started but is again held back by the pace of consumer acceptance and the need to reach a large number of individual households.

Tobacco curing accounts for an estimated 40% of Malawi's fuelwood consumption. Of this, some 400 flue-cured tobacco growers use 75% of the wood, and 42,600 fire-cured growers use the remaining 25%. While energy savings are possible in both fire-cured and flue-cured tobacco production, the immediate potential appears to lie with the former, where considerable preparatory work has been done in the country and where improved practices in other countries can most easily be applied. Therefore, this report focuses primarily on flue-cured tobacco facilities.

The Tobacco Research Authority in Malawi estimates that the amount of wood consumed per kilogram of flue-cured tobacco ranges from 0.02 m³ on the most efficient estates to 0.13 m³ on the least efficient ones -- a range of almost seven to one. Furthermore, the most efficient barns use about three to four times more energy than current best practices in industrialized countries such as the United States. Thus, economically profitable energy efficiency improvements could probably be made in all barns. However, given implementation constraints, a phased program would be more appropriate. Initially, the emphasis should be on low cost, well-tested measures, where the primary objective is to bring the efficiency of below average barns up to the level of the more efficient ones. More fundamental design and technology changes to improve even the most efficient barns could be contemplated as a second phase, particularly as some technical and economic uncertainties associated with them still need to be resolved. This study therefore concentrates on the first phase, and on further work required to resolve some of the uncertainties associated with the more sophisticated measures.
Low Cost Improvements

The study has identified two low cost technical improvements which may be easily adopted to reduce fuelwood use in existing low efficiency flue-cured tobacco barns:

(i) rebuilding furnaces, adding grates and doors; and

(ii) installing controllable top and bottom ventilators.

Preliminary estimates by TRA suggest that the former could result in a 25% fuelwood savings, and the latter a further 15% savings. TRA has indicated that a typical "inefficient" barn may consume 20 m³ of fuelwood per 500 kg cure of tobacco; this translates into a wood savings of 5 m³ and 3 m³, respectively, for the two improvements. Based on six cures (of 500 kg each) per annum and an average cost of MK 6 per m³ of wood, this infers an annual savings of MK 180 and MK 108, respectively. Investment costs for the two measures are MK 250 and MK 160; therefore, assuming that incremental labor costs and O&M costs are small, in both cases the payback period is less than two years. This preliminary analysis suggests that both measures are highly cost effective. However, it is recommended that a 24-month pilot project be conducted to verify these savings in field conditions before proceeding on a full-scale program of implementation in Malawi.

The Pilot Project

The study recommends a pilot project in which 40 low efficiency barns in five main growing regions are upgraded. To carry out a controlled experiment, eight other low efficiency, unimproved barns in each region need to be identified and monitored at the same time. A technical assistant is required for each regional experiment to monitor fuelwood consumption, train barn-tending labor, and evaluate the amount and quality of cured tobacco. Resources will also be required to set up an effective extension, monitoring and evaluation capability at the TRA both for the pilot project and for the subsequent larger scale improvement program. To assess the incremental savings associated with implementing the two measures in improved barns, it is recommended that only one option be installed in some of the barns and that both options be installed in others. The pilot program would be scheduled over a two-year period encompassing two curing seasons. As the curing season is only six weeks long, and allowing another four weeks for data analysis and report writing, there should be ample time available for the additional TRA staff and the five technical assistants to be involved in the other related activities recommended in this report.

Survey of Tobacco Barns

Assuming that the attractive economics of these improvements are verified by the pilot project, the next step would be to establish a similar program for all low efficiency barns. However, before this can be done several issues associated with fuelwood use in the tobacco
industry need to be resolved. In particular, a great deal of uncertainty exists in the following areas:

(i) the number of barns operating at the various levels of energy efficiency;

(ii) the total amount of fuelwood used for tobacco curing in Malawi, and how this is distributed among small and large producers and energy efficient and inefficient producers; and

(iii) the variation in present costs of fuelwood to producers in different regions and how these costs may change in the future.

A detailed survey of all (approximately 400) flue-cured tobacco producers would help eliminate much of this uncertainty, and this study recommends that in parallel with the pilot project, such a survey be carried out by the Energy Studies Unit in the Ministry of Forestry and Natural Resources. A suitably experienced engineer (possibly expatriate) should be made responsible for this operation, and support for this work should be provided by TRA and the extension staff of the Ministry of Agriculture.

**Further Research and Development Work**

The study identified a number of other technical improvements which may lead to further reductions in fuelwood use, but at a higher investment cost. These include:

- efficient flues and chimneys;
- forced draft flue systems;
- cascade continuous curing;
- tunnel continuous curing; and
- bulk curing with a centralized heating plant

An ongoing research program at TRA is evaluating the savings associated with some of these options. This program needs to be strengthened with funds for additional supplies and equipment. The TRA and other interested parties should also consider addressing issues unresolved by this study. In particular, the following need to be addressed:

(i) alternative means of financing a full-scale implementation program, and

(ii) the impact of improved energy efficiency and controlled environment on the quality of tobacco produced, and hence its marketable value.
Fire-Cured Tobacco

The Ministry of Forestry and Natural Resources is currently investigating fuelwood use for fire-cured tobacco. This work could identify possible improvements in fuelwood efficiency and future technical assistance requirements in this subsector.
Background to the Study

1.1 Malawi's climate is ideally suited for tobacco growing. This fact, coupled with the availability of suitable soils, has allowed the development of an industry that currently provides 40-50% of Malawi's foreign exchange earnings.  

1.2 The curing of flue-cured and dark fired-cured tobacco requires an adequate supply of fuelwood. At present, most of this fuelwood is obtained from natural woodland. It has been stated that one hectare of flue-cured tobacco requires 41.7 hectares of natural woodland to sustain production indefinitely.

1.3 Assuming an increase of 3.5% a year in the demand for fuelwood from all sources, the supply of indigenous natural timber would be exhausted by the 1990s. Much of the available natural woodland has already been removed from large tracts of the Central and Southern Regions.

1.4 Much evidence indicates that the amount of wood consumed by the tobacco industry could be reduced considerably through measures to improve the efficiency with which wood is burned. While energy savings are possible in both flue-cured and dark fire-cured production, the immediate potential appears to be in the former, where considerable preparatory work already has been done in Malawi and where improved practices from neighboring countries can be most easily applied. Moreover, there is a far greater concentration of wood use in the flue-cured sector which makes it easier and more profitable to concentrate first on this group: Some 400 growers of flue-cured tobacco account for 75% of the tobacco industry's wood consumption, with the remaining 25% being used by over 42,000 growers of fire-cured tobacco. Estimates of the potential savings in wood consumed by flue-cured tobacco that could be realized through relatively low cost investments and better curing techniques range from 30% to 50%. Potential savings in dark fire-cured production have not been thoroughly explored.


2/ IBID.

3/ IBID.
Objectives of the Study

1.5 The objectives of the study were as follows:

(i) To prepare a comprehensive inventory of the various technical packages that could be used to improve the efficiency of energy use in the Malawi tobacco industry.

(ii) To compare these alternatives in terms of investment cost, likely savings, lead time for implementation, ease of administration, degree of commercial readiness, etc.

(iii) To recommend a costed and scheduled program of action based on the above. This should include the pre-investment work required to achieve these savings and any experimental or pilot projects needed to further evaluate specific technical options not yet fully tested.

(iv) To recommend training and extension measures necessary to ensure the acceptance and successful implementation of the program in the tobacco sector.

(v) To suggest the agencies which would be responsible for coordinating and implementing the project.

Conduct of the Work

1.6 The work was carried out in Malawi by an engineer experienced in tobacco curing and a tobacco extension specialist between June 13 and July 9, 1983. Field visits were made to estates, small holdings, research centers, and discussions were held with tobacco growers, extension workers, researchers and a number of officials concerned with providing services to the tobacco sector.
II. FUEL SOURCES AND USE

Alternative Energy Sources

2.1 Many fuels are used to cure flue-cured tobacco (FCV) around the world. However, Malawi may be one of the few that uses fuel wood almost exclusively.

2.2 In the United States, for example, LPG and fuel oil are primarily used for curing FCV, and hardwood is used for curing dark fire-cured tobacco. Zimbabwe has been using coal for nearly a decade for curing FCV since wood became less available and oil escalated in price. Their producers expressed doubt some ten years ago that they could change to coal (mined within the country) and remain competitive in tobacco production.

2.3 Malawian producers may have a more critical decision to make on the choice of fuel if wood becomes unavailable. Low grade coal is available in the northern part of the country, but the transportation cost appears prohibitive. Other internally available sources of energy such as solar, biomass or field residue, and hydro-generated electric power also have limitations in application and cost.

2.4 Fuels that might be imported include coal, fuel oil, and LPG. The present cost of coal delivered to Blantrye from Mozambique by rail is MK 70 per ton or MK 140 if delivered by truck. The coal still must be delivered to the point of use. Fuel oil is now nearly MK 1 per liter. Any switch to a fuel other than coal would require a large investment in equipment and facilities to enforce.

2.5 Table 2.1 compares the cost of three fuels in poor barns with improved barns equipped with controllable bottom and top ventilators. Fuel oil is not competitive with coal or wood for use in conventional barns. Coal may be competitive with wood at MK 6.50 per m³ if transported by rail and farm delivery is close to the railhead.
Table 2.1 Fuel Cost to Cure 500 Kg of Tobacco

<table>
<thead>
<tr>
<th>Kind of Barn</th>
<th>Fuel Oil</th>
<th>Coal</th>
<th>Wood</th>
</tr>
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<tr>
<td></td>
<td>MK 0.96</td>
<td>MK 70</td>
<td>MK 140</td>
</tr>
<tr>
<td>Poor Barn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel oil, 870 L a/</td>
<td>34</td>
<td>160</td>
<td>320</td>
</tr>
<tr>
<td>Coal 2250 kg b/</td>
<td></td>
<td>160</td>
<td>320</td>
</tr>
<tr>
<td>Wood 20 m³</td>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>Improved Barn with Controllable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel oil 582 L c/</td>
<td>559</td>
<td>55</td>
<td>110</td>
</tr>
<tr>
<td>Coal 778 kg d/</td>
<td></td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>Wood 12 m³ e/</td>
<td></td>
<td></td>
<td>78</td>
</tr>
</tbody>
</table>

a/ Study estimate

b/ R.W. J. Ashburner and P.M. Foot, Zimbabwe Tobacco Association and Wankie Colliery Company, respectively.


d/ E.M. Matthews, M.H. McVickar, and R.B. Davis, Jr. 1946. Curing Bright Tobacco with Coal and Oil, Bulletin 396. Virginia Agricultural Experiment Station, Virginia Polytechnic Institute, Blacksburg, VA.

e/ See discussion of Potential for Saving Fuelwood in the Curing Process, also Appendix E, Wood Use and Cost.
Wood as an Energy Source

2.6 A review of previous reports indicates considerable variation in wood energy values and in the measurement of wood. Table 2.2 gives the density and calorific values, both solid and stacked, for the most common species of wood. The density and calorific values for solid wood seem to be accepted as authentic. However, the density and calorific values of stacked wood are quite uncertain based on reports by the Malawi Division of Forestry (MDF) and the Tropical Products Institute (TPI).

2.7 Measuring wood is further complicated by the absence of a true definition of a cord as described by farmers. A standard cord is generally defined as $1.22 \times 1.33 \times 2.44$ m or 3.96 m$^3$. A stacked cord of wood was described by farmers as either $0.91 \times 1.22 \times 1.83$ m or 2m$^3$, or $0.91 \times 1.52 \times 1.22$ m or 2.53 m$^3$. Therefore, a cord as described by farmers is somewhere between 2 to 2.5 m$^3$.

2.8 MDF has used a stacked dry wood factor of 0.67, or two-thirds of the solid weight of an equal volume. TPI found a stacked density of 259 to 267 kg per m$^3$ from trials in two different years (TPI Report R735). A stacked density of 267 kg per m$^3$ and a solid volume density of 570 kg per m$^3$ gives a ratio of 0.469. Using this factor, the average stacked weight for the several species is 317 kg per m$^3$. For purposes of this report, the stacked density of 325 kg per m$^3$ as suggested in the Tobacco Sector Study, Volume IV, is used.

2.9 The basic calorific value of wood has been given as 18.7 MJ per kg, dry basis, and 14.3 MJ per kg at 25% moisture, wet basis, air dried. This agrees closely with a value of 19.3 MJ per kg on a dry weight basis as indicated by the East African Agriculture and Forestry Research Organization. Other information (Malawi Department of Forestry and Game, S.P.R.O., Zomba, 1978) showed the basic calorific value of wood at 25% moisture content to be 18.7 MJ per kg. A study within Malawi (TPI Report R-735, 1978) gave 18.48 MJ per kg for wood at 25% moisture content, wet basis. The value of 18.7 MJ per kg, dry basis, agrees approximately with many textbook definitions of the basic calorific value of wood.

1/ W.G. Dyson, Tree Breeder, East African Agriculture and Forestry Research Organization, Nairobi, Kenya, letter to Malawi Director of Forestry and Game, Ministry of Natural Resources, Zomba, Malawi, July 4, 1972.

2/ E.D. May, P.A.C.P., for Director of Forestry and Game. Working Papers.
Table 2.2: Density and Calorific Value of Wood 1/

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (dry weight lbs/ft³)</th>
<th>Calorific value solid BTU/ft³</th>
<th>Stacked Drywood applied Solid 0.67 BTU/ft³</th>
<th>Calorific value stacked drywood using 0.469 factor BTU/ft³</th>
<th>kcal/m³</th>
<th>kJ/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachestegia spici formis</td>
<td>393,500</td>
<td>49</td>
<td>32.8</td>
<td>23.0</td>
<td>184,704</td>
<td>1,538,528</td>
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<tr>
<td>Isoberlinia scheffleri</td>
<td>393,500</td>
<td>49</td>
<td>32.8</td>
<td>23.0</td>
<td>184,704</td>
<td>1,538,528</td>
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<td>Jalbernardi globiflora</td>
<td>449,700</td>
<td>56</td>
<td>37.5</td>
<td>26.3</td>
<td>211,198</td>
<td>1,897,382</td>
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<td>Gmelina arborea</td>
<td>224,800</td>
<td>28</td>
<td>18.8</td>
<td>13.1</td>
<td>105,174</td>
<td>958,810</td>
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<tr>
<td>Pinus patula</td>
<td>274,000</td>
<td>34</td>
<td>22.8</td>
<td>15.9</td>
<td>128,135</td>
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<td>43</td>
<td>28.8</td>
<td>20.2</td>
<td>162,211</td>
<td>1,443,463</td>
</tr>
<tr>
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<td>43</td>
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<td>20.2</td>
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<td>1,443,463</td>
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<td>1,443,463</td>
</tr>
<tr>
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<td>21.1</td>
<td>169,456</td>
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<td>28.3</td>
<td>19.8</td>
<td>159,004</td>
<td>1,414,915</td>
<td>5,923,964</td>
</tr>
</tbody>
</table>

1/ Information supplied by Malawi Department of Forestry, Dr. E.D. May.

2/ TPI Report R735, In trials on density of stacked wood 16.2 to 16.7 lb/ft³ was determined and solid volume density 35.6 lb/ft³.
Factors Contributing to Inefficient Wood Use

2.10 Tobacco curing as it is practiced in Malawi comes from experience with facilities constructed of locally available materials and until recently, a reasonably ample supply of wood. The curing process that has been used works with a minimum of knowledge of the process and possible errors by the operators. This chapter will discuss how this process works and how it leads to inefficiencies in wood use. The four major components of the process are (1) the curing structure; (2) furnaces; (3) flues and chimneys; and (4) ventilation. Management and barn packing (loading) also influence fuel use but they are difficult to evaluate because they were not observed at the time of this investigation.

Barn Structure

2.11 Most of the buildings used for tobacco curing are constructed of brick, mud, poles, and metal or thatched grass roofs. Locally made labrite brick is a reasonably good construction material. However, it has a relatively poor insulation value when used in solid walls. Consequently, there is a relatively large conductive heat loss through brick walls. Also, the mud used for mortar is made from soil mixed with water, with no cement or binder added. This serves the intended purpose where it is kept dry but is a poor material for foundations and for surfaces exposed to the weather. Occasional failures of barns were reported to be due mainly to foundation collapse. In some instances, the mortar joints had deteriorated to a point where air could freely pass through the walls. The use of cavity walls to provide a dead air space for insulation was observed at research and demonstration sites.

2.12 Wood poles and lumber used in barns are subject to early failure, mainly because of termite damage. At some locations it was noted that tier poles were supported independently of the wall structure so that they could be replaced without interfering with the walls. There was no evidence of the use of metal termite shields, especially to protect the roof structure.

2.13 The roof covering materials used on barns have relatively little insulating value. This is not a critical factor except in the leaf and stem drying phases of the curing process, and then only where there is no sunlight.

Furnaces

2.14 Furnaces are generally made of brick and mud or mortar cement, in some cases with metal reinforcing to support the top. Furnaces are built on site in several configurations to match the barn and flue layout. Over half of the barns are estimated to have open hearth (hull

1/ Low density, 1890 kg per m$^3$, conductivity (K) = 11 W per m$^2$·OC per cm thickness. For wood K = 1.8.
type) furnaces which are simply a shell with an opening in one end for inserting wood. Open hearth furnaces are inherently inefficient as there is no control over air supply and the burning rate except through wood supply.

2.15 Some furnaces are constructed using both grate and doors for feeding wood and cleaning out ashes; although the design is satisfactory, problems have been noted with operation. Among them: doors are frequently left open, wood lengths are too long to close the door, the back of the furnace or firewall can be knocked out when wood is thrown in, heavy logs may cause the grate to buckle, and grate bars are spaced too far apart — allowing unburned wood and charcoal to fall through.

2.16 It appears that most furnaces are reconstructed after one or two seasons. The idea is to invest as little as possible in furnace material without regard for labor cost as it is relatively inexpensive.

**Flues and Chimney**

2.17 The most commonly used flues are made of sheet iron in pipe sizes of 28 cm and 35.5 cm diameter by 0.6 m to 2.4 m long. The flues extend out from the furnace at a central end point or from two sides, depending on the flue layout. The first section of the flue pipe generally overheats and warps and must be replaced two or three times per season. The other portion of the flue pipe should last several years before it deteriorates from rust. There was some evidence of poorly made joints which would affect the draft generated in the flue system. In general, flue pipes were found to rise slightly, 1 cm to 10 cm, in length from the furnace exit to the chimney outlet.

2.18 At some locations, there was a problem with non-uniform curing which may be caused by unequal heat distribution. This may result from improperly located bottom vents or insufficient flue surface for heat convection. In some of the larger 6 m x 12 m barns, metal drums were located in corners opposite the furnace to increase heat convection at these locations. At some locations on the lower tier, there were reports that too much heat caused the tobacco to dry too quickly. This may have resulted from heat radiating from the flue pipe at the hottest points. The solutions are to separate the tobacco further from the flues, install a heat shield baffle to record radiant heat or to improve the flue design and layout for more uniform heat distribution.

2.19 In a study for the Kasungu Flue Cured Tobacco Authority (KFCIA), TPI (TPI-R653) recommended that a 35.5 cm diameter flue pipe be replaced with a 28 cm pipe which was said to increase the heat transfer efficiency by 20 percent. TRA has confirmed an improvement in fuel efficiency using 28 cm diameter flues in conjunction with a 35.5 cm diameter chimney. The theory is that a smaller pipe results in greater flue gas velocity, more friction, and greater turbulence which results in better heat transfer. The assumption is that the chimney height and differential temperature is sufficient to generate the necessary draft. Before many farmers scrap useable 35.5 cm diameter flue pipe, it might be advisable to try other
alternatives such as changes in chimney damper, size and height, flue baffles and draft control on the furnace to accomplish the savings. Increasing the velocity of flue gas by reducing pipe size increases heat output but also increases friction in the pipe which must be compensated for by increasing stack height and effectiveness.

2.20 To carry the reduction in flue pipe size even further, a few producers were using a 22.8 cm diameter pipe. Among the advantages cited were efficient wood use (10 m³ per 500 kg of tobacco) and 36% less material than in the 35.5 cm diameter pipe. The disadvantages mentioned were quick burnout of the flue near the exit from the furnace, the necessity of cleaning flues after every cure, and an extension of curing by one day as mentioned by one producer.

2.21 In an effort to improve flue design, TRA has tested a flue of rectangular cross section which shows savings of up to 40% in trials on several estates. The rectangular flue has a greater surface area, a smaller hydraulic diameter, and less horizontal surface exposure for upward radiant heat, but it is expected to cost twice as much to construct as the 28-cm round flue pipe. However, the rectangular flue has not been fully evaluated by TRA.

2.22 In general, it is difficult to evaluate flue design independently of chimney design. Many different chimney arrangements exist — from no chimney to brick chimneys which extend above the roof line. Most barns have only one chimney although 6 m x 12 m barns frequently have two chimneys. The flue pipe often will extend through the barn wall and turn upward with a 90° ell. A vertical extension may or may not be attached to the ell. A brick and mortar ell is used in some cases because of the high cost and relatively quick deterioration of metal ells. Brick chimneys are used at some locations in combination with 28 cm and 35.5 cm diameter metal stacks. The cross section area of a brick chimney should be 30% greater than the comparable round metal flue area which is often not the case. Chimney size and height are viewed as a serious problem in the operation of many barns.

2.23 Ventilators The purpose of ventilators is to permit air to enter the barn to pick up moisture and to allow air with excess moisture to leave the barn. The ventilators normally are located at the bottom and top of the barn. The ability to regulate ventilators is extremely important in maintaining a proper drying rate and in conserving fuel.

2.24 Most barns have openings in the wall at or below flue pipe level on the furnace side and on the loading door side. These openings are regulated by a door, brick fill in, or other means. Ventilation at the top is generally unregulated by vents at the eave, at the ridge, or by openings in the sidewalls near the eave which are permanently open. Where a thatched grass roof is used the air readily passes through the roof. Very few barns have adjustable ventilators at the top that can be regulated from ground level. Most operators reason that, if no air can get at the bottom, none will leave at the top. They do not realize that cooler air may enter a top vent on one side of the barn and drop within
the barn to force hot air out of vents on the other side, or that some combination of air circulation may occur.

2.25 Curing tobacco by regulating bottom ventilators and fuel wood input does not require a high level of management; it is difficult to get into trouble in the coloring phase as temperature is kept low and some leaf drying is desirable. If too much air is permitted through the bottom ventilators, the color of the tobacco is likely to show green which is immediately evident. If too little air is permitted, the tobacco will turn dark in color. Once the desired color is obtained, bottom ventilators are opened and temperature is advanced quite rapidly. One farm manager gave the following curing schedule:

1st day - Bottom vents open, top vents permanently open, pack (fill) the barn with tobacco.
2nd day - Bottom vents closed, start fire, maintain 27-29°C.
3rd day - Bottom vents closed, maintain 27-29°C.
4th day - Bottom vents partly opened, continue coloring to 43°C.
5th day - Bottom vents open, advance temperature 5.5°C every six hours from 43° to 54°C.
6th day - Bottom vents partly closed, after temperature reaches 71° to 77°C and until stems are dry.

2.26 The curing schedule obviously requires that a large amount of heat be wasted after a temperature of 60°C is reached. As outlined in Appendix C, only 10-23% of the moisture remains to be removed at this point. Numerous studies have shown that controlling the number of air changes taking place during various phases of the cure is the most important element in fuel savings in good curing facilities.

2.27 At one location a wet bulb thermometer was used in conjunction with the dry bulb thermometer as an aid in determining the ventilation rate or number of air changes. This instrument is highly recommended as a guide to obtain an optimum drying rate (air change), especially in the coloring and leaf drying phases. The use of a wet bulb thermometer in barns with open hearth furnaces did not appear to work, because the temperature fluctuated so much that an average wet bulb depression could not be observed. It appears, therefore, that the lack of control of ventilation rates or air changes accounts for a considerable amount of the excess fuel wood used for curing tobacco.

Existing Wood-Fired Curing Systems

2.28 Perhaps as many different systems for curing FCV can be found in Malawi as in any country in the world. These systems range from the very simple plastered hessian with thatched grass roof to the continuous process in large structures on estates. The method of handling tobacco in the barn also varies. Short clips, long clips, strings, sticks, wire, and rocks were found in use. The capacity of barns varied from 250 to 1000 kg of tobacco per curing for conventional barns, to 50,000 kg for the tunnel system. Flue arrangement, shape and size varied depending on
barn size and other factors. Furnace construction, shape and location also varied. None of the conventional barns observed had controllable or adjustable top ventilators.

2.29 Despite the many barn variations, the curing process is the same, involving a regulated rate of moisture removal from the tobacco leaf. Fuel provides the heat to allow air to absorb the moisture during the regulated drying process. Barns (sometimes called kilns) are enclosures which provide a means for managing the process. One or more of the various curing barns are described in previous reports. 1/ A more detailed description of the various barns' systems observed in Malawi is contained in Appendix D. These barns are briefly described as follows:

Small holder A 3.66 m (12 ft) square or 3.66 m (12 ft) x 4.9 m (16 ft) by 6.7 m (22 ft) high barn with one furnace and shilow or round flues in various arrangements.

Grower Round A 6.4 m to 6.7 m (21 ft to 22 ft) diameter by 7.3m (24 ft) high crown with conical roof, one furnace, and various flue arrangements.

Typical grower and estate A square or rectangular floor plan constructed side by side in batteries of 2 to 12 units. The most common sizes are 6 m x 6 m (20 ft x 20 ft) or 6 m x 12 m (20 ft x 40 ft) by 4 to 8 tiers high. These barns have one or two furnaces and various flue arrangements. This appears to be the most popular type of FCV barn in use.

Bulk Curing A relatively small barn where air is forced through more densely packed containers of tobacco to cure approximately 1100 kg in a week. Power is required to drive a fan, a centralized furnace or boiler provides heat to two or more units. Very few of these high initial cost barns were found in Malawi.

Curing tunnels A large single (or multi-pass) pass structure is used, where tobacco is loaded on trolleys and moved against an airflow with steadily increasing temperature and moisture saturation deficits. Power is required for fans and heat is provided by a central boiler. Two large curing tunnels are used in Malawi, each capable of curing up to 121 ha (300 acres) of tobacco a year.

2.30 Other curing systems or arrangements were either experimental or being installed for use during the 1984 curing season.

(2) Government of Malawi, Ministry of Agriculture, Tobacco Sector Study, Volume IV, Production Factors, MWO07/3 10.82.
Potential for Saving Fuelwood in the Curing Process

2.31 Various estimates have been made of the amount of fuelwood required to cure tobacco in Malawi. It was estimated that 0.02 m³ to 0.13 m³ of solid fuelwood on a dry basis was required to cure a kilogram of tobacco. If it is assumed that one curing of tobacco in a typical barn weighs 500 kg and fuelwood stacked density is 0.469, it will take 27.7 m³ to 180 m³ of stacked fuelwood at 25% moisture content to cure a barn of tobacco. In another report it was stated that "a moderately efficient furnace and barn unit requires 47.6 m³ solid wood to cure 1680 kg of FCV tobacco." A ratio of 9.7 kg of wood used to one kg of tobacco cured was reported; however, the ratio is 9.2 if solid wood density is 325 kg/m³. The same report gave a stacked wood density of 325 kg/m³ at 25% moisture content. Using 47.6 m³ solid wood to cure 1680 kg of tobacco amounts to 30.2 m³ of stacked wood at the 0.469 density factor and 25% moisture content to cure 500 kg of tobacco. At the density factor of 0.67, the amount of wood becomes 21.2 m³ to cure 500 kg.

2.32 In a 1946 report on wood use it was reported that from 5.4 m³ to 7.2 m³ of wood were required to cure 245 kg of tobacco. This is 12.9 m³ of wood per 500 kg of tobacco in block and frame barns equipped with open hearth furnaces and adjustable bottom and top ventilators.

2.33 In a report dating back to 1931 it was reported that 13 m³ of red gum wood were required to cure 500 kg of tobacco in a wood frame barn equipped with adjustable bottom and top ventilators (Progress Report I, Curing of Tobacco by Electricity, State Electricity Commission of Victoria, Wangaratta District, Victoria, Australia). The report made no mention of the type of furnace used.

2.34 Some of the responses by producers interviewed by the team are outlined in Appendix E. One manager in the Central Region representing 38 barns which cured an average of 504 kg of tobacco per barn per curing said that 10 m³ to 24 m³ of fuelwood were used, or a mean figure of about 17 m³ per 500 kg of tobacco cured. Some of the barns were equipped with improved furnaces. Another manager of small holder growers said it required 15.5 m³ of wood to cure 500 kg of tobacco in small barns with both improved furnace and flue system. In round barns with improved furnace and flue system, it took 16.6 m³ of wood to cure 500 kg of tobacco.

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iii/ E.M. Matthews, M.H. McVickor, and R.B. Davis, Jr., 1946: Curing Bright Tobacco with Coal and Oil, Bulletin 396, Virginia Agricultural Experiment Station, Virginia Polytechnic Institute, Blacksburg, Va.
tobacco. In the Southern Region a manager said about 15 m$^3$ of fuelwood were required to cure 500 kg of tobacco in an average size barn equipped with an improved furnace. On another estate, where 120 hectares of tobacco are grown, 10.5 m$^3$ of wood per 500 kg of tobacco cured were required for barns with improved furnaces and flues. Unimproved barns were requiring 22.2 m$^3$ of wood to cure 500 kg of tobacco.

2.35 Since fuelwood use varies considerably even with similar curing facilities, the estimates represent a consensus figure within a range. The range for poor barns might be from 15 to 65 m$^3$ of wood to cure 500 kg of tobacco, based on the definition of "poor barns", skill of the operator, condition of the tobacco, and weather. In the aggregate, TRA estimates that existing "poor barns" use an average 20 m$^3$ of wood to cure 500 kg of tobacco and that the national average is 12 m$^3$ for 500 kg. Details of the estimated wood requirements for various curing alternatives are shown in Table 3.1.
III: TECHNICAL PACKAGES TO IMPROVE CURING SYSTEMS

3.1 Several options are available for reducing the use of fuelwood in curing tobacco. Generally, they involve improvements to existing systems and management or consideration of complete new systems. Fortunately, most of the alternative systems and improvements have had some application in Malawi or are presently under study.

Improving Existing Barns and Management

3.2 A first priority in reducing fuelwood use is to improve the furnaces in barns. Some change in the construction procedure and configuration is suggested by TRA and is being adopted by a few growers. One is to reduce the size of the mortar joint and to expose a relatively greater amount of the brick surface to the fire.

3.3 Barns with open hearth (hull) furnaces consume at least a third more wood than those that have furnace doors and grates. The cost of upgrading a furnace in a typical barn is estimated to be MK 250. The equipment is available locally and the improvement could be made prior to the 1984 curing season.

3.4 With reference to possible use of ceramic material with greater resistance to high temperature, the team interviewed the geologist at the Malawi Department of Geological Survey in Zamba. It was reported that raw materials of sand, clay, and cement are abundant or adequate within the country. It also was reported that a mineral called kaonite that will withstand high temperature is available from a deposit at Kaphiri-dimba. This mineral may be crushed and mixed with local clay to make firebrick, or possibly mixed with mortar to improve its heat resistance characteristics. However, an earlier investigation by TRA indicated that using firebricks was quite expensive.

3.5 Other suggestions for improving furnace design as illustrated in Appendix F include the use of a five bar, 76-cm long grate, sloping firebox sides and vertical end to the grate, enlarged ash pit, an after burner area, continuously rising exit to flues, and loading and ash clean out doors.

3.6 A second priority is to install controllable top vents in existing barns, which should result in a further savings of 18 m$^3$ per annum in wood use per barn. A controllable top ventilator may be constructed on the farm or purchased locally at a cost of MK 160. Attention should also be given to better or more operable ventilators at the bottom of the barn. Again, these additions can be made before the next curing season; however, training operators to properly manage the ventilators may be more difficult. Making both first and second priority improvements along with the installation of a good chimney, closing of eave openings, repairs to mortar joints in sidewalls, and a good fitting door and bottom ventilators, should reduce fuelwood consumption by approximately 48 m$^3$ per annum (or 40 percent) over an unimproved poor barn.
3.7 A third priority is to install high efficiency flues and chimneys in existing barns. It is not suggested that existing useable flue pipe be replaced, but that the best possible pipe arrangement is made so that the pipe exits from the furnace at the top of the arch or plate and is gradually inclined upward to the chimney. When the flue pipe needs replacing, it is suggested that a 28 cm (11") diameter pipe be used rather than 35.6 cm (14") pipe; also shallow and rectangular cross section type flues should be considered as well as other flue types or arrangements now being investigated by TRA. High efficiency flues should reduce wood fuel use by 3 m$^3$ per curing (500 kg) of tobacco. The cost of installing high efficiency flues may actually be less than replacement with flues of existing shape and size. Replacement for a 28 cm (11") diameter flue pipe is available locally. It may cost close to MK 175 to replace old 35.6 cm (14") diameter pipe. Other types of flues or alterations being tested by TRA may require local fabrication. The rectangular cross section flue may cost 200% to 250% more than the round pipe unless it is mass produced. The farm constructed brick tunnel (35.5 cm wide inside) flue with 56 cm (22") wide corrugated iron cover may cost one-half to two-thirds that of a normal round flue pipe. It is not necessary to learn new skills to operate a barn with high efficiency flues. A combination of first, second and third priority improvements is expected to reduce fuelwood use by 55% or 66 m$^3$ per annum.

**Installing forced draft and ducted bottom vents to improve furnace in existing barns**

3.8 This level of improvement requires a source of power for the forced draft fan or fans. It has been tested at 10 barns during one season at one location by TRA. The results, as compared with the ordinary furnace, were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Wood Used (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary furnace, standard flues</td>
<td>11.9</td>
</tr>
<tr>
<td>Forced draft furnace, standard flues</td>
<td>8.0</td>
</tr>
<tr>
<td>Forced draft furnace, rectangular flues</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Similar systems are being used for coal burning furnaces in Zimbabwe.

3.9 A sketch of this system is shown in Appendix E. A forced draft system is under construction in the Kasungu area for 12 barns, with the air plenum and fan unit designed for expansion to 24 barns. It is budgeted to cost MK 2000, excluding the cost of the engine to power the 1KW fan. This amounts to MK 167 per barn and the operating cost will be about MK .50 per hour for all barns. Wood is available on this farm at a cost of about MK 50 per m$^3$ excluding production cost. (See Appendix D, General Farming Co.) The forced draft system, along with previously discussed improvements, should save 67% of the wood that a poor barn would use or 81 m$^3$ for 3000 kg of tobacco cured a year. The investment cost of this improvement is estimated at MK 735 per 500 kg of curing capacity. Thus, its incremental benefit cost ratio and payback period are relatively poor, except in special circumstances. Moreover, since the system is still under study and there is very limited availability of electric power, it is recommended that its large scale promotion be delayed.
Installing cascade continuous curing system in existing barns

3.10 Again, this system requires an even larger source of power for a fan or fans. Since many barns are constructed in batteries of six or more, the system can be readily adapted to existing barns. The system has proven applicable in Zimbabwe with coal-fired furnaces and is currently being tested by TRA at Bunda College of Agriculture with wood-fired furnaces. Reported findings show excellent fuel savings, quality of cure, and ease of operation. In March, 1983, 17 barns of tobacco were cured in the demonstration unit, with a 69% fuel savings over the conventional barns nearby. A sketch of the system may be found in Appendix F.

3.11 A block of four-tier barns 12 m x 6 m (40' x 20') was modified to form eight (6m x 6m) barns with one 12 m x 6 m original barn to contain the heating units. All barns were fitted with an airtight ceiling of plastic sheet and a vertical brick duct on one wall. The main hot air duct was constructed below the floor so that the heated air exchange could be routed to any barn. The hot air is introduced to the barn in the stem drying phase and continues through each other barn from top to bottom in the sequence of leaf drying and coloring phases. During sunlight hours, solar energy is picked up between the metal roof and the airtight ceiling to preheat make-up air to roughly 20% of its requirements.

3.12 This system uses two 5 1/2 KW fans to operate, and it costs MK 20,000 to convert the eight barns with 4000 kg curing capacity. The fuelwood required was 4.65 m³ per 500 kg cured (no increase in density), resulting in a savings of 69% compared to a standard barn using 15 m³. TRA believes that a functional non-experimental system would use 3.5 m³ of wood to cure 500 kg of tobacco, or a savings of 82% over a typical poor barn. The cost of the improvement would be approximately the same or MK 2500 per 500 kg of capacity. The investment is a disadvantage but, along with less wood use, the system has some advantages. There are no furnaces and flues, so tobacco can be hung lower in the barn and at greater density. The fire hazard is reduced and the central furnace is more easily stoked. As with most improved systems, it should contribute to a more uniform quality of tobacco throughout the barn.

3.13 The system merits further study, particularly with respect to reducing fan power, increasing curing capacity, and reducing length of cure. Use of customary construction materials and barn orientation to aid in solar energy collection at minimum cost also needs further investigation. The possibility of using a central heating plant and steam power for the fans should be examined. Another possibility is to use fans powered by engines operating on wood produced manufacturers' gas. Research and field studies are being conducted on several potential
Many makes of central heating plants are commercially available for potential application to tobacco curing systems.

3.14 In terms of reducing wood use, the system appears practical if it can be located on a power supply line supplied by hydrogenerated electricity. However, it requires further testing and is not immediately applicable for the industry.

Installing insulation, forced air recirculation, solar collectors and heat pipe extractor additions to existing barns 2/.

3.15 This system falls into the same category as cascade continuous curing except that an even greater investment and array of equipment is proposed to reduce fuel wood use. The system has been recommended by consultants and partly installed on a farm of J.P. Stephens Investments, Ltd. in the Blantyre area.

3.16 The modifications proposed by the consultants for three 7 m x 7 m x 7-8 m high barns include thermal insulation, introduction of loops with air recirculation (continuous curing), introduction of regulation of air flow in existing hearth, introduction of solar collectors and a heat pipe. All of these energy saving techniques have been or are being tried for tobacco curing with the possible exception of the heat pipe.

3.17 Several studies in the US 3/ and Canada 4/ have shown that the addition of thermal insulation reduces heat losses and consequently fuel use. The feasibility study gives a maximum transmission heat loss of 43,180 kcal/h which, by installing 300 m² of insulation at a cost of MK 4.44 per m², is expected to save 27% of heat requirements. Conventional barns with good furnaces are using approximately 15 m³ of wood to cure a barn of tobacco so the savings are 4 m³ per cure or 24 m³ per season due to insulation. TRA has experimented with the cavity wall which provides


2/ J.P. Stephens Investments, Ltd.


a dead air space for insulation at essentially no increase in the cost of materials, but builders suggest that it may be more difficult to construct.

3.18 The introduction of loops or cascade air movement has already been discussed under the cascade continuous curing system. This is projected to save about 20% of heat requirements but involves the installation of fans and air ducts. Because of the installation of electrically powered fans, the feasibility study suggests a doubling of barn capacity. Past experience indicates that barn capacity only can be increased by about 50% if present tobacco handling techniques are used and adequate air flow is provided.

3.19 The introduction of air flow to existing hearths was discussed in para. 3.7. The introduction of a heat recovery pipe to save 11.6% of the heat requirement has received little attention by researchers. Spending MK 750 per barn plus transportation and installation for the heat pipe to save 1 3/4 m$^3$ of wood per cure appears to be less attractive than spending the same amount on insulation. Also, any mechanical system equipped with a sensing wick is likely to require considerable attention in the atmosphere of a tobacco barn.

3.20 Installing solar collectors at a cost of MK 31.67 per barn plus transportation and erection to save 5.7% or 0.9 m$^3$ of wood per cure falls in the same category as the heat pipe. Using a solar collector as an integral part of the building with little extra cost for installation has proven to be economically feasible. Experience in the US indicates that approximately 16% of the energy can be obtained from solar and up to 32% where large roof surfaces are available. TRA believes that up to 20% of the heat energy can be provided by solar through the bare plate attic collector being tested in the cascade continuous curing system.

3.21 The consultants' proposal for J.P. Stephens Investments, Ltd. does not appear entirely feasible at the moment even though some of the proposed features have already been proven in practice and others have been researched in several countries. Increasing barn capacity to 1200 kg per curing does not appear realistic with present leaf handling methods. The maximum average amount which might be expected for the barn size under consideration is 750 kg, and this is likely to require a greater air flow than proposed (but with little more cost). Also, it is likely that the barn will be used for 6 cures per season rather than 12. Hence, a more realistic quantity of cured tobacco per year per barn would be 4500 kg rather than 7200 kg.

3.22 Operating the proposed system would require a high level of management and expertise in maintaining the equipment, especially the automatic controls. Moreover, several components of the system are not available in the country. Given these factors and the presence of more economically attractive and simpler efficiency improvement options, this particular proposal does not warrant a high priority at this time.
Installing continuous tunnel curing system (new barn)

3.23 Installing the tunnel system permits the elimination of two-thirds of the existing curing barns. Some barns must be retained to provide curing space, generally at the beginning and end of the curing season, when not enough tobacco is available for the tunnel to operate. A tunnel requires reaping six days per week, hence it is not suitable for the small tobacco grower. Smaller units handle 12-16 ha of tobacco, whereas larger units handle 120 ha.

3.24 Tunnel systems are very efficient wood users. The 120 ha system on the Makande Estate near Mulanje reportedly used an estimated 2.8 m³ of dry wood to cure 500 kg of tobacco with a centrally-fired high pressure boiler. TRA believes that a tunnel system should save 86% or 17.3 m³ of wood over a typical poor barn of an equivalent 500 kg curing capacity. The estimated MK 400,000 system cost to install makes it a high investment facility to cure approximately 275,000 kg a year. Power is required to operate the fans and could be a significant portion of operating cost.

3.25 The system requires that the operator understand the basic principles of tobacco curing. It is simple to operate except when a problem arises such as non-uniformity of tobacco supply or mechanical interruption. The quality of the tobacco coming from the tunnel is as good as that expected from any system.

3.26 Coal-fired tunnel systems have been used satisfactorily in Zimbabwe for more than ten years. The wood-fired units in Malawi also have operated satisfactorily for several years. The tunnel system apparently will require an investment of about 25% more than an equal capacity of conventional barns. With conventional barns in place and in good repair, a detailed economic analysis is recommended before changing to the tunnel system. In addition, a source of long term funding will be required before any changeover is made. A tunnel system to match a given situation would probably take a year to plan, design and construct. All segments of the system are commercially available, although some equipment would have to be imported. It is recommended that field studies be carried out at the two existing facilities to determine the exact amount of wood and other energy used to cure tobacco in the tunnel system.

Bulk Curing System (new barn)

3.27 The bulk curing system was developed and used primarily in the United States to reduce labor in the harvesting of tobacco. A bonus in the system is that it uses less of comparable kinds of energy than the conventional, less densely packed stick, string, or clip loaded barns. Centrally-fired wood boilers have supplied heat to clusters of barns at the very efficient rate of 2-2.5 m³ of stacked wood per 500 kg of tobacco cured.
3.28 Bulk barns are normally manufactured off site and delivered to the farm, although some units are constructed on the farm from local materials. The cost to purchase and erect a pre-manufactured bulk barn and central wood fire heating system with a 1133 kg curing capacity is estimated to be MK 20,000. In addition, a local source of electric power is needed. In a nation of limited energy resources, it appears that hydro-generated electric power is the only viable source.

3.29 A changeover to bulk barns would require a large capital investment and the importation of some system components. In view of the limited availability of hydro-generated electric power in rural areas and low labor costs, the bulk system does not appear to merit wide application in Malawi.

**Preliminary Economic Analysis**

3.30 Table 3.1 provides a comparative economic evaluation of the various technical improvements that can be made to existing barns and more sophisticated technology in new barns. Incremental savings (in terms of woodfuel) are determined with respect to progressive levels of improvements to the 'base-case' typical inefficient barn which uses 20 m$^3$ of fuelwood per 500 kg cure of tobacco. Annual wood savings are estimated on the basis of six cures per season. Justification for a wood price of MK 6 per m$^3$ is given in paragraph 3.34. Simple paybacks are calculated for each improvement based only on marginal fuelwood savings and investment cost. The uncertainties associated with even these basic cost elements do not justify a more detailed analysis incorporating the time value of money, and economic lifetimes. Labor costs, power costs and operations and maintenance costs also have been excluded even though they may not be insignificant. Nevertheless, the analysis is quite illuminating; the improvements fall into three distinct categories:

(i) low cost and economically attractive investments in existing barns;

(ii) high cost (long payback) investments in existing barns; and

(iii) high cost investments in new barns.

3.31 Installing doors and grates on furnaces is the most attractive investment, with a payback of less than two years. This is closely followed by installing adjustable ventilators in barns. The savings associated with these two improvements are to be further evaluated in a pilot project described in paragraph 5.15.

3.32 Installing high efficiency flues also appears to result in a quick payback. However, savings for this improvement were only estimated from TRA laboratory work; therefore, it is not recommended that high efficiency flues be included in the pilot project as yet. Considering the attractive payback, it is recommended that research efforts be intensified in this area.
Table 3.1 Payback on Technical Improvement to Flue-Cured Tobacco Facilities

<table>
<thead>
<tr>
<th>Improvement a/</th>
<th>Average Wood Use Per 500 kg Cure (m³)</th>
<th>Marginal Wood savings per 500 kg Cure b/ (m³)</th>
<th>Wood savings per annum c/ (Mₖ)</th>
<th>Savings at 6 MK/m³ (MK)</th>
<th>Investment Cost (MK)</th>
<th>Payback period d/ (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Barns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Improvements</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Doors and Grates on furnaces</td>
<td>15</td>
<td>5 e/</td>
<td>30</td>
<td>180</td>
<td>250</td>
<td>1.4</td>
</tr>
<tr>
<td>Adjustable ventilators</td>
<td>12</td>
<td>3 e/</td>
<td>18</td>
<td>108</td>
<td>160</td>
<td>1.5</td>
</tr>
<tr>
<td>High efficiency flues</td>
<td>9</td>
<td>3 e/</td>
<td>18</td>
<td>108</td>
<td>175</td>
<td>1.6</td>
</tr>
<tr>
<td>Forced draft system</td>
<td>6.5</td>
<td>2.5 e/</td>
<td>15</td>
<td>90</td>
<td>735</td>
<td>8.2</td>
</tr>
<tr>
<td>Cascade continuous curing</td>
<td>3.5</td>
<td>16.5 f/</td>
<td>99</td>
<td>595</td>
<td>2500</td>
<td>4.2</td>
</tr>
<tr>
<td>Insulation, solar, cascade, heat pipe combination</td>
<td>2.5</td>
<td>17.5 f/</td>
<td>105</td>
<td>630</td>
<td>12000</td>
<td>19.1</td>
</tr>
<tr>
<td>New barns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tunnel Continuous curing</td>
<td>3.0</td>
<td>17 f/</td>
<td>102</td>
<td>612</td>
<td>6500</td>
<td>10.6</td>
</tr>
<tr>
<td>Bulk Curing</td>
<td>2.5</td>
<td>17.5 f/</td>
<td>105</td>
<td>630</td>
<td>8800</td>
<td>14.6</td>
</tr>
</tbody>
</table>

a/ Not intended as an exhaustive list of possible curing systems.
b/ Source: TRA and personal communication with growers.
c/ Assumes 6 cures per season.
d/ No consideration is given to incremental labor, power or O&M costs, nor improvements in the quality of tobacco. There is no time discounting of costs or benefits. The payback period is simply the ratio of the value of incremental annual savings at a wood price of 6 MK/m³ to the incremental investment cost. However, it should be noted that the financial rate of return for the first three measures is well in excess of 100 percent, assuming a 10 year plant life, simplified uniform net benefit stream and incremental annual labor and O&M costs equal to 10 percent of initial investment.
e/ These improvements would be applied sequentially and the marginal savings are those associated with each incremental improvement.
f/ These improvements constitute self contained and mutually exclusive options. The marginal savings and investment costs are measured against the "no improvement" situation.
3.33 All other improvements in both new and existing barns are clearly unattractive from an economic perspective at this time. Research efforts should continue, with priorities given to the more likely candidates for implementation in the future.

Establishing Fuelwood Cost

3.34 An effort was made to establish the cost of fuelwood. Responses to questions on fuelwood cost are outlined in Appendix D. Fuelwood is either grown on the farm or purchased from the Forest Reserve. If it is purchased, the Forest Reserve charges a fee of MK 1.50 per m$^3$ on the stump. The former either provides his own labor to cut and haul the wood or contracts a crew to deliver the wood to his barns. The labor cost to cut wood varied from MK 0.29 to MK 0.70 per m$^3$. The hauling cost varied from a low of MK 0.21 for wood cut on the farms to MK 4.50 per m$^3$ for wood cut on the Forest Reserve 11 km away. The total cost for wood purchased from the Forest Reserve appears to be about MK 6.0 for a typical hauling distance and this is the figure used in the calculations of benefits in this study. However, it is important to note that the cost varies considerably by region and is much higher in some wood deficit areas in the center and south of the country.

Tobacco Quality as Affected by Curing Facilities

3.35 The quality of tobacco is affected by many factors including the curing process. It is difficult to obtain good quality leaf from poorly grown, immature, or overripe tobacco. On the other hand, tobacco with a potential for excellent quality can be deteriorated in the curing process. Curing faults include brown scald, green scald, sponge, scorch, dead tissue, swell stems, barn rot, etc. Most of these curing faults can be reduced or eliminated with proper ventilation and temperature adjustments during the curing process. 1/

3.36 There were relatively few comments by those interviewed on quality deterioration during curing. Most comments related to uneven curing within the barn. The evidence suggests that quality could be enhanced considerably by improvements in curing facilities and practices. In particular, a more uniform cure throughout the barn would help maximize the quality of the leaf. While it can be reasonably assumed that improved facilities and practices contribute to better quality tobacco, it is difficult to place a monetary value on quality improvement without supporting data from monitored tests. Consequently, no allowance has been made for higher value production in calculating the benefits of the improvements recommended here.

Next Steps

3.37 The above analysis demonstrates that there are a number of technical options — of varying degrees of readiness, sophistication, costs and benefits — which could substantially reduce the wood energy requirements for flue cured tobacco processing in Malawi. It is also the case that because of manpower, institutional and financing constraints, not all of these options can be tackled simultaneously. Rather, a phased program is required beginning with the lowest cost (and highest return) measures to bring the low efficiency barns to the level of the more efficient ones. Even these measures cannot be applied immediately to all the low efficiency barns because an effective extension network for large scale dissemination has to be built up and the precise number and location of all the low efficiency barns has to be determined.

3.38 Given these factors, the initial step proposed by this study is to embark on a pilot program of low cost improvements in about forty barns in five different areas of the country. This pilot project will provide actual operating experience for the improved facilities, enable the training of a cadre of extension workers who would subsequently disseminate this information on a larger scale, and also serve as a valuable demonstration exercise.

3.39 Specifically, it is recommended that:

(i) Five cooperative growers of FCV with 16 conventional poor barns each should be selected, each one in a different tobacco producing area. Their agreement should be sought to carry out the pilot project on their estates.

(ii) Eight of the barns for each grower should be equipped with improved furnaces, including grates and doors, and controllable top and bottom ventilators. Another block of eight barns should remain unmodified.

(iii) A technical assistant should be stationed on the estate for the entire curing season in 1984 and 1985 to monitor fuel wood consumption in each block of eight barns. Another important function would be to train barn-tending labor in the correct use of the equipment in the improved barns.

(iv) These farms should be visited regularly by TRA experts and extension personnel in order to monitor progress, identify any problems and generally obtain information on practical difficulties growers might have in implementing these measures. This information is vital and must be obtained before the full extension program is implemented.
3.40 The cost of the specific improvements at these barns is estimated as follows:

**Equipment and Installation Costs**  
*(All labor to be provided by cooperators)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost (MK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnaces for 40 barns</td>
<td>40 x 250</td>
<td>10,000</td>
</tr>
<tr>
<td>Adjustable top ventilators</td>
<td>40 x 160</td>
<td>6,400</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>40 x 40</td>
<td>1,600</td>
</tr>
<tr>
<td>Salaries and expenses of technical assistants</td>
<td>-</td>
<td>18,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>36,000</strong></td>
</tr>
</tbody>
</table>

3.41 However, it is important to note that this is only a part of the costs of an overall efficiency improvement program. As discussed in the following chapter, these improvements will be implemented effectively only if a suitable extension network exists. Such a network should be developed in parallel with the implementation of the pilot program so that a full scale program of improvements can be started in 1986. Moreover, to resolve the uncertainties on current wood use levels by different types of barns and to obtain a definitive picture of the numbers of barns of varying efficiency levels a survey of all barns is also required. This too is detailed in the following chapter. Finally, to prepare for a second phase of the program which would entail the installation of more sophisticated improvements still under development and testing, the ongoing research and development effort in this area needs to be strengthened as outlined in Chapter V.

3.42 To support these actions the Government also needs to examine carefully a number of policy measures which would encourage more efficient wood use by the tobacco industry. These include:

1. Provide tax incentives to encourage the use of efficient wood-burning equipment.
2. Provide tax incentives to encourage the establishment of adequate fuelwood plantations.
3. After a suitable period of notice, make the issuing of licenses to cut wood in forestry reserves conditional on growers installing fuel efficient furnaces and adjustable ventilators in curing barns.
4. Increase the price of licenses to cut wood from the present MK 1.50 per cubic meter to the true cost of production. This increase in price could be on an escalating scale so that the people who require wood for cooking would not be unduly penalized.
5. Require banks to certify that borrowers of government-backed funds have installed efficient wood burning equipment and adjustable ventilators, and barn operators have attended TRA Training Schools.
A related issue is the policy adopted for financing barn improvements. The financing of tobacco production in Malawi was discussed in the Tobacco Sector Study. It suggested the establishment of an alternative source of development finance for modernizing estate production facilities through the Investment and Development Bank of Malawi, Limited (INDEBANK) and its established facilities. INDEBANK was established to fund viable projects which further the nation's economic development. Several constraints on financing were identified, particularly those related to long term credit. Short term credit for one year or less can be obtained from commercial banks. Generally, it will take more than one year, but less than five, to pay back barn improvement loans.

The total cost to improve FCV barns was estimated at MK 2.5 million which is about seven percent of projected gross sales receipts. Thus, the amount of funding is relatively small, or around MK 0.12 per kg of tobacco sold. Whether this is significant in terms of net returns depends on the savings and cost of fuelwood. If a minimum cost of fuelwood is MK 3.50 per m³, which appears reasonable, the investment could be recovered in less than five years.

The following are some of the options now available or proposed for financing barn improvements:

(i) Growers - voluntary
(ii) Commercial banks
(iii) Government guaranteed loans through commercial banks
(iv) INDEBANK
(v) Tobacco levy
(vi) Government mandate

The best program is one by which barn improvements are made and financed by growers who are convinced that their investment will be recovered by fuelwood savings and possible improvement in tobacco quality. A good extension program backed by effective research will be required to effect this change over a period of a few years. Producer response would be more rapid if commercial banks could make longer term loans or government backed loans for repayment periods up to five years. Their agricultural liaison officers or managers could insure that funds were properly spent for loan improvements during their routine service calls. INDEBANK might also provide the credit, but certain constraints on producers' loans would need altering. A tobacco levy could be imposed and collected when the tobacco is marketed. This levy

might be collected by the procedure used for TRA funding and returned to producers after certification that barn improvements have been made. A levy seems less desirable as producers do not have use of the funds before making improvements and overhead costs in handling funds are incurred. An alternative similar to that proposed by the Tobacco Sector Study suggests that the Government mandate a program of licensing furnace improvements and adjustable ventilators. Such programs generally add to government cost, are negatively received by the producer, still need an educational component, and may be difficult to enforce.
IV. INTRODUCING NEW TECHNOLOGY

Existing Extension Services

4.1 Three agencies in Malawi provide extension services to tobacco producers: the Ministry of Agriculture, Commercial Banks, and the Tobacco Research Authority.

4.2 Ministry of Agriculture The largest agency is the Ministry of Agriculture. Its extension function is carried out by the Department of Agricultural Development (DAD) through a decentralized system of eight Agricultural Development Divisions (ADDs). The ADDs are broken down into 40 Development Areas (DAs) and these in turn are subdivided into 173 Extension Planning Areas (EPAs). Each ADD is headed by a Programme Manager who has under him both supervisory and technical staff.

4.3 On the ground each EPA is subdivided into 5-10 sections with similar farming conditions. Each section has an extension Technical Assistant (TA). TAs undergo two years of post-junior certificate training at a college of agriculture before they join the Department of Agricultural Development as extension workers. Unfortunately, they have little training or experience in flue-cured tobacco production in general and almost none in the engineering aspects of tobacco curing.

4.4 The main source of tobacco extension from DAD comes from tobacco specialist officers who disseminate tobacco information and train TAs. Though they will require more training, a number of them have extensive experience in the flue-cured tobacco production. However, they also have administrative and regulatory functions such as issuing licenses and administering quotas. These activities, combined with transport restrictions, seriously inhibit their mobility on the job and consequently their effectiveness.

4.5 Commercial Banks Two commercial banks make an important contribution to tobacco extension. Although their main concern is to safeguard their own interests, they provide a valuable extension service to estates in tobacco areas. The role of the banks in providing such a service is outlined in the Tobacco Sector Study, Vol. IV, pg. 76-78.

4.6 Both banks have employed agriculturists to act in an advisory and reporting role, basically to ensure satisfactory control over lending to the Estate Tobacco Sector and to raise management standards. At present, the National Bank of Malawi has eight agricultural liaison officers stationed in the main tobacco producing areas and the Commercial Bank of Malawi has six area managers performing the same functions.
4.7 **The Tobacco Research Authority** Tobacco extension in Malawi was greatly strengthened by the formation of the Tobacco Research Authority in January 1980. Although the TRA's main function is research, about 30% of its staff time is spent on extension work.

4.8 The TRA is fortunate to have the services of a very qualified engineer, who has much experience in tobacco curing equipment and techniques, and is also very capable in the training and extension fields. Another member of the TRA also has experience in tobacco curing and extension; others would require additional training to effectively introduce the required technology.

4.9 Two Liaison Officers, one dealing with dark fire-cured tobacco and the other with flue-cured tobacco and burley, work full time in extension. Other specialists prepare extension information and are available on request to address field days or farmers' meetings.

4.10 The TRA also produces timely extension newsletters on different aspects of production. These are very useful in making growers aware of new technology and research developments.

4.11 The TRA is funded through levies on the sale of tobacco. Consequently, it is financed by the growers. It is administered by a board on which the Government and growers are represented. Certain senior staff members of the TRA have their salaries and expenses paid by international organizations such as FAO and the Ministry of Overseas Development in the United Kingdom.

4.12 **Other Extension Agencies** Another potentially valuable extension service is provided by companies growing tobacco on a large number of estates. These companies employ experienced agriculturists as area managers, each being responsible for a number of estates.

4.13 These area managers have an extension function in keeping their estate managers up to date with the latest technology. However, this function is confined to the estates that they control.

4.14 **Commercial Companies** Certain commercial concerns provide an advisory service, basically for the use of their products. Other companies have sponsored visits of outside experts to provide technical information to growers.

**Constraints to Adopting Recommended Technology**

4.15 The following are viewed as constraints to the adoption of new technology for achieving higher energy efficiency:

(1) Growers are unaware of what fuelwood actually costs them and what savings can be made by using the recommended technology. [1]

[1] TRA
(ii) Though the two commercial banks are well placed to meet seasonal credit requirements, they are not in a position to grant long term development loans to convert fuel inefficient barns to more efficient structures. 1/

(iii) New technology will require careful operation to obtain benefits. Because estate production of flue-cured tobacco usually takes place on a very large scale, many estate managers are reluctant to change a system that works, albeit inefficiently, because of fears that unsophisticated labor will have trouble applying the technology and that expensive mistakes will be made. 2/

(iv) Many estate leasees and managers are reluctant to invest in anything that will not show an immediate profit. They are not in Malawi indefinitely and therefore may not be around to reap long term benefits of an investment in improved curing facilities.

4.16 Clearly these constraints will need to be overcome if the proposed efficiency improvement program is to be adopted on a large scale. It is also clear that such an extension program could not be mounted by the official extension service on its own. Rather, all parties active in this industry need to coordinate their efforts. To this end, a recommended first step is that a meeting of all interested parties should be held to obtain agreement that an extension education program is necessary and desirable. Interested parties would include:

1. The Tobacco Association representing growers;
2. The Ministry of Agriculture;
3. The Ministry of Forestry and Natural Resources;
4. The commercial banks;
5. The Tobacco Research Authority;
6. General managers of large estate-operating companies;
7. Commercial suppliers of the necessary equipment.

4.17 The meeting would outline the present situation, show the need for improvement, and seek commitment to a program. Once agreement had been reached the proposed technical package would be outlined. Constraints would have to be identified and proposals to overcome

2/ TRA and estate managers.
The constraints put forward. A program of action then would be formulated which would define the involvement and action of each party.

4.18 While the final arrangements for allocating responsibility for the extension program would be made by the Government, a strong case can be made for entrusting the TRA with the primary coordination responsibility. It is the agency which has the greatest technical expertise in the area of improved efficiency and it will be closely involved in the pilot program as well as ongoing research into alternative technical packages. The general manager and the agricultural engineer at the TRA are very experienced in tobacco curing and extension work. As indicated above, however, TRA will need additional personnel and other resources to carry out this work. An extension engineer is needed to provide educational information to growers, not only for wood conservation curing practices, but also for irrigation, field machinery, and other production engineering technologies. An extension engineer would allow the present engineer to spend more time on research and research-related facility projects. Both will have responsibilities apart from the proposed extension program so, although they will be able to contribute to the program, further backup should be obtained. 1/

4.19 It would be very advantageous for someone from the Ministry of Agriculture to be involved in the program on a "full-time" basis. This could be achieved by sending an experienced tobacco specialist from DAD to TRA for at least the first year of the program. Close contact with the agricultural engineer would build up his knowledge and improve his ability to give expert advice. However, the specialist would require transport and a budget to cover transportation costs. Under present circumstances, this could not be financed by TRA and would need to be funded from other sources. Secondment of the tobacco specialist presently stationed in Lilongwe would eliminate the need to provide housing.

Proposed Extension Programme

Prerequisites

4.20 Prerequisites for a successful extension program to encourage growers to use fuel efficient curing equipment are as follows:

(i) The recommended equipment must be available in Malawi.

(ii) Finance for the equipment must be available on acceptable terms.

(iii) Commitment to the extension program must be given by all organizations that are involved in the program.

1/ This assumes that arrangements will be made to extend the stay of both the general manager and the agricultural engineer beyond January 1984, when their present FAO funded contracts expire.
(iv) Constraints on the acceptance of the extension message must be identified and strategies devised to overcome these constraints.

(v) All personnel involved in the program must receive the necessary training and have the information necessary to operate effectively.

(vi) Constraints on effective extension operation, such as transport difficulties, lack of visual and equipment and shortage of personnel should be identified and arrangements made to compensate for such constraints.

Preparatory Work

4.21 The first essential aspect of the extension program is to collect reliable information about the current situation. There is some discrepancy between estimates of fuelwood used, cost, and other factors given in this report as compared with previous reports. Fuelwood use and measurement were discussed under "Wood as an Energy Source" and "Potential for Saving Fuelwood in the Curing Process". Producer estimates of MK 5.50 to 6.50 per m$^3$ of purchased fuelwood are shown in Appendix E. The Tobacco Sector Study estimates a stumpage price for stacked fuelwood of MK 8.20, 13.41, and 26.36 per m$^3$ for high, medium, and low yields, respectively. The transportation cost must be added which makes the cost of farm-produced fuel wood much greater than that purchased or reported by producers. To obtain more reliable information the following is needed:

(i) Details on the number of barns operating on each estate. Details on construction materials, furnaces, flues, chimneys and ventilation systems being used in each barn.

(ii) Details on where each estate obtains its fuel wood requirements, distance this fuelwood is carted and estimates of how much fuel wood is used a year on each estate.

4.22 This information could be collected by extension workers in the course of normal farm visits using a questionnaire. The Energy Unit of the Forestry Division might carry out the inventory in the course of its normal activities. If a complete inventory is not practical, a random sample of producers should be visited, this information collected, and the country-wide situation estimated from the results. This information is essential to establish a base on which the program is built and from which progress can be evaluated.

Extension Material

(i) Information sheets on actual fuel wood costs considering all expenses. Some of this information is available from the TRA, but it needs to be updated and put into a detailed form that will make an impact on growers. Though some growers have good records of what fuel wood is costing them, most seriously underestimate the cost of obtaining their requirements.

(ii) Information sheets on what savings can be made by using improved technology, such as correct furnace design, controllable ventilators, wet and dry bulb thermometers, etc. Some of this information is available from growers, some from the TRA, and some from neighboring countries. It needs to be put together in an easily understood form.

(iii) Information sheets on the costs/benefits of using new technology. Many estate managers and leasees are reluctant to invest in improved systems because of the initial capital costs that they feel could reduce their incomes in the short term. Information from the TRA indicated that savings from using improved technology could pay for the installation in less than a season in some cases and within two seasons in the majority of cases. This information needs to be highlighted.

(iv) Information sheets on the correct operation and maintenance of new equipment. Success will not be achieved merely by installing better systems. They need to be operated correctly if benefits are to be obtained. Simple instruction sheets covering operating techniques, maintenance requirements, etc. need to be prepared.

Program of Action

Awareness Campaign

4.23 A planned campaign should be mounted to make growers aware of the present situation, the costs to themselves, the consequences of doing nothing, the technology available to improve matters, the cost of this technology, and the benefits to be derived. This could be done by means of newsletters, field days, discussion groups and individual visits to estates. TRA would be responsible for providing the information needed, newsletters and for a series of field days. The other extension agents, area managers, bank representatives, tobacco specialists from DAD would be responsible for individual visits and discussion groups.

4.24 This "awareness campaign" would be aimed at all growers of flue-cured tobacco. However, not all growers will show interest immediately, although certainly a proportion of growers in all areas will be
interested. These growers should be identified by extension workers on the basis of their response to the awareness campaign.

Interest Stage

4.25 Once interested growers have been identified, extension efforts should be directed at them. They should be invited to discussion groups at which more detailed information such as practical aspects of installation, materials, methods, etc., would be given and discussed.

Trial Stage

4.26 Growers who adopt new technology as a result of the extension programme must be identified and every effort made to assist them when they first start operating. Extension workers should visit early adopters at the beginning of the curing season and correct faults in operation. This would be the responsibility of extension workers normally operating in the area. Problems that could not be solved on the ground should be referred back to TRA for expert advice.

4.27 Early adopters should be encouraged to measure the savings in fuel wood they are achieving. Other benefits that accrue and any management difficulties that are experienced should also be noted.

4.28 Management difficulties are bound to occur as most estates operate on a very large scale. It is highly unlikely that all barns on an estate would be converted to new systems in the first year. Workers tending barns, therefore, have to remember to use different methods with the old and new systems. This could be a major cause of problems. Most of these workers have had limited education, they resist change and are likely to have trouble understanding the different approaches needed with the different new systems. These difficulties could be minimized if a team could train the labor at the barns.

4.29 A "labor-training" team could be formed from technical assistants from TRA. They would be trained at TRA and become involved in the extension program at the "trial" stage. A member could then operate in a district with the sole objective of training the barn-tending labor of early adopters in that district. This training would be given to the labor in their own language. Follow up visits would be made throughout the curing season.

Evaluation Stage

4.30 At the end of the curing season, a meeting should be held for all personnel involved in the campaign. Reports on the number of early adopters, their experience with the improved technology, results and problems should be presented for discussion. Based on these results, plans should be made for further extension efforts in the next year. Any shortcomings in the previous program should be identified and corrected.
4.31 The impetus for adopting the new technology in the succeeding year will in large measure depend on the success of the first year's campaign. The early adopters will become the main proponents of change to fuel-efficient systems. Arrangements should be made, therefore, to provide additional technical backup in the succeeding year.

Provision of Extension Material

4.32 The technical material for the program will come from TRA. There is no problem in producing the material but often there are printing delays. This could be avoided if TRA operated their own plain paper copier. This would make sure that technical information was available at the correct time to make maximum impact.

Visual Aids

4.33 Numerous studies have shown that "seeing and hearing" is far more effective in understanding an extension message than "hearing" alone. It is recommended that TRA obtain an overhead projector to be used in conjunction with talks at field days and discussion groups. Equipment to allow the projector to be run off a automobile battery would also be needed.

Program Continuation

4.34 After the completion of the pilot project, it is expected that a coordinated extension program on reducing fuelwood use will continue within the existing framework and funding of the ADD in the Ministry of Agriculture, extension in TRA, and the Wood Energy Unit in the Ministry of Forestry and Natural Resources.

Estimated Cost of Extension Program (24 months only)

4.35 The following is a schedule of personnel and equipment for conducting the programs with their approximate costs:

<table>
<thead>
<tr>
<th></th>
<th>MK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel:</strong></td>
<td></td>
</tr>
<tr>
<td>Extension Engineer</td>
<td>150,000</td>
</tr>
<tr>
<td>Assistant</td>
<td>5,000</td>
</tr>
<tr>
<td>Secretary</td>
<td>3,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>159,500</td>
</tr>
<tr>
<td><strong>Equipment:</strong></td>
<td></td>
</tr>
<tr>
<td>Vehicle</td>
<td>15,000</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1,500</td>
</tr>
<tr>
<td>Office Equipment</td>
<td>2,500</td>
</tr>
<tr>
<td>Vehicle and Motorcycle Operation</td>
<td>6,000</td>
</tr>
<tr>
<td>Contingencies would cover public address, visual aids, and publications equipment</td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>189,500</td>
</tr>
</tbody>
</table>
V. RESEARCH AND DEVELOPMENT

Introduction

5.1 The major research activities on tobacco curing are being conducted by TRA. The Wood Energy Division of the Ministry of Forestry and Natural Resources is testing various wood burning stove arrangements for residential use and facilities for making charcoal. The view was expressed that the Division has the responsibility to the small holder, especially in wood use for tobacco curing. That testing and extension programs on small holder tobacco curing and facilities will be conducted on or from the Natural Resources College Campus by the Wood Energy Division.

5.2 Experimental or pilot extension projects relate mainly to on-farm demonstrations, trials, field studies, and other information dissemination techniques. TRA is cooperating with farmers on tobacco curing demonstrations that will be reviewed later in this report. The Wood Energy Division mentioned programs on rural surveys on tree planting, a small holder barn study, and the use of a regional mobile film unit as special methods of disseminating information to the public. Although no programs of awards, contests, demonstrations, etc., are now used to promote forestry and wood conservation, the Forestry Extension Working Committee has these programs under review. Both the Department of Forestry and the Wood Energy Division observed that any technology program to reduce wood use in tobacco curing should be done in conjunction with a tree planting program.

5.3 As most of the current research and field testing activities are being conducted by TRA, the discussion on constraints, problems, needs, and programs will concentrate on this organization. The major constraint at present is the shortage of technical facilities and staff. Another constraint is the lack of instrumentation and analytical equipment; the present staff are doing an outstanding job with available facilities, equipment and instrumentation.

5.4 Present research is limited mostly to field trials or demonstration (extension) of prototypes constructed on order by local commercial firms or outlets. As is most frequently the case in working with cooperators, development is slow, expensive, and unsatisfactory in spite of helpfulness and goodwill. Instrumentation for field studies, as already mentioned, is almost nonexistent and the work is being done in almost complete isolation of constructive criticism or discussion with other competent authorities.

5.5 Since TRA began its operation in 1980, it has done an excellent job in building facilities and a staff, but new organizations with limited funds take time to develop. The scarcity of local inputs such as brass or aluminum bar and sheet, brass machine screws, laminated plastic, etc., make the development of an engineering laboratory slow and costly. Many technical requirements must be specially imported, causing a four to six month delay in beginning or completing experiments.
5.6 If immediate solutions for reducing wood use in tobacco curing are to be achieved in the near future, the cooperation of several organizations or institutions, and liaison with other research institutions may be necessary. This is particularly true for basic laboratory studies. Much of the necessary research requires a foundation of basic study that has little to do with tobacco and could be done in an established engineering laboratory. Some research is relatively simple but difficult to quantify, such as determining the optimum flue shape and chimney height to give the most efficient rate of heat transfer. Other work, such as furnace design and optimum combustion conditions, is more complex and is being researched in several countries around the world. However, the need for results is more pressing in Malawi because it depends solely on wood energy for tobacco curing. The best liaison with institutions doing similar research occurs through professional contacts, reports and meetings.

**TRA Research Expansion Needs**

5.7 If TRA is to expand research to support an extension program and to prepare for a second phase of more sophisticated improvements in tobacco curing technology and facilities, it needs:

(i) To cooperate with other institutions or organizations in carrying out research in their facilities or to have research done on a contract basis with a commercial organization. The Polytechnic in Blantyre was mentioned as a possible cooperator.

(ii) To develop closer contacts with other research programs on wood burning technology and especially for tobacco curing.

(iii) To have its work coordinated with other institutions and governmental divisions to develop effective programs and minimize duplication of effort. The TRA Advisory Board is suggested as the coordinating group.

5.8 Research program needs for the immediate future fall into three areas: (i) basic laboratory studies; (ii) the integration of basic studies with present knowledge and practices in pilot field studies; and (iii) monitoring of the on-farm full-scale application of any advances leading to further development and refinement.

5.9 To meet these needs TRA plans to carry out the following activities for FCV tobacco curing if funds can be made available:

(i) High efficiency flues. Rectangular cross section and other shapes being considered. Tests show savings of up to 40% in field trials on several estates.

(ii) Forced draft furnaces. Tested for one season at one location. Shows an apparent benefit of 33% with standard flues and 45% with rectangular flues. A valid cross comparison has not been possible.
(iii) Furnaces draft regulation. Tests indicate that present draft control methods used on wood furnaces are unsatisfactory. An investigation of stack dampers and the possibility of automating these from a barn temperature sensor is planned.

(iv) Steel furnaces. Tests by BAT in Kenya showed a benefit when compared to brick. The savings may be due to rapid heating of the furnace (probably firebrick lined) to adequate temperatures for ignition of volatiles. A field test of one of these units is planned.

(v) Flue test rig. Flues cannot be properly evaluated in the field due to uncontrolled variables introduced during curing. Construction of the testing facility has been postponed until:

(a) basic studies on flue shape and size have narrowed the options.

(b) adequate instrumentation is available to evaluate performance.

(c) A wood stocker (possibly a saw dust or chip feeder) has been identified to obtain a uniform firing rate.

5.10 The importance of this work can be illustrated by an example: the present development of rectangular cross section flues indicates a significant improvement in fuel savings over conventional circular ones. It could be safely recommended to growers to install 800 mm by 70 mm flues connected to 28 cm diameter chimneys, because this combination has been shown by TRA to save up to 40% of the fuel wood (in crude volumetric terms) used by conventional flues. However, the effect of varying both flue and chimney dimensions and lengths has been shown only theoretically. There may be more cost effective combinations or adjustments made. It would appear that the basic studies, followed by pilot evaluation and field trial, are urgently needed before scarce capital is spent on a less-than-optimum solution.

Estimated Cost of Research Program

5.11 For TRA to carry out this R&D program, the first requirement is extension of the contracts of the General Manager and Agricultural Engineer beyond 1984. However, additional resources are also required. In terms of personnel, at least one technician with a strong background in electronics is needed if reliable instrumentation, data acquisition, and data analysis are to be carried out. Part of the technician's duties would be to train Malawian counterparts.
5.12 The cost of the technician's services and of the other equipment required is listed below:

<table>
<thead>
<tr>
<th>Description</th>
<th>MK</th>
</tr>
</thead>
<tbody>
<tr>
<td>One suitable vehicle and an operational budget for one staff assistant</td>
<td>15,000</td>
</tr>
<tr>
<td>Instrumentation Technician</td>
<td>10,000</td>
</tr>
<tr>
<td>Maintenance and operation</td>
<td>6,000</td>
</tr>
<tr>
<td>Instruments at three locations with automatic logging to collect data on:</td>
<td></td>
</tr>
<tr>
<td>- Temperature furnace, flue, stack and barn</td>
<td></td>
</tr>
<tr>
<td>- Humidity</td>
<td></td>
</tr>
<tr>
<td>- Pressure-forced and induced draft</td>
<td></td>
</tr>
<tr>
<td>- Air flow</td>
<td></td>
</tr>
<tr>
<td>- Gas velocity - stack and flue</td>
<td></td>
</tr>
<tr>
<td>- Gas analysis - stack</td>
<td>17,000</td>
</tr>
<tr>
<td>Micro computer and peripherals for analysis and presentation of data</td>
<td>7,500</td>
</tr>
<tr>
<td>Test rig for flues</td>
<td>6,000</td>
</tr>
<tr>
<td>3 fans and motors - induced and forced draft testing &quot;on farm&quot;</td>
<td>5,500</td>
</tr>
<tr>
<td>Sawdust burner for test rig</td>
<td>10,000</td>
</tr>
<tr>
<td>Ducting and related supplies</td>
<td>12,000</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>90,000</strong></td>
</tr>
</tbody>
</table>
VI. FUELWOOD USE IN DARK FIRE-CURED TOBACCO

Introduction

6.1 In 1981, there were 37,186 dark fire-cured tobacco growers in the Northern Division producing 25,617 ha of tobacco, and 5443 growers in the Southern Division producing 3,492 ha, yielding an average of 0.6 to 0.7 ha per producer. Generally, small production requires relatively small curing facilities. For a harvesting system in which leaves are reaped on roughly a weekly schedule, the barn needs to be only large enough to take care of a weekly reaping. Curing space requirements are also reflected from relatively low production at around 300 kg per ha.

Facilities

6.2 As an introduction to a description of curing facilities used in Malawi, it might be instructive to review the curing procedure and methods of handling presented in Appendix C. Interviews with several operators of dark fire-cured systems showed varying curing procedures. One location used 3 m x 4.8 m (10 ft. x 16 ft.) barns four tiers high with 0.3 m thick earth sidewalls and a thatched grass roof. In addition to the entrance door, there was a small 0.3 m square (12" x 12") ventilation door in the front gable end. Two small fire pits were located along the center line of the barn. The operator said it took about 1 m³ of wood to provide heat and smoke for curing 23 - 27 kg (50 - 60 lbs) using the following schedule:

- Wilting with no fire: 4 - 5 days
- Slow fire - coloring: 4 days
- More fire - drying: 2 days

The barn is used two or three times during the season.

6.3 In the Mulanje area, a small grower had 2.3 m x 3.6 m (10' x 12') earth wall barns with thatched grass roofs for firing tobacco. He also had one open pole structure with a thatched grass roof for wilting tobacco and another enclosed structure with a wooden floor slightly longer than the two curing barns for handling and packing tobacco. The two curing barns are used four times during the season, and each holds 42 - 44 sticks of 100 leaves or 18 to 23 kg (40 - 50 lbs) per cure. A small open-ended mud oven or hover with ten .5 cm (2") diameter randomly placed holes covered the single fire pit in the curing barns. All of these structures were in the compound with the dwelling.

6.4 The curing schedule was to hang the tobacco on sticks (100 leaves per stick) in the wilting shed for three days during leaf coloring. The tobacco was then moved to the barn and fired for four days to dry the leaf, with the brick in the gable end ventilator removed. After ten days, the tobacco was moved to the storage building where it

1/ Volume IV, Tobacco Sector Study (MW007/3 0.82) Tables 1.03 and 2.05).
was hung for stems to completely dry. An estimated 18 m³ of wood per 500 kg of tobacco was required.

6.5 In the Northern Region the tobacco is generally fired for a longer period of time, although now there appears to be a tendency toward reduced firing as it is done in the Southern Region. Buyers of tobacco have indicated a desire for more of the heavily smoked northern tobacco. A typical schedule in the Northern Region is to fire the tobacco over a three-week period. Coloring takes place for approximately five days to a week when little or no fire is used. The temperature is kept under 30°C when firing during the coloring phase with little or no ventilation. After 4 - 5 days, the temperature is raised just below 40°C and some air is introduced to dry the leaf very slowly for 4 - 6 days; care is taken to prevent the tobacco from sweating in the barn. Then the temperature is raised just below 50°C for another 4 - 5 days with increased ventilation for midrib drying. After midrims are dry, the farmer may let the fire go out at night and start fires every second day. Obviously, barns are used over a longer curing period in the northern region. Some variation in this procedure is also practiced for heavily-smoked tobacco.

Fuelwood Requirement

6.6 The amount of fuel wood required to cure dark fire-cured tobacco has not been established. Reliable estimation is complicated by the varying degrees of firing from the Northern to the Southern Region and the concurrent use of fuel wood supplies for domestic use and tobacco curing. One source (WEP, working papers, 1979) suggested that it required two-thirds as much wood to cure one kilogram of dark fire-cured tobacco as flue-cured tobacco. If this figure is accepted, then 14 m³ of wood are required to cure 500 kg of tobacco, or 233,270 m³ of wood to cure the entire crop. This is about 1/4 of that used for FCV. It does seem reasonable to assume that dark fire-cured tobacco requires less wood for curing than FCV as no heat is used for the first days of coloring and it appears that the leaf is removed from the barn before the stem is completely dry.

Potential for Reducing Fuel Wood Use

6.7 The most important factors in inefficient wood use in the curing of dark fire-cured tobacco appear to be the kind of structure used and the use of uncontrolled ventilation, especially in the leaf and partial stem drying phase. In view of the economic status of most producers, little can or should be done to improve facilities without a thorough study. More knowledge by the producer of the curing process might lead to better use of wood fuel. This might be accomplished by an educational effort to ensure that the producer understands the purpose and principles of the curing process. It should help him to better regulate ventilation so that he does not waste wood. A suggestion to tighten up the structure by placing low cost, used plastic fertilizer bags under the thatched grass roof would lower fuelwood use if the farmer understands how to operate a tighter structure from a ventilation standpoint. Any other
suggestions for upgrading facilities should recognize the resource limitations, small volume of tobacco produced, and customary handling techniques.

6.8 The TRA has done some work in an effort to assist the dark fire-cured producer. An experimental 2.4 m x 2.4 m (8' x 8') -2 pit barn for primed leaf has been constructed. A pipe inlet for air control and a raised floor are features of this facility.

Extension Services

6.9 Extension services to the growers of dark fire-cured tobacco are provided by the Ministry of Agriculture through the Department of Agricultural Development. Tobacco specialists are stationed at the Agricultural Development Division headquarters, and technical officers and technical assistants are stationed in development areas. Their main function is to train technical assistants in the extension planning areas so that they are in a position to provide for the extension needs of the growers. However, they have to be able to give extension advice on all types of tobacco.

6.10 There is an urgent need to provide more tobacco specialists and greater specialization. It is recommended that flue cured, fire cured, burley and sun air cured-oriented specialists be appointed to the ADDs where these crops are grown. Specialization would improve technical competence and lead to better training of ETAs and a more effective extension effort.

6.11 The Tobacco Research Authority is also involved in fire-cured tobacco extension work through the efforts of the fire-cured liaison officer. His principal responsibility is to train extension staff from the Agricultural Development Division, but the TRA also holds field days on topical aspects of production for growers of fire-cured tobacco. Specialists from the TRA give talks and demonstrations at these field days.

Constraints to Adopting Technology

6.12 Though there are many growers of dark fire-cured tobacco, each one produces only a very small amount of fire-cured tobacco. Quota restrictions limit the amount each producer may sell. Few quotas allow the production of as much as 1000 kg, and most quotas are even smaller. This small scale of production requires that costs be kept to a minimum if any real profit is to be made. Producers are therefore unlikely to adopt technology that is expensive either in terms of capital investment or growing cost. The only extension recommendations likely to be accepted are suggestions which reduce the fuelwood requirements of curing techniques. The TRA has some indication that fuelwood reductions are possible using different ventilation techniques. However, this work is far from complete as potential benefits have not been quantified.
Proposed Extension Program

6.13 No specific extension program to reduce fuelwood use by producers of dark fire-cured tobacco can be recommended at this stage because the proper information on how to achieve this is not available. However, it is suggested that more effort be put into training extension personnel in dark fire-cured production. The appointment of specialist dark fire-cured tobacco officers to be stationed at ADDs should be considered. This would improve training of TAs in Extension Planning Areas and provide the expert backup necessary for effective extension. Training of dark fire-cured extension specialists should be undertaken by experienced tobacco specialists presently in ADD with assistance from the Tobacco Research Authority. An input from the Wood Energy Unit should be incorporated into the program.

6.14 The short-term extension strategy should concentrate on educating TA's and growers on the curing process and the requirements of the market. There is evidence that many growers have reduced fuel wood usage by reducing firing time in barns and drying tobacco under ambient conditions in a shelter. If done in excess, this practice could substantially reduce the quality of the crop, and growers need to be made aware of these dangers.

Summary

6.15 The Extension Service needs to increase the number of tobacco specialists, seriously consider the appointment of dark fire-cured specialists, improve training of TAs and mount an extension education program aimed at providing an understanding of the curing process and how this affects market requirements.
Annex A

List of Persons Met

Asherson, J. S. General Manager, ESCOM
Ball, David Agricultural Liaison Officer, National Bank of Malawi, Namwera
Barclay-Smith, R. W. General Manager, Tobacco Research Authority
Barton, Peter Professor, Polytechnic, University of Malawi
Bernard, M. P. Engineer, Tobacco Research Authority
Case, Roger J. F. General Manager, Mpasadzi Scheme, KFCTA
Chadwick, D. General Manager, General Farming Co. Ltd.
Chamayere, W. E. Division of Forestry
Chavula, M. Sr. Agric. Extension Officer, Blantyre A.D.D.
Chawinga, R. Project Officer, Mulanje R.D.P.
Chembezi, D. M. Economic Planning Division
Chilemba, E. M. Fire Cured Liaison Officer, Tobacco Research Authority
Chimaliro, E. M. J. Ministry of Forestry
Chirwa, G. Chief, Planning Division, Ministry of Agriculture
Clark, J. Forestry Research Officer, FRIM, Forestry Research Institute
Erez, Dr. A. Planning Advisor, Ministry of Agriculture
French, Dr. D. S. Wood Energy Project, Economic Planning Division
Galimoto, G. A. Wood Energy Project, Economic Planning Division
Green, J. Estate Manager, McInge Area
Harris, Dr. J. Professor, Polytechnic, University of Malawi
Johnson, Dr. Otto Department of Geological Survey
Kachoka, V. T. Dep. Chief, Planning Div., Ministry of Agriculture
Kavinya, R. F. Senior Economist, Ministry of Agriculture
Legge, Dr. J. T. Chief, Agricultural Research Officer, Min. of Agric.
May, E. D. Chief Conservator of Forests, Ministry of Forestry
McDonald, Hugh Manager, Tobacco Training Institute, Zimbabwe
Ndisale, B. M. Assistant Chief Agricultural Developmental Officer, Ministry of Agriculture
Ndovi, W. M. Project Manager, Wood Energy Project
Ngumbi, Alex General Manager, KFCTA (Kasungu Flue Cured Tobacco Authority)
Nyasulu, K. M. Assistant Project Manager, Wood Energy Project
Nyirongo, M. G. Principal Economist, Office of the President & Cabinet
Openshaw, Keith Field Director, USAID
Phiri, J. Public Relations Officer, Auction Holdings, Ltd.
Phocas, Nick Assistant Manager, Makande Estate
Redmile, Jack S. Grower, Trelawney, Zimbabwe
Shumba, S. Programme Manager, Balbytre ADD
Sosola, Mr. Assistant Estate Manager, General Farming Co. Ltd.
Sprowson, John Area Manager, General Farming Company, Ltd.
<table>
<thead>
<tr>
<th>Name</th>
<th>Position/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stevens, J. P.</td>
<td>J. P. Stevens Investments, Ltd.</td>
</tr>
<tr>
<td>Tembo, D. N.</td>
<td>Chief Administrator, Division of Forestry</td>
</tr>
<tr>
<td>Terrell, J. L.</td>
<td>Tobacco Officer, Kasungu ADD</td>
</tr>
<tr>
<td>Tsonga, E.</td>
<td>Assistant General Manager, Tobacco Research Authority</td>
</tr>
<tr>
<td>Vanzyl, Tony</td>
<td>Tobacco Training Institute, Zimbabwe</td>
</tr>
<tr>
<td>Yiannakis, Harry</td>
<td>Grower, Tambala Estate, Namwera</td>
</tr>
<tr>
<td>Yiannakis, Paul</td>
<td>Grower, Tambala Estate, Namwera</td>
</tr>
</tbody>
</table>
Annex B

The Tobacco Curing Process

Flue Cured Virginia

Tobacco curing is a controlled process of removing moisture from the leaf. It takes heat energy to evaporate the moisture which is provided through respiration by the tobacco itself or by supplemental sources. Green tobacco varies in moisture content based on stalk location of the leaf, growing season, and other factors. Generally, 6 kg or more of moisture must be evaporated to yield 1 kg of marketable leaf.

The theoretical minimum energy required to cure tobacco is around 4600 kJ/kg of tobacco depending on the amount of heat lost from or stored in the curing structure. 1/ A practical exchanged air schedule in non-continuous curing facilities dictates that minimum energy use will be 30 percent more than the theoretical minimum or 6000 kJ/kg of tobacco.

Curing of FCV involves three phases to obtain a yellow, orange, or gold colored dry leaf. These phases are (1) leaf coloring, (2) leaf drying, and (3) stem drying. Leaf coloring can be obtained only within limits of temperature and relative humidity conditions. Generally, the temperature cannot exceed approximately 42°C and the relative humidity cannot fall below about 80% for prolonged periods to obtain the desired color. After this color has been obtained, an increase in temperature and a decrease in relative humidity will retard the respiration process and the color will be fixed when biological processes are stalled. The remainder of the curing involves the drying of lamina, midribs, and stems.

It has been established that FCV can be cured in five to six days under proper environmental conditions. It takes about three days to color the leaf when 47-48% of the moisture is removed, one to two days for leaf drying when 40-42% of the moisture is removed, and one day for stem drying when 10-23% of the moisture is removed. For dark fire-cured and other air cured tobaccos, the coloring phase is extended to 7 or more days to allow the yellow, orange, or gold color to change to brown.

Energy conservation is related to efficient moisture removal. Energy consumption for curing is related to the moisture removal rate; however, some heat energy, especially during the coloring phase, comes from respiration. In a well managed cure, up to 30% of the fuel energy will be required in the coloring phase, roughly 30-50% in the leaf drying phase, and 20-40% in the stem drying phase depending on the amount of time devoted to each of the last two phases.

The air exchange rate relates directly to the drying rate and energy use in non-continuous type curing facilities. In the coloring phase, the air changes per hour for a typical cure should not exceed a mean of about 36 with a range from 15 at the beginning to 65 at leaf drying. During leaf drying, 36 to 62 air changes per hour are typical, with a maximum of 70. During stem drying, the air changes per hour range from 15 to 25. Total air changes per cure are about 5450 for the average tobacco.

These guidelines are all that are essential to cure tobacco with a minimum of energy in non-continuous type curing facilities. In practice, few facilities are constructed to permit operation at these more optimum conditions. The amount of energy used for curing FCV varies considerably depending on the kind of facilities. Table C-1 shows fuel energy use by various curing systems as reported in Malawi and at other locations. While an estimated theoretical minimum energy use has been set at 6000 kJ/kg of tobacco, the only system which comes close to this is a solar cross flow bulk barn, and the solar fraction input is not included in the supplemental heat required. Typically, efficient curing systems are requiring fuel energy inputs of 18,000 to 20,000 kJ per kg of tobacco cured.

Conventional wood fired curing barns using flues require energy inputs of 150,000 kJ per kg of tobacco cured. There are several reasons for this, one of which is the inherent difficulty of burning air dried wood at a high enough temperature to obtain its full heat value of approximately 18,660 kJ per kg at dry weight basis, or 14,300 kJ per kg 25% moisture content (wet basis). For instance, to burn carbon monoxide, one of the volatiles given off by the wood, the firebox temperature must be above its ignition temperature of 600°C. Common brick and cement mortar used to construct barn furnaces will not continuously withstand this temperature. The air fuel ratio in most barn furnaces is such that one is lucky to get 50% of the heat energy from the wood. It takes about 2.86 kg of air per kg of wood and 75% excess air does not greatly reduce efficiency. Uncontrolled air contributes to inefficiency. Other factors such as deficiencies in flue design, chimneys, barn ventilation rate, structure heat loss, and management cause a realistic efficiency of only about 10 to 13% or wood energy use 37 times the theoretical minimum.

The curing of dark fire-cured tobacco is also a controlled moisture removal process as previously mentioned; the difference from flue cured is that the coloring process is allowed to extend until the leaf attains a brown color. During this phase some drying should be taking place; however, relative humidity should not be permitted to drop below about 80% for any prolonged period of time. Once the leaf has obtained its color, the drying process can proceed quickly or slowly depending on the procedure used.

The procedure used to attain the same or nearly the same result may be quite different in major producing areas of the world. An explanation of the most widely used procedure in the US will serve to highlight these differences. After the tobacco reaches maturity, the
entire plant (stalk and leaves) is removed from the field by cutting the stalk at its base above the ground level. The stalk is split from the top and hung with split sides over the stick — the butt end up — or the stalk is speared onto the stick. The stick containing some five to six stalks may have one end forced into the ground such that the plant hangs and is allowed to wilt in the field. In some cases, the lower leaves are reaped before cutting, but generally this is not the case. The cut tobacco may also be mounted on mobile frames in the field where it remains for a couple of days to wilt and precolor.

The tobacco is then transported to barns of various sizes ranging from 4.9 m x 4.9 m (16' x 16') to 7.3 m x 11 m (24' x 36') x 5 to 6 tiers high. The sticks of tobacco are placed in the barn on tier rails at a spacing of about 20 cm (8") depending on the size of the tobacco. The tobacco is allowed to continue to color with very little ventilation and no fires for about five days, depending on the weather. After a certain stage of ripening has been reached and the leaf becomes turgid, small hardwood fires are made at about 1.8 m (6') intervals on the floor of the barn, mainly to provide smoke and heat to remove some moisture from the leaf. The firing process is continued until the lamina of the leaf is dry, never attaining more than about 43°C (110°F) in the barn. After the leaf and midribs are largely dried, no further fires are made except in damp weather. The tobacco remains in the barn some six weeks or longer until the stems and stalks are dry.

In Malawi, only the leaves of the tobacco are cured and this is generally accomplished in two weeks or less so that the barn may be reused for another reaping. The procedure and type of barns used are described in the Government of Malawi, Ministry of Agriculture Tobacco Sector Study, Volume IV.
<table>
<thead>
<tr>
<th>System (Flue Cured)</th>
<th>Fuel Used</th>
<th>Report Year</th>
<th>Location</th>
<th>Supplemental Heat* Required kJ per kg of Tobacco</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Conventional stick barn</td>
<td>#2 Fuel Oil</td>
<td>1976</td>
<td>NC-USA</td>
<td>26,300</td>
<td></td>
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<tr>
<td>2.</td>
<td>LPG</td>
<td>1980</td>
<td>NC-USA</td>
<td>18,257</td>
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<tr>
<td>3.</td>
<td>#2 Fuel Oil</td>
<td>1982</td>
<td>VA-USA</td>
<td>47,130</td>
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<td>4.</td>
<td>LPG</td>
<td>1982</td>
<td>NC-USA</td>
<td>37,924</td>
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<td>5. Manufactured bulk barn</td>
<td>LPG</td>
<td>1976</td>
<td>NC-USA</td>
<td>18,400</td>
<td>5 cures per season</td>
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<tr>
<td>6.</td>
<td>LPG</td>
<td>1977</td>
<td>GA-USA</td>
<td>20,000</td>
<td>seasonal average</td>
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<tr>
<td>7.</td>
<td>LPG</td>
<td>1977</td>
<td>NC-USA</td>
<td>32,092</td>
<td>3 barns for season</td>
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<td>8.</td>
<td>#2 Fuel Oil</td>
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<td>NC-USA</td>
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<td>9.</td>
<td>LPG</td>
<td>1978</td>
<td>NC-USA</td>
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<td>10.</td>
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<td>19. Tunnel continuous forced air</td>
<td>Coal</td>
<td>1977</td>
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<td>27,020</td>
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<td>20. Solar cross flow bulk barn, heat rec.</td>
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<td>23.</td>
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<td>Wood</td>
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<td>26. Multi-barn forced air continuous, brick</td>
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<td>Malawi</td>
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<td>27. Conventional, unimproved, brick</td>
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<td>122,310</td>
<td>4 kg coal/kg tobacco</td>
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<td>28. Tunnel continuous forced air</td>
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<td>26,026</td>
<td>2.6 m³/500 kg tobacco</td>
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* The heat from supplemental fuel source is based on a gross heat value of fuel and does not include energy from other sources such as solar or electrical motors.
## References for Table B-1

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<td>3</td>
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<td>Cundiff on-farm test, same as for system 6.</td>
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<td>16-17</td>
<td>Same as for system 3.</td>
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22 Lambert, A. J. personally collected data.

23 Watkins, Rupert, and Paul E. Sumner personal communications.

24 Redmile, J. S., personal communications.


26 Same as for system 25.


28 Phocas, Nick, Interpreter for Toeker, personal communications.
Annex C

Descriptions of Existing Curing Systems

Tobacco curing barns in use in Malawi may be classified as either conventional or forced air ventilated. Most of the FCV tobacco is cured in conventional barns of varying sizes and levels of improvement. The use of barns with forced air ventilation is very limited, partly due to unavailable electric power in rural areas. The various kinds of barns found in use in Malawi are discussed here.

1. Conventional Barns

    (a) Small holder barns (square or rectangular floor plan). Considerable variation may exist in size, structural materials, and flue (heat exchanger) layout. Typically this 250 stick, 4 tier barn is 3.66 m (12 ft.) square by 6.7 m (22 ft.) high, although the TPI report suggested that a 3.66 m (12 ft.) x 4.9 m (16 ft.) would be less expensive and easier to build and use. The walls are 23 - 30 cm (9 - 12 in.) thick, constructed from locally made laterite bricks with mud from soil as mortar to a height of about 4.4 m (14 1/2 ft.). Tier poles and the roof frame structure are made from locally available wood. The roof cover may be thatched grass or corrugated galvanized metal.

    A similar size barn has been constructed with gum poles and cement washed hessian (burlap) in place of the mud brick walls. The roof may be either thatched grass or metal. This kind of construction was being phased out at one location. At another location, the interior wall was lined with a single layer of used plastic-lined fertilizer bag material to reduce fuel use.

    Furnace construction and flue arrangement also vary considerably. The furnace for the small holder barn is generally placed near one corner on the side opposite the loading door to form a U arrangement for flue placement. The furnace is constructed of brick and mud with walls 25.4 cm (10 in.) to 30 cm (12 in.) thick extending upward and forming a semi-circle arch as a top. The part of the furnace which extends approximately 0.6 (6 ft.) into the barn is box-shaped. The furnace is approximately 1.2 m (4 ft.) long by 0.76 m (2 1/2 ft.) high. Mortar joints are generally thick and crumble when heated, requiring frequent reconstruction of the furnace. The furnaces may or may not be equipped with a grate and doors for fuel loading, draft regulation, and ash cleanout. The grates may be of steel I beams, cast iron round bars, or commercially available cast iron.

    The flue pipe extends out from the furnace and slightly rises near the inside perimeter of three sides of the barn and exhaust to a stack or chimney which varies in height on the barn wall. The flue pipe is either 35.6 cm (14 in.) or 28 cm (11 in.) in diameter.

    In some cases, a brick and mud tunnel approximately 0.4 - 0.5 m wide and high with a sheet metal or corrugated cover replaces the flue
pipe inside the barn. In another location, a shilow flue system was used which consisted of arched galvanized corrugated iron sheets located over the ground. The 1.5 m (5 ft.) length of arched sheet was exposed over 1.2 m (4 ft.) of horizontal ground. The furnace was located in the center of the barn inside the loading door. The W System of air distribution exhausted to two chimneys. The base of the furnace is located below ground level or the inside flue surface is elevated above outside ground level.

The location of air inlets varies depending on the flue arrangement used and whether barns are located side by side. In any case, vents are located on the exposed wall with loading door, and on the furnace wall side or other exposed wall. Generally, 30 cm (1 ft.) square ventilators are placed in three sidewalls near the ground approximately 0.6 m (2.5 ft.) from each corner of the barn. These are blocked with bricks, wooden planks, or metal doors to control air entry to the barn. Square top ventilators may be located in each roof gable end.

Two or more barns may be constructed side by side.

(b) Round Barns (grower) At one location, round barns 6.4 m - 6.7 m (21 - 22 ft.) in diameter were observed. The walls were built of laterite brick, similar to that used in some of the small holder barns. It has been reported that walls may be constructed of corrugated asbestos sheets at other locations (TPI R653). The conical roof is thatched with grass supported by poles. It is approximately 7.3 m (24 ft.) to eave height. Some 450 to 500 2.1 m (7 ft.) strings of leaves (110 leaves per string) are placed in the barn to give an approximate capacity of 454 kg (1000 lbs) of cured tobacco.

The furnace is made of laterite bricks and cement mortar or mud with or without grate and doors. It is constructed such that the flue pipes exit perpendicular to the lengths of burning wood in the split flue or T-type flue configurations. The furnace is constructed in a manner similar to that for small holder barns where the U-type flue configuration is used. The flue gases exit to a single chimney or vertical stack pipe. Flue pipes are normally 28 cm (11 in.) or 35.6 cm (14 in.) in diameter.

Intake vents are approximately 25.4 cm (1 ft.) square and are located at three equidistant points near the ground around the barn. No provision was made for exit air venting except for that naturally occurring through a thatched roof and eave openings.

Typical grower and estate barns. These barns are constructed in various sizes but generally have a square or rectangular floor plan and are built side by side in batteries of 2 to 12 units. Some of the dimensions are 4.9 m x 4.9 m (16' x 16'), 4.9 m x 6 m (16' x 20'), 6 m x 6 m (20' x 20'), and 6 m x 12 m (20' x 40'). Dimensions may vary 0.6 m (2 ft.) or more in each direction. The number of tiers high varies from four to eight. The walls are constructed of laterite brick, mortared together with mud. A typical wall may be 45.7 cm (18 in.) wide at ground
level, tapering to 30 cm (12 in.) wide at the first tier. The roof is either a shed or gable design, constructed of local poles with a corrugated galvanized metal cover. Tier poles are supported by the side walls and with other brick on pole uprights in some cases.

More than half of the barns of this type are thought to have open hearth furnaces (hull type). Hence, many furnaces have a grate and door, but the doors are frequently left open. Several of those interviewed stated that it is difficult to maintain temperature with an open hearth furnace where fluctuations are often as much as +170\(\degree\)C (+300\(\degree\)F). The larger barns are often equipped with two furnaces and either one or two chimneys or metal stacks. A typical 6 m x 6 m (20' x 20') barn will have one furnace located in the center of the sidewall opposite the barn loading door. The furnace is generally located inside the barn although part of the furnace may protrude to the outside in some instances. The chimney is usually located above the opening or door for supplying wood to the furnace.

A variety of flue arrangements and sizes can be found. Typically, two flue pipes extend from the end of the furnace toward the loading door and then turn to the left and right around the inside perimeter of the barn returning to a common exhaust tee pipe over the furnace. The flues normally used are 28 cm (11 in.) and 35.5 cm (14 in.) in diameter. Some 22.8 cm (9 in.) diameter flues, brick tunnels with metal cover, shiow, and experimental rectangular cross section flues also were used.

Four bottom ventilators are provided -- usually on the furnace side and loading door side of the barn near the ground. The barns at the ends of the battery also may have vents on the third side. The vents vary in size but are usually about 0.37m\(^2\) (4 ft.\(^2\)) each. They are either equipped with doors, or brick are laid in the opening to regulate incoming air. Exhaust air at the top of the barn is rarely controlled. In gable roof barns air vents are located at the ridge and under the eaves. In the single roof slope (shed) barns, two vents are located on exposed sidewalls near the roof and the eaves are open. The 0.6 m (2 ft.) square vents are usually equipped with doors which are left open.

**Forced Air Ventilation System**

(a) Bulk Curing Barns Two bulk-curing barns were seen in Malawi, although they operated somewhat differently from the procedure widely used in the USA. To reduce labor, the tobacco is placed into curing containers (approx. 144-208 kg per m\(^3\) or 9-13 lbs of green tobacco per cu. ft.) where it is cured by forced draft in barns normally 3 m (10 ft.) wide by 2.4 m (8 ft.) high by 8.2 m (27 ft.) to 12 m (40 ft.) long. Fuel requirements to cure the same amount of tobacco are generally less than in less densely packed conventional barns. The capital cost of a bulk barn is around $12,000 (MK 16000 in Malawi) for a unit that will cure approximately 1134 kg (2500 lbs) of dry leaf in six days. Electricity and some management skills are required to operate the system.
Steam from a wood-fired boiler provided heat for the bulk curing barns used in Malawi, and ESOCOM provided electricity. The labor saving feature of bulk barns is not seen as a benefit for the Malawian producer. Central station electricity generally is not available in rural areas and diesel generated power is roughly four times as costly as electricity.

(b) Curing Tunnels. Two large curing tunnels capable of curing tobacco from 121 ha (300 acres) a year are used in Malawi. One observed in the Mulanje area cures around 7000 kg of tobacco a day. The single pass tunnel is more than 7.0 m (238 ft.) long by 18 m (60 ft.) wide and 3 m (10 ft.) high divided longitudinally into two curing chambers, each with three-wheeled trolleys side by side. The trolleys are normally moved forward every three hours with an average of one loaded trolley cured every hour. Tobacco on the trolleys moves against an air flow with steadily increasing temperatures and saturation deficits. A wood-fired boiler provides steam at 1000 Pa to heat exchangers where heat is picked up by air supplied with four 566 m³/min. (20,000 CFM) fans. The 77 - 930 (170 - 200°F) air is introduced at the stem drying end of the tunnel. The stoker (fireman) estimated that the boiler used 40 m³ of dried indigenous wood every 24 hours which is an efficient use of wood. The cost of the system is estimated to be MK 400,000.
Appendix D

Wood Use and Cost, Response of Selected Producers

General Farming Co.
26 estates, 2000 ha, 1000 barns
Estate #37
Tobacco production: 60 ha, 115,000 kg per annum
Facilities: 38 barns with capacity of 500 to 1000 kg
per cure each
Wood use: 10 to 24 m³ of stacked wood per barn of tobacco
cured
Wood cost: Labor to cut, MK 58 per cord (2m³)
Delivery to barn, MK 42 per cord
Production on farm -
clear land and plant blue gums, MK 248/ha
plant in combination with tobacco,
MK 150/ha
Total Cost: unknown

Kasungu Flue Cured Tobacco Authority
Approximately 1000 smallholders,
Tobacco production: 4770 ha, 1.7 mln. kg
4 to 6 ha at 356 kg/ha per smallholder.
Facilities:
Smallholder barns: 5 barns with capacity of 330 kg each per cure
Round Barns - 6 barns with capacity of 250 kg each per cure.
Wood Use:
Smallholder barns - 120 cords (@ 2.5 m³) of indigenous wood to
cure
9700 kg of tobacco or 15.5 m³/500 kg
Round Barns - 120 cords (@ 2.5 m³) of wood to cure 9042 kg of
tobacco or 16.6 m³/500 kg
Barns with thatch roof take 1/3 more wood
Wood Cost: Unknown
Smallholders cut wood on Authority-managed land.
The Authority is planting 80 ha annually for next 6 years.

Makande Estate
Tobacco Production: 180 ha of FCV, 452,000 kg
Facilities: Tunnel system - 121 ha, 300,000 kg
Conventional barns - 59 ha, 152,000 kg
Wood Use: Tunnel system, 40 m³ per day
2.8 m³ per 500 kg of tobacco cured
Conventional barns - 15 m³ per barn of 317 kg capacity 23.7 m³ per
500 kg of tobacco cured
Wood cost: Purchased - measured mixed indigenous wood delivered by
truck from a distance 35 km (round trip) MK 6.50 per m³
Labor for cutting - MK .60 to MK .70 per m³
Forest Reserve - MK 1.50 per m³
Hauling - MK 4.35 per m³
Pambala Estate

Tobacco Production: 180 ha FCV

Facilities:
- Conventional barns with improved furnaces and flues
- Conventional poor barns with open hearth (hull) furnaces

Wood Use:
- Improved barns - 10.5 m³ per 500 kg of tobacco cured
- Poor barns - 22.2 m³ per 500 kg of tobacco cured

Wood Cost:
- Using own labor and trucking 22 km (round trip) MK 5.00 to MK 6.00 per m³

Forest Reserve: MK 1.50

Estimated cutting and hauling: MK 3.50 to MK 4.50 per m³

Other Comment: A neighbor is hauling wood 80 km (round trip). The average hauling distance in the Namuna area is estimated at 32 km (round trip). Hauling cost is MK .14 per km per m³ at another location. This farm is planting 80 ha of trees.
Annex E

Sketches of Some Alternative Curing Facilities and Improvements
Figure 1. Typical ventilator and furnace construction details.
Figure 2. A furnace and flue layout.
Figure 3. Typical farm constructed top ventilator for tobacco barns.
ROOF VENTILATOR

FOR
FLUE CURED TOBACCO BARN

The roof ventilator permits the regulation of temperature and humidity during the curing period. The ventilator can be installed in old or new tobacco barns of log, frame, or masonry construction.

A saving of approximately 50 per cent in the cost of fuel has been reported in the curing of tobacco in barns with the new type ventilator and with insulated walls and roof. Frame walls should have two layers of boards with building paper between. The walls of tight log barns need no additional insulation. The roof and gable ends of both log and frame barns should be tight and insulated. Suitable materials for insulation are aluminum foil, aluminum foil supported on paper, rock wool, filter glass or similar fireproof materials.

Small openings in the foundation walls uniformly distributed around the building are required for proper air circulation through the barn. These openings can be filled with rock wool or equivalent. A sufficient amount of air will filter through the rock wool when the roof ventilator is opened.

The ventilator is held open by fastening the opening and closing rope to the bottom tier poles or by any other effective means.

HOW TO BUILD IT.

1. Cut roofing on both sides of ridgeboard six and one-half inches from center of ridgeboard. Opening is to extend full length of barn except for one rafter space (2' to 3') at each end of the roof.
2. Provide a six inch opening between the sheathing and the ridgeboard on both sides of the ridgeboard. Opening to extend full length of barn except for one rafter space (2' to 3') at each end of the roof.
3. Cut eight 1" x 6" x 12' braces and nail to rafters.
4. Cut 1" x 8" boards and nail to braces.
5. Cut 1" x 6" boards for doors, install hinges, and then fasten doors to 1" x 8" boards.
6. Cut 2' x 3' x 2'-8' ventilator rafters and nail in place.
7. Install pulleys and ropes for opening and closing the doors.
8. Install 1" poultry netting to keep birds out of ventilator.
10. Install flashing to prevent leakage around ventilator.

BILL OF MATERIALS

FOR
Roof Ventilator for Flue Cured Tobacco Barns
(10' x 16')

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<thead>
<tr>
<th>Material</th>
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<td>Side Boards</td>
<td>2 pcs.</td>
<td>1&quot; x 3&quot; x 12'</td>
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<tr>
<td>Doors</td>
<td>2 pcs.</td>
<td>1&quot; x 3&quot; x 12'</td>
</tr>
<tr>
<td>Braces</td>
<td>1 pcs.</td>
<td>1&quot; x 6&quot; x 12'</td>
</tr>
<tr>
<td>Rafters</td>
<td>3 pcs.</td>
<td>1&quot; x 3&quot;</td>
</tr>
<tr>
<td>Sheathing</td>
<td>36 bd.</td>
<td>10&quot; x 30&quot;</td>
</tr>
<tr>
<td>Roofing</td>
<td>13 Lm.</td>
<td>36&quot; wide</td>
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<tr>
<td>Asphalt roofing</td>
<td>2 Lm.</td>
<td>(asphalt roofing or equivalent)</td>
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<tr>
<td>Pulley</td>
<td>4</td>
<td>1&quot; wheel diameter</td>
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<tr>
<td>Hinges</td>
<td>6</td>
<td>(2-3&quot;) T-hinges</td>
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<td>Poultry netting</td>
<td>25 Lm.</td>
<td>12&quot; wide</td>
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<tr>
<td>Nails</td>
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Figure 4. Construction instructions for tobacco barn roof ventilator.
Tobacco Barn Ventilator

Figure 5. Section of ventilator showing ground level control from barn outside.

Figure 6. Section of ventilator showing ground level control from barn inside.
CONTROLLED ROOF

Tobacco Barn Ventilator
FOR ALL TYPES TOBACCO BARNs.

EASILY AND SAFELY REMOVES MOISTURE WITH EXCLUSIVE "EZ-RIDE" DAMPER CONTROL

- ELIMINATES MAIN CAUSE OF SWEATING
- NO MORE "BROWN SCALD" AND "SPONGE"
- WORKS PERFECTLY WITH ANY CURER
- MORE ECONOMICAL, MORE EFFICIENT CURING

Figure 7. Commercial type tobacco barn top ventilators.
Figure 8. Section of cascade continuous curing system.

Figure 9. Section of typical conventional estate battery barn.
Figure 10. Cascade continuous curing system with fan for each chamber as proposed by J. S. Redmile, Zimbabwe.