Design of Hybrid Solar Tobacco Curing System for Small scale Farmers in Zimbabwe

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Abstract

The study investigated the prospects of incorporating solar thermals together in conjunction with existing traditional sources in the curing of tobacco. Field work was done to assess current practices by small new tobacco farmers and the average space sizes of barns they were currently using. Effort was made to utilize solar during the day for this process, to reduce on coal/wood consumption rate. The research went on to look at the sizing of the solar field, and environmental impact assessment on the current curing barns of Zimbabwe.

Key words
Tobacco curing, solar thermals, hybrid system, environment, sustainable energy

1.Introduction

According to the International Journal of Agriculture Innovations and Research tobacco curing accounts for 5% of Africa's total deforestation, 12% of deforestation in Southern Africa, and 200 000 hectares of forest are cut down each year for tobacco production. The majority of this (69%) is used as fuel, whilst the remainder (15%) is used for constructing barns and racks, including those used for air cured tobacco which does not require fuel. Zimbabwe is ranked the fourth leading producer of high quality flue-cured tobacco which constitutes 64% of all tobacco grown worldwide. The use of energy with less impact to the environment is required to assist in the preservation of the environment. The use of petroleum, coal and natural gas resources as energy sources is limited, and hence it is unsustainable. The gases produced by the burning of fossil fuels have a negative impact on the environment as they contribute to global warming.The current burning of fossil fuel like coal and firewood in a tobacco curing barn in Zimbabwe emits carbon dioxide (CO_2). It is against this background that a feasibility study of tobacco curing using clean sources of energy which are safe, efficient and economic, is pursued to reduce the emission of flue gases, deforestation, pollution, land degradation and a host of other effects they cause.The study explores the implementation of a solar – wood/coal fired hybrid tobacco curing system as the energy solution for small scale farmers. The coal/wood being made available when solar energy suffer from intermittency of day/night cycles, and reduced irradiation periods during winter, cloudy days, and short transients.

2.Background Literature

A growing number of small scale farmers have moved to tobacco farming. The attractiveness of the crop is depicted by general increase in the price per kilogram on the market in Table 1. Tobacco is now the mostly grown cash crop as farmers see high prospects of improving their living standards in a depressed economy. These farmers have turned to natural forest as the cheapest source of energy to cure their tobacco leaf.

Table 1: Zimbabwe flue cured tobacco exports (Zimbabwe Tobacco Association, 2004)

Year	**Mass/tons**	**Value(US$)**	**Price/kg**
2014	64,897	318,539,144	$4.91
2013	153,350	877,487,161	$5.72
2012	129,699	770,901,059	$5.94
2011	144,275	729,771,863	$5.06
2010	86,815	383,976,982	$4.42

1.1 Tobacco Curing Process

The curing of tobacco is critical as it determines the price and grade fetched by the crop on the market. Curing preserves the quality, flavor and aroma of the tobacco. It is a process of removing chlorophyll from the tobacco leaves and giving the leaves a yellow appearance. The tobacco handling personnel estimate that 75 percent of the market value of the tobacco is achieved through color. During the curing process starch is converted to sugar which will give the tobacco a sweet flavor (Sauer et al, 2005). The drying or curing process of tobacco leaves happens when heat is distributed uniformly by the use of a heat exchanger of fluetubes inside a tightly closed barn. The leaves are loosely hung inside thebarn so that easy flow of hot air is permitted. The mode of heat transfer to the leaves is mainly by natural convection. The common fuel used may be wood,coal and LP gas (Hurin,1982). The main threes stages of curing are as shown in Fig 1.0 and Fig 2.0 below:

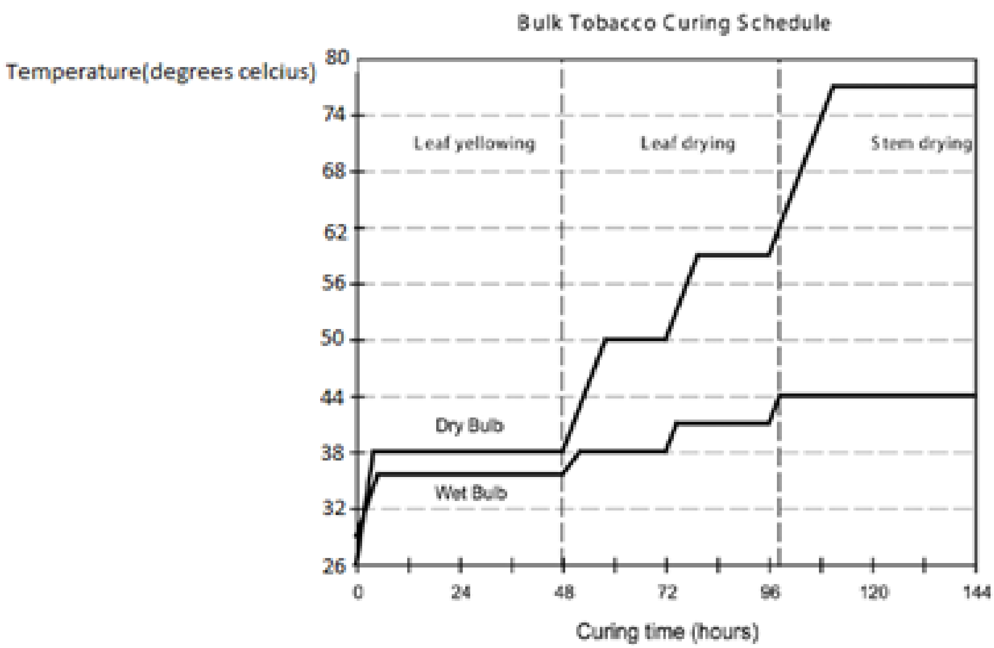

Figure1. Curing of tobacco stages (Chivuraise, 2001)

***Leaf yellowing stage**:* It is the stage of the curing process where the green leaves of tobacco start changing color from green to yellowish. The curing environment in the barn in monitored and maintained at a constant temperature of 35 degrees Celsius as depicted in Figure 2.

Yellowing stage Leaf drying stage Stem drying

Figure 2. Curing stages (Hurin, 2004)

Leaf drying stage: In this stage, tobacco leaves wilt and lose their moisture content and become dry. The leaf drying process takes place at constant temperature of 50 and 58 degrees Celsius.

Stem drying:It is the final stage of the curing process of the tobacco .The final stage high temperatures must be attained for this process to be achieved. A constant temperature of 75 degrees Celsius is ideal for this stage.

The tobacco curing is commonly effected through drying using air, flue gases and in some instances the sun:
Air curing method – air is mainly used in the curing of cigarettes and burley tobacco, where tobacco leaf is hung in well-ventilated barns. The curing itself takes a period of four to eight weeks. Tobacco cured in this manner is low in sugar and has high nicotine content.
Flue curing method - The curing barn is coal or wood fired to produce the hot gases which would help in the removal of the leaf chlorophyll from the tobacco leaf. The heat energy is transferred in the barn by the use of a heat exchanger. Fire curing is used to cure Virginia tobacco, and this method of curing is considered expensive. The process results in cured tobacco which is high sugar and low nicotine content.
Sun curing method- Tobacco leaves are cured by being exposed to direct sunlight to dry. This method is commonly used in cigarette manufacturing were tobacco of low sugar and high nicotine content is required.

For commercial purposes, air and sun drying are not economical options in the curing of bulky quantities to produce quality tobacco for the market. Thus flue curing remains as the primary viable process employed by small scale farmers. For sustainability hybrid energy systems may be considered for curing to reduce on usage of non renewable energy sources and minimise the damage on the environment. A hybrid tobacco curing system is the one fired by more than single source of energy. The variety sources of energy that can be used are wood, coal, wind, solar and others. This study explores the prospects of having a hybrid solar-coal fired tobacco curing system for Zimbabwean small scale farmers.

1.2Availability of Solar Radiation

Solar radiation provides clean source of energy if properly harnessed. Studies have shown that the radiation received in Zimbabwe is the same across the country regardless of the season. It was also noted that 59% of the time in winter, areas in Southern Africa receive daily radiation greater than 6.5kWh/m^2. The basis of solar energy is based on radiation trapped by the collector as for air heating of the tobacco curing system through the heat exchanger. Determination of the available radiation for the solar collector is based on equation depending on the radiation intensity. Parameters such as solar declination angle (δ), solar hour angle and sunset hour angle (ω/ω_s), extra-terrestrial radiation and the clearness index (H_0 /K_T), tilted plane radiation and ambient temperature (Hove et al, 2006). The monthly hourly irradiation incident on a collector I_{coll} can be represented by the following equation (Diffie et al, 1991)

$$I_{coll} = H_h \left[\left(r_h - r_h \frac{H_d}{H_h} \right) \frac{\cos\theta_{coll}}{\cos\theta_z} + r_d \frac{H_d}{H_h} \right]$$

Where H_h is the monthly average daily horizontal hemispherical irradiation and H_d is the monthly average daily diffuse irradiation. The conversion from monthly average daily hemispherical and monthly average daily diffuse irradiation to monthly hourly average values is represented by the coefficients r_h and r_d (Beckman (1991)). The ratio $\frac{H_d}{H_h}$ is conveniently determined, where measurements of diffuse radiation are not available, from a selected correlation of this ratio with monthly average clearness index, K_h available in the literature, for the purpose of this study the Hove and Gottsche (1999) correlation, that was developed locally, is favored. This would later guide the sizing and evaluation of solar thermal collectors to be used for curing process.

1.3Energy Balance Equation of Flat Plate Collector

The thermal performance of solar thermal collector is evaluated by an energy balance that determines the portion of the incoming radiation delivered as useful energy to the working fluid. Not all radiation enters the collector, as part of it is reflected back to the sky. The absorbed radiation is transmitted through glazing and a portion is absorbed by the glazing. The transmitted radiation then reaches the absorber plate as short wave radiation. Therefore a conversion factor which indicates the percentage of solar rays being transmitted is necessary (Struckmann, 2008). And the rate of useful energy by the collector is given by:

$$Q_i = G_{coll}(\tau\alpha).A$$

The temperature of the collector rises and gets higher than the surrounding temperatures. At this point heat is lost the atmosphere by radiation and convection. The heat loss rate is then proportional to the difference between the absorber plate temperature and the ambient temperature. The rate of heat loss Q_o also depends and the collector temperature T_c and on the overall heat loss coefficient U_L.

$$Q_o = U_L A(T_c - T_a)$$

Thus the rate of useful energy extracted by the collector, (Q_u) is the rate of useful energy less the amount lost by the collector to its surroundings. This then yields to the writing of equation 15 below.

$$Q_u = A_c[G_T \tau\alpha. - U_L(T_c - T_a)]$$

Thus heat carried away by the fluid in the collector can be expressed as shown below.

$$Q_u = mc_p(T_0 - T_i)$$

The above equation is somehow inconvenient due to the difficulty in defining the collector average temperature. A quantity known as the "collector heat removal factor" (F_R) that relates the actual useful energy gain to the useful gain given that the collector is at a fluid inlet temperature T_i is defined by the following equation (5). The actual useful energy gain (Q_u) being extracted by the collector, is a product of the maximum possible useful energy gain and the collector heat removal factor F_R

$$Q_u = F_R A[G_T \alpha\tau - U_L(T_i - T_a)]$$

The above equation is a widely used relationship for measuring collector energy gain and is known as the Hottel-Whillier Bliss equation (Q_u) to the incident solar energy over a particular period. The concept of energy gain of collectors lays the ground for the thermal solar collectors for curing process.

1.3 Solar Thermal Collectors

A solar thermal collector can be considered to be special kind of heat exchanger that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector (Kalogirou, 2004).

Solar energy collectors

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

Table 2. Types of collectors and indicative temperatures (Kalogirou2004)

The common types of solar thermal collectorsare:stationary and concentrating (this has the same area for intercepting and for absorbing solar radiation); and non-concentrating (usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux).The most common solar thermal collector is flat plate solar air collector, and it is mostly used for space heating. Its absorber plate could be made from either metallic or non-metallic material. The air collector system eliminates the problems caused by liquid collectors such as leaks, and freezing. The configuration has to generate more power needed for the circulating fans.

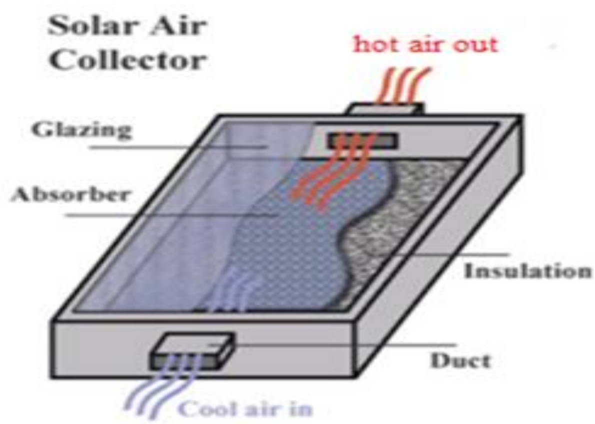

Figure3. Flat plate air collector (Anon 2014)

Glazed solar air collectors are mainly used for space heating, and the heat energy is transferred through ducts to the process area. Absorber material captures radiation from the sun and heat transfer is achieved through the process of conduction. Solar air heating is the most cheaply solar technology for both industrial and commercial applications, hence prospects for it being utilized in tobacco curing.

3. Methodology

Tobacco curing system sizing was done after a study on solar radiation received in Zimbabwe. Also environmental impact assessment (EIA) was carried out through a deep study of combustion of fossil fuels and look on the impact of greenhouse gases on the environment. Sizing of the solar thermal system process was undertaken to generate optimum operating parameters of the solar field.For complete evaluation of collectable insolation by a collector, there was need for the knowledge of hourly distribution of daily solar radiation, the diffuse fraction of global radiation and many other factors. To increase convenience in solar energy a calculation a solar energy calculator was also constructed using excel spread sheet. This reduced the strenuous work that is needed for the calculation of the energy. The following input data were needed to get the insolation needed on hourly basis for each day of a given month: date which represents the season variation; latitude which represents the design location; meteorological data i.e. the recorded average daily horizontal radiation, MJ/m^2; collector orientation i.e. azimuth ; and incidence angle. After inserting the above inputs on the input sheet, the following results were obtained r_b, the ratio of beam radiation on tilted surface to that on horizontal surface

I_d, monthly average hourly diffuse irradiation
I_{coll}, monthly average hourly irradiation incident on the collector

4. Design Details

4.1 Solar Thermal Barn

The solar thermal system was sized to provide adequate heat for effective tobacco curing based on the current barn size of 6m x 6m x 9m. The key objectives were for the system to reduce firewood consumption by at least 20 % and as well improve the efficient of the curing barn in terms of reduced heat losses.

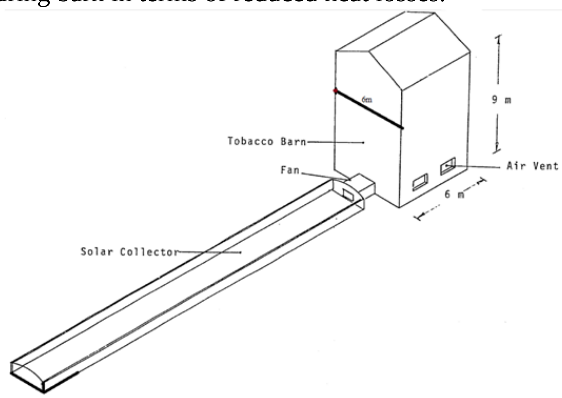

Figure 4. Solar thermal lay out

The practical parameters considered included functionality and reliability in terms of the required heat delivery and quality tobacco curing as required by the market. Simplicity of lay out and ease of maintenance were also put into perspective for cost effectiveness of assembly, operation, easy maintenance and part replacement. Efficiency improvement on the current pole and dagga heat exchangers required attention. Solar thermals collectors have an efficiency of 30%, compared to 15% for the photovoltaic systems, making them a better option for tobacco curing process.

4.2 Barn Parameters

Some basic calculations were done to size the solar thermal system, fan, photovoltaic (PV) system to power the fan and tobacco curing barn insulation to reduce heat losses as a way to improve the efficiency of the current curing barn.

Current throughput (Cundiff, 1980)

Amount of wood used, m : 7 kg
Amount of tobacco cured : 1 kg
Calorific value of wood, C_v : 4.6 MJ/kg

Amount of coal used, m : 4.5 kg
Amount of tobacco cured : 1 kg
Calorific value of coal, C_v : 10.9 MJ/kg

Energy supplied by fuel = m xC_v
Energy liberated by fuel = C_v of fuel×mass of fuel to produce 1kg of tobacco.
Energy produced by wood = 4.6×7 = 32.2MJ/kg
Energy produced by coal = 10.9×4.5 = 49.05 MJ/kg

Barn insulation

Proper barn insulation material reduces the amount of heat energy losses during the curing process. It also minimizes the time taken for the system to reach its thermal equilibrium therefore reducing the amount of fuel being used thereby improving the curing efficient. A material with a high R-value needs to be used (where R-value is the measure of a material's ability to resist heat flow from one side to the other) for effective of insulation.

Table 3. R- value of different materials

Insulating materials	Thickness(mm)	R value
Expanded Polystyrene (Extruded)	25.4	5.00
Polyurethane Foam (Foamed on site)	25.4	6.25
Polyisocyanurate (Foil Faced)	25.4	7.20

Polyurethane foam is used to offer insulation to the barn it has an R-value of 6.25 and readily available. The polyurethane is sprayed on the inside of the barn.It was also established that percentages of **time** and **energy** saved in the curing process through use of polyurethane foam as barn insulation on average was **4.1%** and **13.1%** respectively.

From Figure 1 it was established that the curing process takes **144 hours** per a batch.

If the tobacco curing barn is insulated using polyurethane of thickness 25mm and R-value of 6.25 the curing period will be now = 144 - (144 x 0.041)

= **<u>138 hours</u>**

From above, the energy required for the curing process when using wood is **32.2MJ/kg** of tobacco. For an insulated curing barn the required energy will be = 32.2 – (32.2 x 0.131)

= 32.2 - 4.2

= **<u>28MJ/kg</u>**

Barn ignition

Accidental burning of curing barns was also noted as prevalent among small scale farmers. This problem was mostly caused when dry leaves fell incidentally onto hot metal or heat exchanger, and igniting a whole barn into ashes. Statistics showed that 18% of barns burn down whilst containing tobacco in Zimbabwe (Munanga, 2014). These mishap could be avoided by replacing the 40cm diameter metal flue heat exchanger with six of dimension 20cm x 4cm diameter each, flue pipes which are covered and insulated from the earthen floor with a 3 to 1 ratio mixture of sawdust and clay (Dale, 2004).

Fan Sizing

The fan was sized to blow effectively hot air from the flat thermal solar collector to the curing barn. Effective volume of curing barn = length x width x height

= 4 x 4 x 6

= **96 m^3**

Density of the curing barn = mass / volume

= 1500 / 324

= **4.63kg of fresh tobacco/m^3**

Assumed data

The air flow rate inside the barn = 0.15 m^3/min per m^3 of volume

The total air flow rate, Q= 0.15 x 96 = 14.4 m^3/min = 0.24 m^3/s

Pressure drop = 1.5 m air per depth

Total pressure drop H = 1.5 x 6 = 9m

Fan efficiency, η= 60%

Fan power rating, $\mathbf{P} = \dfrac{\rho QHg}{\eta} = \dfrac{4.63 \times 0.24 \times 9 \times 9.81}{0.6} = \mathbf{163\ Watts}$

To allow for possible over loading, a design factor of 1.2 to be considered on the recommended fan power. Fan power rating = P x safety factor
= 163 x 1.2
= **200 Watts**

Collector Sizing

The sizing of the solar thermal system to heat the curing barn space was based on the fact that, the tobacco curing season is around the period from November to April of each year. The long term monthly average daily global radiation data of a documented location in Mt Darwin part of the country was used.

Table 4: Long-term Monthly Average Daily Global Radiation (Hove, 1999)

station	Latitude	longitude	Long-term Monthly Average Daily Global Radiation(MJ/m^2)											
	(degrees)	(degrees)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
MtDarwin	-16.8	31.7	18.6	21.2	23.1	24.2	24.4	24.6	23.2	22.4	22.7	21.4	19.9	18.1

Average daily radiation = (24.4+24.6+23.2+22.4+22.7+21.4) / 6
= $\mathbf{23.12\ MJ/m^2}$

Average hourly radiation = (23.12 x 10^6) / (12 x 3600)
= $\mathbf{535.19\ W/m^2}$

$$q_{useful}=\dot{m}Cp(t_o - t_i)$$

where
q_{useful} = efficiency x insolation rate
$\dot{m}$ = mass air flow rate per m^2 of collector area
C_p = 1005 J/kg-°C (specific heat of air)
$(t_o - t_i)$ = temperature rise across the collector

Ambient temperature $(t_o - t_i)$ is 25 degrees Celsius which is enough for the two curing stages.
Mass air flow, $\dot{m}$ = (daily radiation x efficiency) / (C_px temp rise)
= (535.2 x 0.5) / (1005 x 25)
= $\mathbf{0.011/s\text{-}m^2}$

For total air flow of 0.24 m^3/s = collector area = Q/ $\dot{m}$ = (0.24) / (0.011) = $\mathbf{22m^2}$

Mass in kilogram of tobacco cured in the barn = 1500/6 = **250 kg**

Solar energy contribution = $\dfrac{\text{daily solar radiation x curing period x efficiency x size of collector}}{\text{Mass of tobacco cured}}$

Solar energy contribution = (23.12 x 6 x 0.5 x 22) / 20
= **6.1 MJ/kg of cured leaves**

According to Cundiff (1978), 20 MJ heat energy input is needed per kg of cured leaves.

Solar energy contribution % = (6.1/20) x 100 %
= **30.5%**

Sizing of invertor to power the fan

For a photovoltaic (PV) system, its installation depended on the ambient temperatures of the area for which it was to be installed. Again, monthly ambient temperatures for Mt Darwin from November to April for the curing months in the area were considered as in Table 5.

Table 5. Temperature for Mount Darwin (World Weather, 2015)

Temperature	Nov	Dec	Jan	Feb	Mar	Apr
Max	32	29	29	29	29	28
min	19	19	19	29	18	15

Ambient temperatures were computed from the solar calculator whilst using the maximum and minimum temperatures of experienced in the area of concern.

Table 6. Ambient temperatures of Mount Darwin (Excel Spread sheet, 2015)

time	nov	dec	jan	feb	mar	apr
05:00-06:00	19	19	19	19	18	15
06:00-07:00	19.49478	19.3806	19.3806	19.3806	18.41866	15.49478
07:00-08:00	20.90381	20.46447	20.46447	20.46447	19.61091	16.90381
08:00-09:00	23.01256	22.08658	22.08658	22.08658	21.39524	19.01256
09:00-10:00	25.5	24	24	24	23.5	21.5
10:00-11:00	27.98744	25.91342	25.91342	25.91342	25.60476	23.98744
11:00-1200	30.09619	27.53553	27.53553	27.53553	27.38909	26.09619
12:00-13:00	31.50522	28.6194	28.6194	28.6194	28.58134	27.50522
13:00-14:00	32	29	29	29	29	28
14:00-15:00	31.50522	28.6194	28.6194	28.6194	28.58134	27.50522
15:00-16:00	30.09619	27.53553	27.53553	27.53553	27.38909	26.09619
16:00-17:00	27.98744	25.91342	25.91342	25.91342	25.60476	23.98744
17:00-18:00	25.5	24	24	24	23.5	21.5
18:00-19:00	23.01256	22.08658	22.08658	22.08658	21.39524	19.01256

The solar inverter would be expected to convert solar radiation from a 4m^2 solar panel to electricity to power the fan. The fan rating was 200W.

Table 7. Inverter specifications (Civic Solar, 2015)

Name	Xantrex TR
Efficiency	94%
Frequency	50Hz
AC Voltage	230
AC Power out	480W

Table 8. Power output (Excel Spreadsheet, 2015)

time	$TIME_{RAD,CO}$	nov	dec	jan	feb	mar	apr
05:00-06:00	5.5	0	0	0	0	0	0
06:00-07:00	6.5	41.72881	42.63115	42.05039	39.30616	37.2588	35.34382
07:00-08:00	7.5	118.5707	117.7711	114.1568	113.5621	119.1782	122.1376
08:00-09:00	8.5	195.4797	193.1762	186.889	189.0114	202.6614	211.2067
09:00-10:00	9.5	260.9275	257.878	249.5743	254.254	274.5888	287.8642
10:00-11:00	10.5	306.5663	303.6349	294.076	300.6193	325.2976	341.5188
11:00-1200	11.5	328.3652	326.0768	315.9731	323.442	349.9589	367.2098
12:00-13:00	12.5	325.6505	324.0411	314.0101	321.4253	347.5293	364.1972
13:00-14:00	13.5	299.5261	298.3502	288.98	295.3943	319.019	333.7515
14:00-15:00	14.5	252.2806	251.3725	243.3001	247.8497	266.9383	278.448
15:00-16:00	15.5	188.147	187.6362	181.542	183.5993	196.2702	203.4152
16:00-17:00	16.5	114.2948	114.5126	111.0022	110.4245	115.5656	117.8193
17:00-18:00	17.5	40.49373	41.66081	41.09345	38.41244	36.33194	34.32016
18:00-19:00	18.5	0	0	0	0	0	0

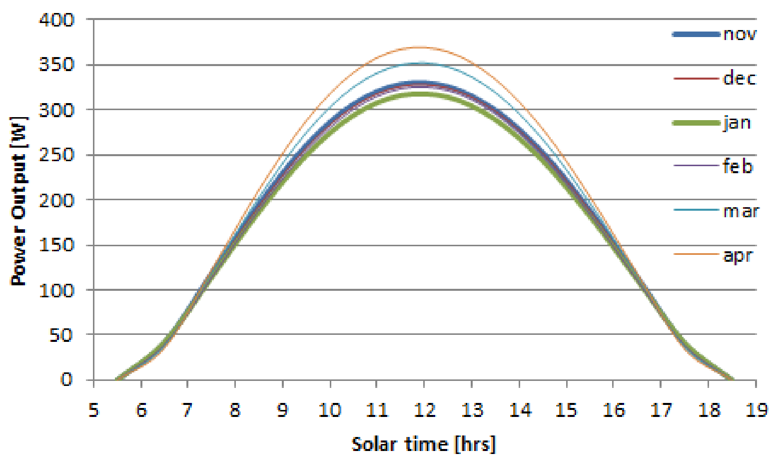

Figure 5. Power output from invertor against the solar time (Nov to Apr)

Table 9: Input table for the solar calculator

COMPUTER PROGRAM INPUTS		
INPUT	VALUE	UNIT
Date	10-Dec-02	
latitude	-16.8	DEGREES
Azimuth	180	DEGREES
Tilt	22	DEGREES
GHI	24.6	MJ/m2

Reduced emission of greenhouse gases (GHG)
The amount ofcoal/wood burnt would be reduced upon implementation of the solar hybrid system especially during the day and hence air pollution would be reduced. Thus air pollution would be limited and at peak only during the night when the solar field would be inactive. Overall air pollution would be reduced and effectively preserving the environment. The system would as well reduce pressure on the consumption of such as wood and coal in curing of tobacco.

Table 10. Mass of flue gases per mass of cured tobacco

Products of combustion	mass (kg/kg fuel)
CO_2	3.01
SO_2	0.02
N_2	10.72
H_2O	1.08

Flue gases being produced in the tobacco curing system per mass of tobacco cured:

Mass of coal used to produce 1kg of cured tobacco = 4.5kg

N_2 produced in curing system = 4.5 x 10.72
= **48.24kg/kg of cured tobacco**

SO_2 produced in curing system = 4.5 x 0.02
= **0.09 kg/kg of cured tobacco**

CO_2 produced in curing system = 4.5 x 3.01
= **13.55 kg/kg of cured tobacco**

H_2O produced in curing system = 4.5 x 1.08
= **4.86 kg/kg of cured tobacco**

Total products of combustion/kg fuel = 3.01+0.02+10.72+1.08
=**14.83 kg/kg fuel**

4.3. Cost Evaluation

The costing of the solar thermal system was given as in Table 11 and the overall cost at the time of analysis was USD3000.

Table 11. Solar thermal unit costing

Source	COMPONENT	QUANTITY	COST (US $)
MATE3	Advanced System Display and Controller	1	80
Panasonic	HIT Photovoltaic Module	1	490
MK/Deka	Battery & cables	1	100
Xantrex	Invertor	1	1000
Alibaba	Fan	1	100
Alibaba	Solar thermal	1 x ($22m^2$)	1100
Insulators	polyurethane	For 80 m^3	130
Total			3000

The use of a solar thermal to tobacco curing barns is feasible .The cost of design and assembly is $3000. Each curing session in a barn (6m x 6m x 9m) will have at least 250kg of tobacco which when sold on the market for $4 per kg on average.A total of $1000 would be realized in revenue per curing session, so the payback period is most likely to be achieved in one season making the project economically ideal for small scale farmers in long term savings on energy.

5. Conclusion and Recommendations

From the study that was done it was recommended that a flat plate air collector of a size 22m^2 facing North at a tilt of 22 degrees could be used in conjunction with coal/wood in tobacco barn.The collector will be coupled to a 200W fan or blower which would be powered by a photovoltaic system of solar invertor size of (230V, 480W). The solar inverter would have its own 4m^2 solar panel for energy supply.

Table 12. Flue gases mass reduction achieved by design

Products of combustion	Current mass of flue gas produced/kg	Mass of gases on implementation of design/kg
CO_2	48.24	48.24 x 0.22 = **10.6**
SO_2	0.09	0.09 x 0.22 = **0.02**
N_2	13.55	13.55 x 0.22 = **2.98**

The potential use of solar energy to complement the heat energy requirement for small scale farmer tobacco curing in Zimbabwe is feasible and economically viable. According to design if a curing barn is properly insulated, wood energy required is 28MJ/kg instead of the traditional 32,2 MJ/kg to fully cure a kg of leaf tobacco. So by implementing a flat plate air collector of a size 22m^2 to an insulated barn will make a contribution of 30.5% of the energy required for tobacco curing.According to this investigationit was shown that solar could be used to produce heat that could be used in the curing barn. Hence this studywas vital in assessment of solar energy potential is reducing emission of greenhouse gases.

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Biography

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