ECONOMIC APPRAISAL OF INDUSTRIAL SOLAR DRYING (PART I)

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Abstract

Major goals of industrialization include but not limited to provision of employment, establishing a platform for overall national development and improving the monetary income of whoever is involved which invariably improves the standard of living. A better pre-visibility study must encompass a well analysed economic appraisal of the plan. Computer programme was generated to analyse the economic aspect of industrial solar drying. The appraisal was carried out with the software using the Life Cycle Savings (LCS) technique. Three locations in Nigeria (i.e. Ibadan, Kano and Port Harcourt) were selected and their respective economic appraisal simulated. Sample simulations reveal that at a realistic initial moisture content of 30% (% wet basis) of the agricultural produce, economic analysis of over 20 years reveal that recommended solar collector area of 85.46m^2, 80.71m^2 and 75.96m^2 supplied about 67%, 88% and 55.8% of the annual energy needed for Ibadan, Kano and Port-harcourt respectively which are the specific sizes at which life cycle solar savings are optimal.

Keywords: Industrialization, Pre-visibility, Life Cycle Savings, Software, iteration.

Nomenclatures;

C_A=Total area dependent cost

C_E=Total area independent cost

Cs=Total cost of installed solar energy equipment

PW=Present Worth

PWF= Present Worth Factor

d =Market discount

i, =Interest rate

1.0 Introduction

The Sun is the largest source of energy in the solar system and it has the potential to supply all the energy requirement of the earth. Its economic potential for any country however depends on a specific location and locality. Solar energy is the most abundant energy source in the solar system. Despite the abundance of this energy, little use is being made of it in most part of the world. This could be attributed to the initial high cost of solar energy technologies, although on a life cycle costing basis, it is generally competitive with other energy technologies where a level playing field is provided and environmental cost are considered.

Solar system applications are found in different facet of life. These include space heating, water heating, industrial/domestic cooking, drying of agricultural products, solar cooling and photovoltaic generation of electricity.

1.1 Why Solar Drying?

The energy from the sun reaching the earth's atmosphere amounts to about 1.395k W/m^2. This amount is only $1/10^{10}$ of the actual energy released by the sun. Out of this energy, 23% are used as source of hydrological cycles and photosynthesis in plants, 47% are absorbed by the atmosphere, land and ocean and are converted to long wave radiation (terrestrial radiation) and 30% are reflected and scattered back into space [1]

The use of solar dryers represents an alternative to the traditional open sun drying in developing countries. It satisfies several conditions such as fast processing, better quality of product, low energy demand and non-contaminating energy source. The main disadvantages of solar dryers are the limited time of solar radiation and the short season of harvesting of many agricultural products. Several designs of solar dryers have been proposed of ruse in the developing countries. It has been concluded that to meet the increasing demands for food preservation in developing countries, simple, cheap but efficient solar dryers should be developed where forced convection and supplementary heat are applied. [2]

The drying potential in a cabinet drying bed can be employed when air is first dehumidified and then employed for drying of agricultural foodstuffs in an attached dryer. The proposed solar drying installation in this work is a coupling of solar collector, auxiliary energy source, and solar dryer of forced-convection type. The processes of mass and heat transfer in these units are simulated. The drying kinetics in a fixed-bed assumes a non-isothermal non-trace plug flow system with some basic variables. [7]

One main reason for considering solar is due to its environmental friendliness, as it doesn't give out any form of environmental pollution, like smoke which characterizes the conventional fossil fuel heater. It also runs smoothly (i.e. silently). This is because it has no mechanical moving part. And this also means that wear and tear in solar systems is relatively small, if not totally eliminated. [7]

The environmental benefit of solar application also includes no global-warming potential associated as in conventional drying systems with fossils fuels.[6] with increasing fossil fuel prices opting for solar system in order to meet the heat energy requirement will save fuel costs and also, it is economically competitive on a life cycle costing basis. [6]

1.2 Cost of solar energy delivery

The cost of any energy delivering process includes all items of hardware and labour that are involved in installing the equipment, plus the operating expenses.

Factors that may be taken into consideration includes interest on borrowed money, property tax and income tax. Property tax and income tax may not be applicable in a country like Nigeria also the equipment resale value, maintenance insurance, fuel and other operating expenses should be taken into consideration.

Installed cost of solar equipment can be shown to be sum of two terms [2]

C_A = total area dependent cost (₦)

C_E = total cost of equipment which is independent of the collector area (₦)

Therefore $C_s = C_A A_C + C_E$

Where, C_S = total cost of installed solar energy equipment (₦)

A_c = collector area (m^2)

The total area dependent cost, C_A include costs such as the purchase and installation of collector and a portion of storage cost.

The area independent cost C_E includes items like controls and bringing the construction erection equipment to site.

Operating cost that are associated with solar process include cost of auxiliary energy, energy cost for operating fans/blower (this energy is often termed parasitic energy and should be minimized by careful design, extra insurance exists on solar equipment, maintenance etc.

1.3 Economic figures of merit

Some of the criteria proposed and used for evaluating and optimizing economics of solar energy systems are;

1.3.1 Least Cost Energy (LCE): This is a reasonable figure of merit if solar energy is the only energy resource. The system with the least cost can be defined as that showing the minimum owing cost over the life of the system.

1.3.2 Life Cycle Cost (L.C.C.): This is the sum of all the cost associated with an energy delivering system over its lifetime or over a selected period of analysis. This method includes inflation when estimating the future expenses.

1.3.3 Life Cycle Savings (L.C.S): It is also known as the net present worth and it is defined as the difference between the life cycle of conventional fuel (only system and life cycle cost of the solar plus auxiliary energy system).

1.3.4 Annualized Life Cycle Cost (ALCC): This is the average yearly outflow of money (cash flow)

1.3.5 Pay-back Time: This have many definitions but in this paper, it is taken to be the time needed for the cumulative savings to equal the total initial investment, i.e, how long it takes to get investment back by saving fuel.

2.0 Methodology

Solar System Cost Analysis

In mathematical model formed, the annual cost for both solar and non-solar system to meet energy need. [2], and can be expressed as

2.1 Yearly Cost = Mortgage payment + Fuel expense + Maintenance and Insurance + Parasitic energy cost + Property tax - Income tax savings (1)

For income producing installation: [2]

2.1.1 Income tax savings = Effective tax rate X (Interest payment) + Property tax + Fuel expense + Maintenance and insurance + Parasitic energy cost + Depreciation (2)

Effective tax rate = Federal rate X State tax - (Federal tax-state tax) (3)

Solar savings = Cost of conventional energy - Cost of solar energy (4)

With saving concept, it is only necessary to estimate the incremental cost of installing solar system because the solar system may have some equipment which are also common to the conventional non solar system. For example the auxiliary furnace and much of the duct work or plumbing in solar system are often the same as would be for a non-solar system.

Therefore, solar savings can be rewritten as expressed below, [2]

Solar savings = Fuel saving – Incremental Mortgage payment - Incremental insurance and maintenance

- Incremental parasitic energy cost + Tax saving (5)

For income producing system [2]

2.1.2 Income tax rate = Effectiveness tax rate x (incremental interest payment + Incremental property tax + Incremental maintenance and insurance + Incremental parasitic energy cost - value of fuel saved……….(6)

Fuel saved is a negative tax deduction since a business already deducts fuel expenses, therefore, value of fuel saved is a taxable income [2]

Discounting of future cost: Inflation

An approach to solar process economics is to use life cycle cost method that takes into account all future costs. The method provides a means of comparison of future costs with present costs. This can be done by discounting all anticipated costs to the common basis of present worth (or present value), that is, what would have been invested today, at the best alternative investment rate to have the funds available in the future to meet all anticipated expenses. The reason that cash flow must be discounted lies in the time value of money [2]

Present worth (PW)

The relationship for determining the present worth of an amount 'A' needed 'N' (usually years) in future, with a market discount rate of 'd' (present per time period) is [3]

$$PW = \frac{A}{(1+d)^N} \tag{7}$$

Present Worth Factor (PWF)

If obligation reoccurs each year and inflate at a rate' 'i' per period, a present worth factor, PWF, of 'N' such payment can be found by using the following relationship [3]

$$\text{PWF (N, i, d)} = \frac{1}{(d-i)}\left[1-\left[\frac{1+i}{1+d}\right]^N\right], \quad for, i \neq d \tag{8}$$

PWF (N, i, d) = N (1+i) for i=d

The Computer program-solar Air Heater

The computer program makes use of the metrological data to design the solar collector. The program attempts to obtain a collector area which is capable of supplying the whole annual air heating load based on the size of a single solar module which is also a variable.

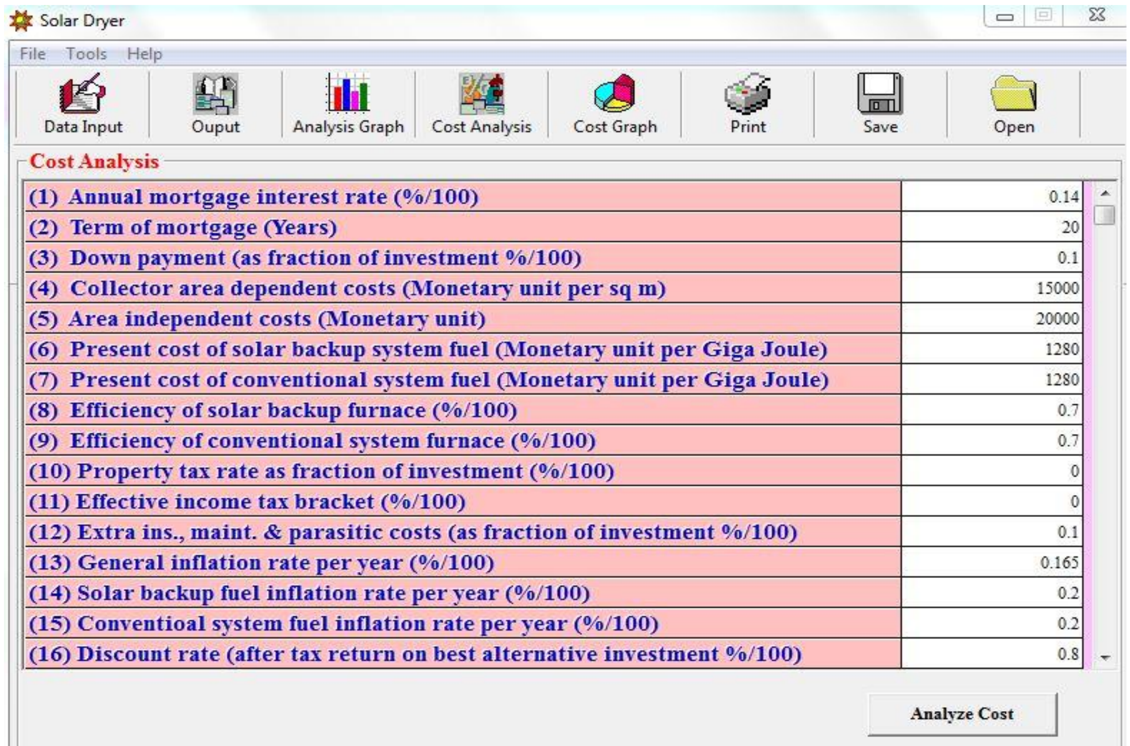
Although the attainment of this state might not be practically possible as there will always be some period of cloudiness, but as the number of solar modules increases the annual fraction by solar also increases. The economic analysis is performed using the life cycle savings method. By considering the life cycle saving of the different collector size (or area) and their corresponding annual solar fraction by solar, the economically optimum collector size can therefore be selected. If cost effectiveness is to be considered, the optimum collector is often the one with the highest solar savings.

The database contains the global radiation [4] and the extraterrestrial solar radiation [5], average sunshine hours, and average relative humidity of 10 different locations in Nigeria. The database also contains properties of air as the working fluid [1] and also that of steam. Other data in the data base are monthly averaged ambient temperature of each location, the geographical position and their monthly averaged wind speed. The database also contains data on the materials that could be used in constructing the solar collector, thereby providing the users with a choice of materials and hence cost flexibility. The program gives room for adding, deleting or editing the data concerning any location. Also, additional materials which could be used in constructing the collector can also be added to the database but with the required material properties.

3.0 Results and Discussion

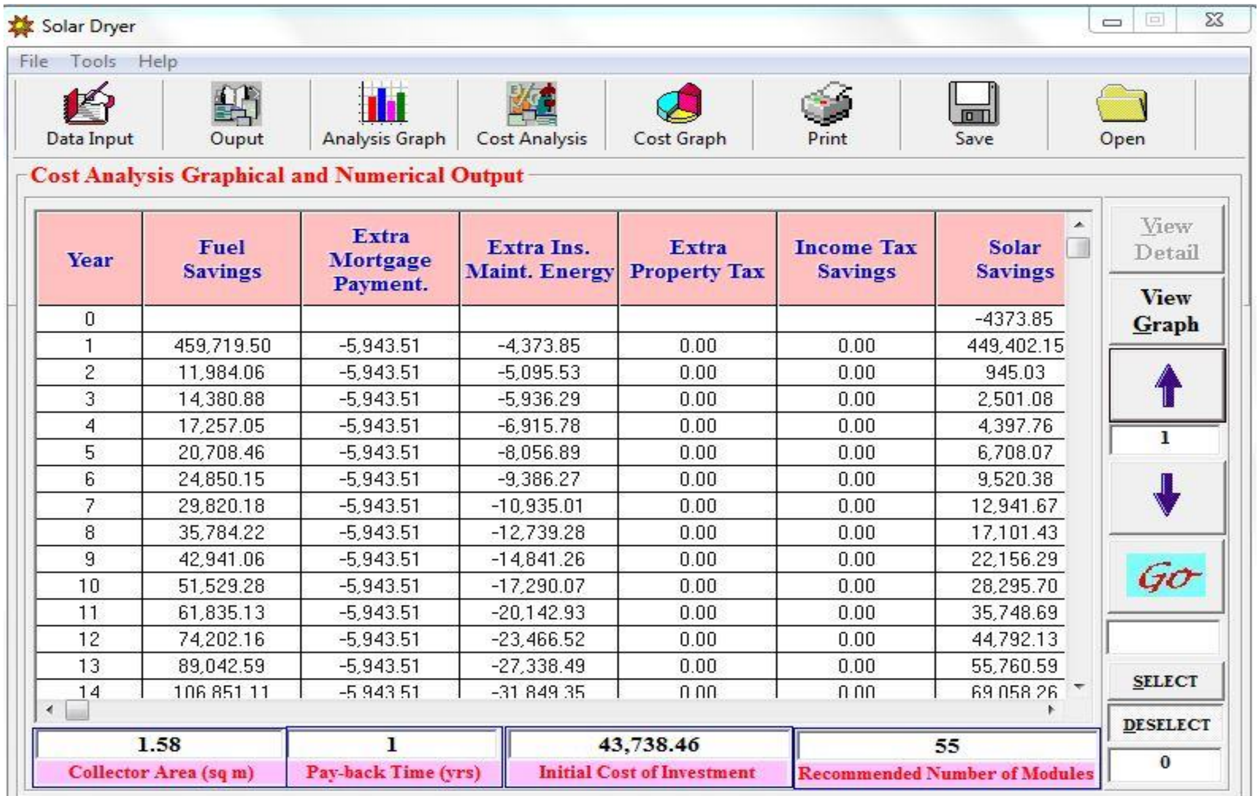
(Simulation Sample Results)

Table.1.Cost Analysis of Ibadan with 30% and 15% initial and final moisture content respectively



(1) Annual mortgage interest rate (%/100)	0.14
(2) Term of mortgage (Years)	20
(3) Down payment (as fraction of investment %/100)	0.1
(4) Collector area dependent costs (Monetary unit per sq m)	15000
(5) Area independent costs (Monetary unit)	20000
(6) Present cost of solar backup system fuel (Monetary unit per Giga Joule)	1280
(7) Present cost of conventional system fuel (Monetary unit per Giga Joule)	1280
(8) Efficiency of solar backup furnace (%/100)	0.7
(9) Efficiency of conventional system furnace (%/100)	0.7
(10) Property tax rate as fraction of investment (%/100)	0
(11) Effective income tax bracket (%/100)	0
(12) Extra ins., maint. & parasitic costs (as fraction of investment %/100)	0.1
(13) General inflation rate per year (%/100)	0.165
(14) Solar backup fuel inflation rate per year (%/100)	0.2
(15) Conventioal system fuel inflation rate per year (%/100)	0.2
(16) Discount rate (after tax return on best alternative investment %/100)	0.8

Table.2.Numerical output of Ibadan with 30% and 15% initial and final moisture content respectively



Year	Fuel Savings	Extra Mortgage Payment.	Extra Ins. Maint. Energy	Extra Property Tax	Income Tax Savings	Solar Savings
0						-4373.85
1	459,719.50	-5,943.51	-4,373.85	0.00	0.00	449,402.15
2	11,984.06	-5,943.51	-5,095.53	0.00	0.00	945.03
3	14,380.88	-5,943.51	-5,936.29	0.00	0.00	2,501.08
4	17,257.05	-5,943.51	-6,915.78	0.00	0.00	4,397.76
5	20,708.46	-5,943.51	-8,056.89	0.00	0.00	6,708.07
6	24,850.15	-5,943.51	-9,386.27	0.00	0.00	9,520.38
7	29,820.18	-5,943.51	-10,935.01	0.00	0.00	12,941.67
8	35,784.22	-5,943.51	-12,739.28	0.00	0.00	17,101.43
9	42,941.06	-5,943.51	-14,841.26	0.00	0.00	22,156.29
10	51,529.28	-5,943.51	-17,290.07	0.00	0.00	28,295.70
11	61,835.13	-5,943.51	-20,142.93	0.00	0.00	35,748.69
12	74,202.16	-5,943.51	-23,466.52	0.00	0.00	44,792.13
13	89,042.59	-5,943.51	-27,338.49	0.00	0.00	55,760.59
14	106,851.11	-5,943.51	-31,849.35	0.00	0.00	69,058.26

Collector Area (sq m)	Pay-back Time (yrs)	Initial Cost of Investment	Recommended Number of Modules
1.58	1	43,738.46	55

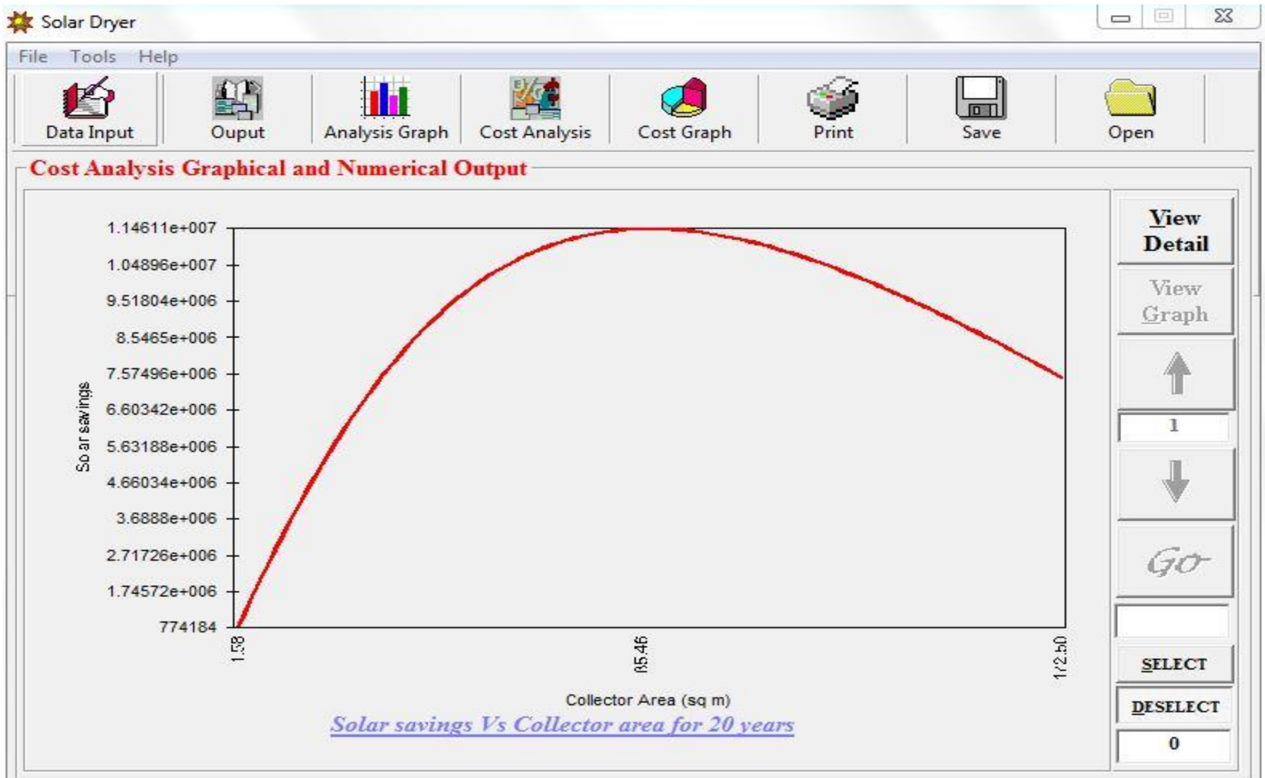


Fig.1.Graphical Analysis of Ibadan with 30% and 15% initial and final moisture content respectively

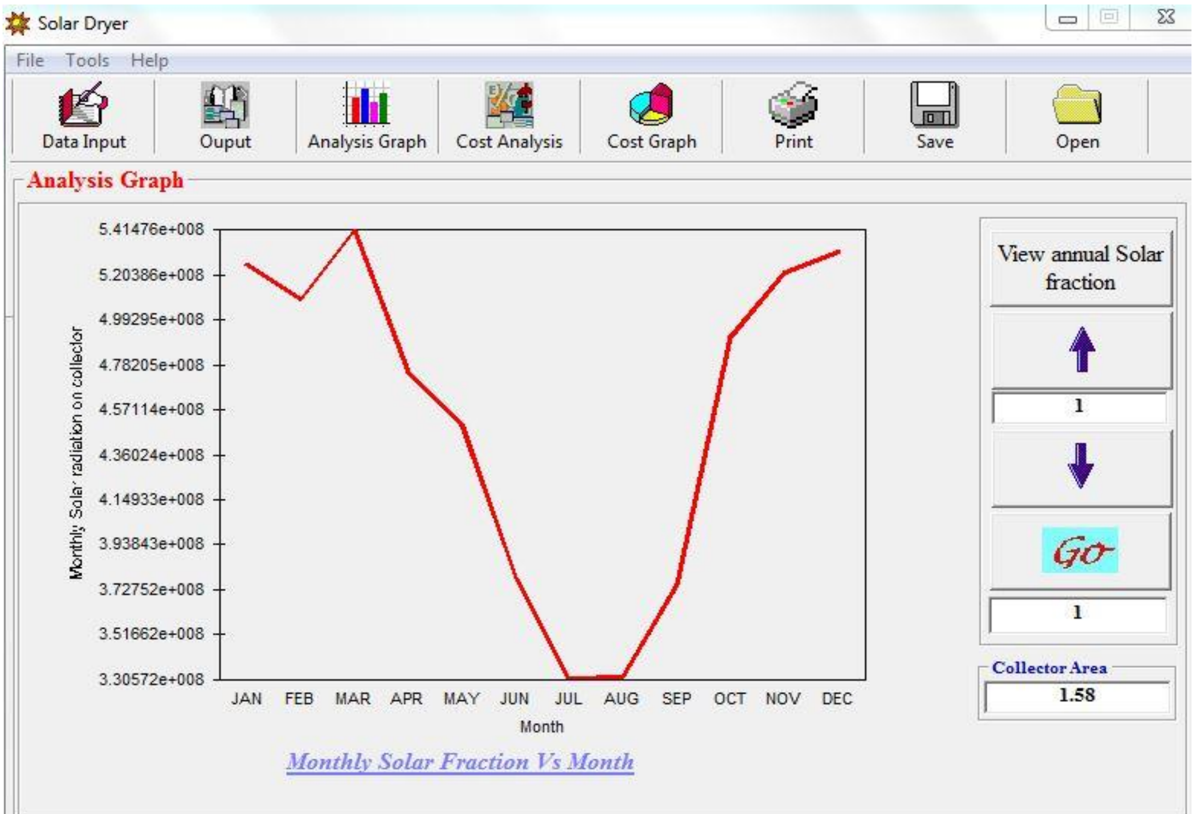


Fig.2.Graphical Analysis of Ibadan with 30% and 15% initial and final moisture content respectively

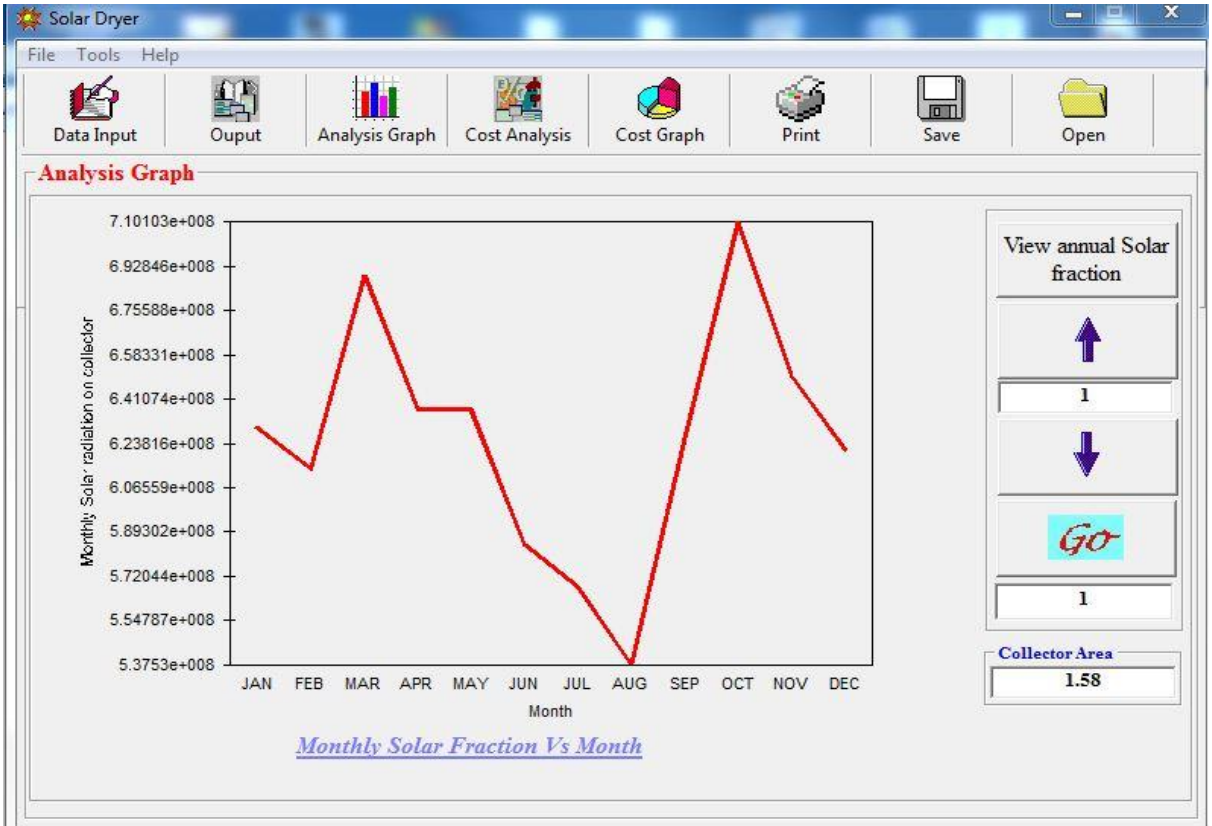


Fig.3 Graphical Analysis of Kano with 30% and 15% initial and final moisture content

Table 3: Numerical output of Kano with 30% and 15% initial and final moisture content

Cost Analysis Graphical and Numerical Output

Year	Fuel Savings	Extra Mortgage Payment.	Extra Ins. Maint. Energy	Extra Property Tax	Income Tax Savings	Solar Savings
0						-4373.85
1	455,984.93	-5,943.51	-4,373.85	0.00	0.00	445,667.58
2	16,465.55	-5,943.51	-5,095.53	0.00	0.00	5,426.51
3	19,758.66	-5,943.51	-5,936.29	0.00	0.00	7,878.86
4	23,710.39	-5,943.51	-6,915.78	0.00	0.00	10,851.10
5	28,452.46	-5,943.51	-8,056.89	0.00	0.00	14,452.07
6	34,142.96	-5,943.51	-9,386.27	0.00	0.00	18,813.18
7	40,971.55	-5,943.51	-10,935.01	0.00	0.00	24,093.04
8	49,165.86	-5,943.51	-12,739.28	0.00	0.00	30,483.07
9	58,999.03	-5,943.51	-14,841.26	0.00	0.00	38,214.26
10	70,798.84	-5,943.51	-17,290.07	0.00	0.00	47,565.26
11	84,958.60	-5,943.51	-20,142.93	0.00	0.00	58,872.16
12	101,950.32	-5,943.51	-23,466.52	0.00	0.00	72,540.30
13	122,340.39	-5,943.51	-27,338.49	0.00	0.00	89,058.39
14	146,808.47	-5,943.51	-31,849.35	0.00	0.00	109,015.62

Collector Area (sq m)	Pay-back Time (yrs)	Initial Cost of Investment	Recommended Number of Modules
1.58	1	43,738.46	52

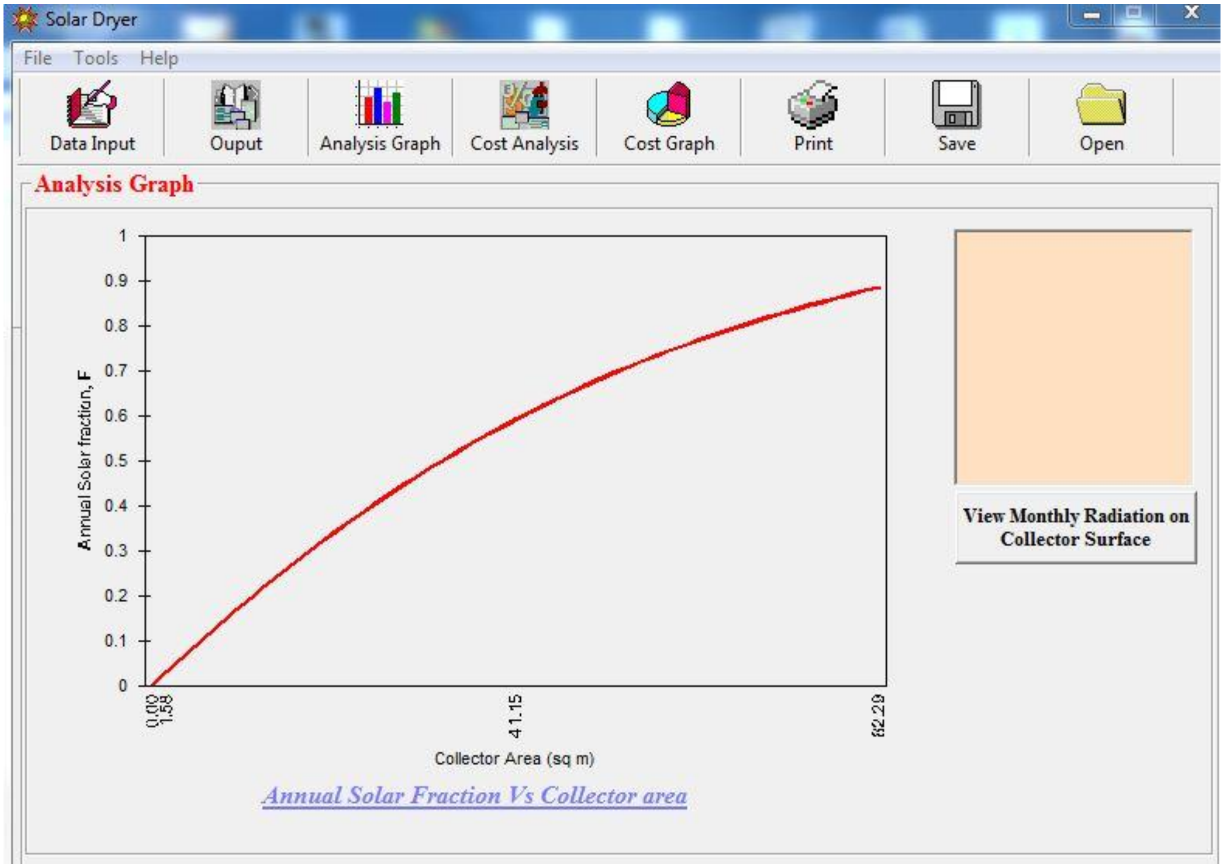


Fig.4 Graphical Analysis of Kano with 30% and 15% initial and final moisture content

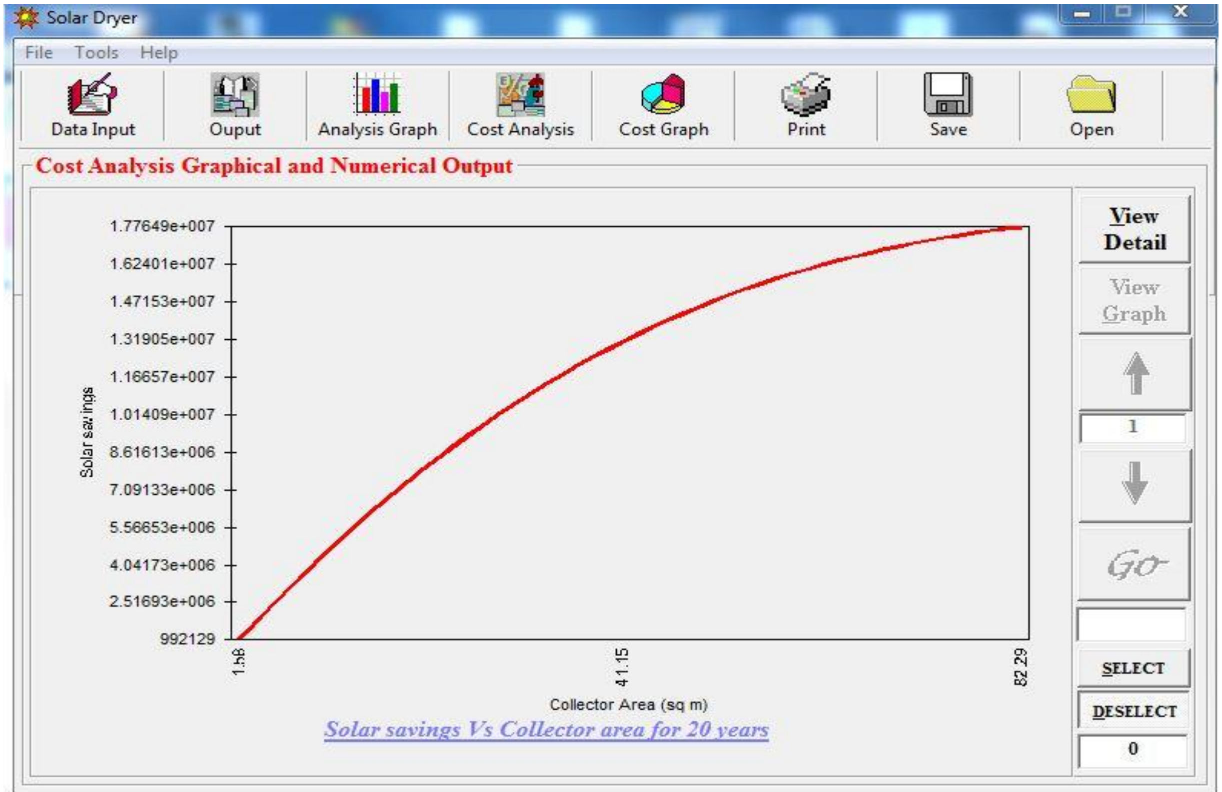
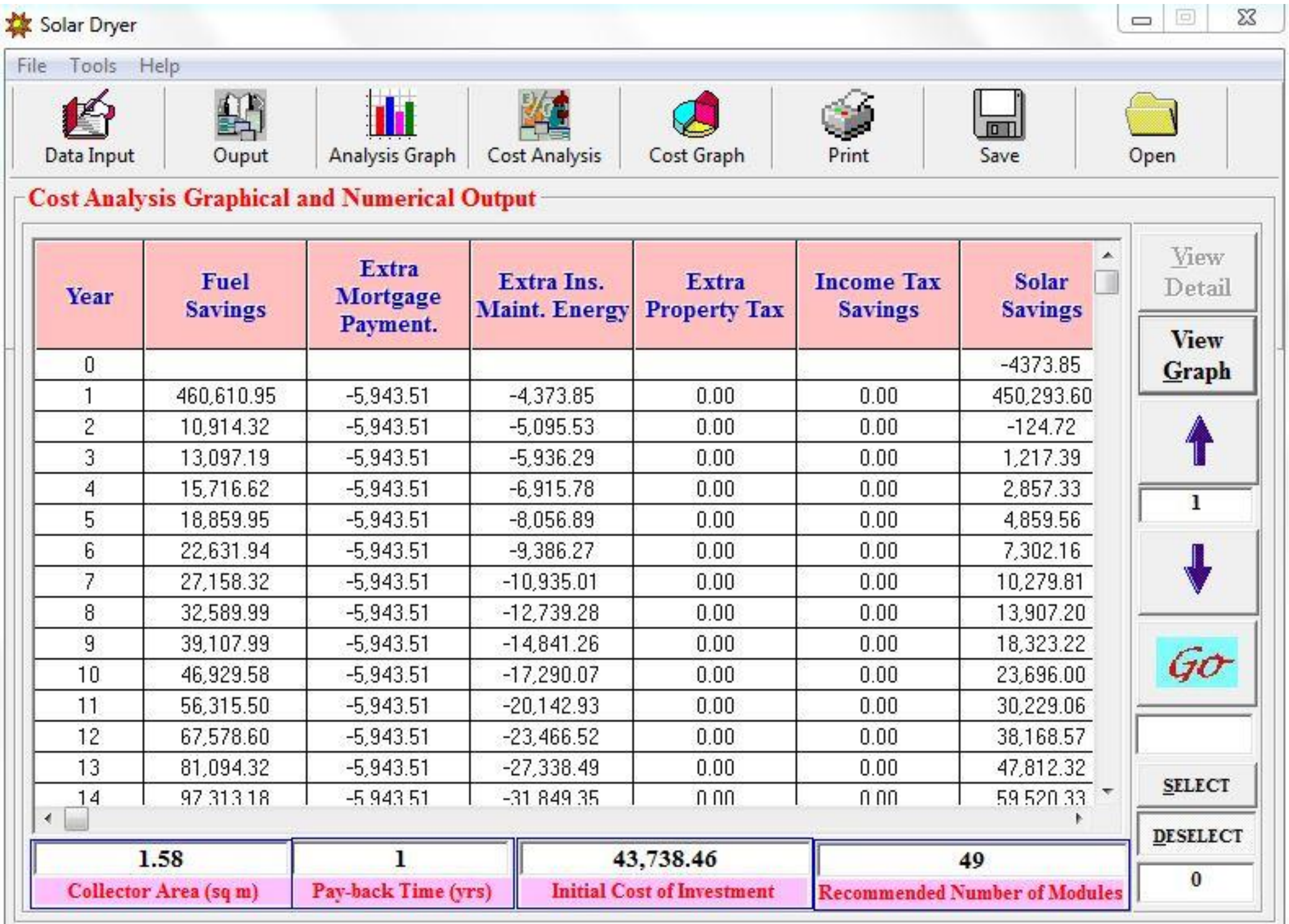


Fig.5. Graphical Analysis of Kano with 30% and 15% initial and final moisture content

Table 4: Graphical Analysis of Portharcourt with 30% and 15% initial and final moisture content



Solar Dryer

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Cost Analysis Graphical and Numerical Output

Year	Fuel Savings	Extra Mortgage Payment.	Extra Ins. Maint. Energy	Extra Property Tax	Income Tax Savings	Solar Savings
0						-4373.85
1	460,610.95	-5,943.51	-4,373.85	0.00	0.00	450,293.60
2	10,914.32	-5,943.51	-5,095.53	0.00	0.00	-124.72
3	13,097.19	-5,943.51	-5,936.29	0.00	0.00	1,217.39
4	15,716.62	-5,943.51	-6,915.78	0.00	0.00	2,857.33
5	18,859.95	-5,943.51	-8,056.89	0.00	0.00	4,859.56
6	22,631.94	-5,943.51	-9,386.27	0.00	0.00	7,302.16
7	27,158.32	-5,943.51	-10,935.01	0.00	0.00	10,279.81
8	32,589.99	-5,943.51	-12,739.28	0.00	0.00	13,907.20
9	39,107.99	-5,943.51	-14,841.26	0.00	0.00	18,323.22
10	46,929.58	-5,943.51	-17,290.07	0.00	0.00	23,696.00
11	56,315.50	-5,943.51	-20,142.93	0.00	0.00	30,229.06
12	67,578.60	-5,943.51	-23,466.52	0.00	0.00	38,168.57
13	81,094.32	-5,943.51	-27,338.49	0.00	0.00	47,812.32
14	97,313.18	-5,943.51	-31,849.35	0.00	0.00	59,520.33

Collector Area (sq m)	Pay-back Time (yrs)	Initial Cost of Investment	Recommended Number of Modules
1.58	1	43,738.46	49

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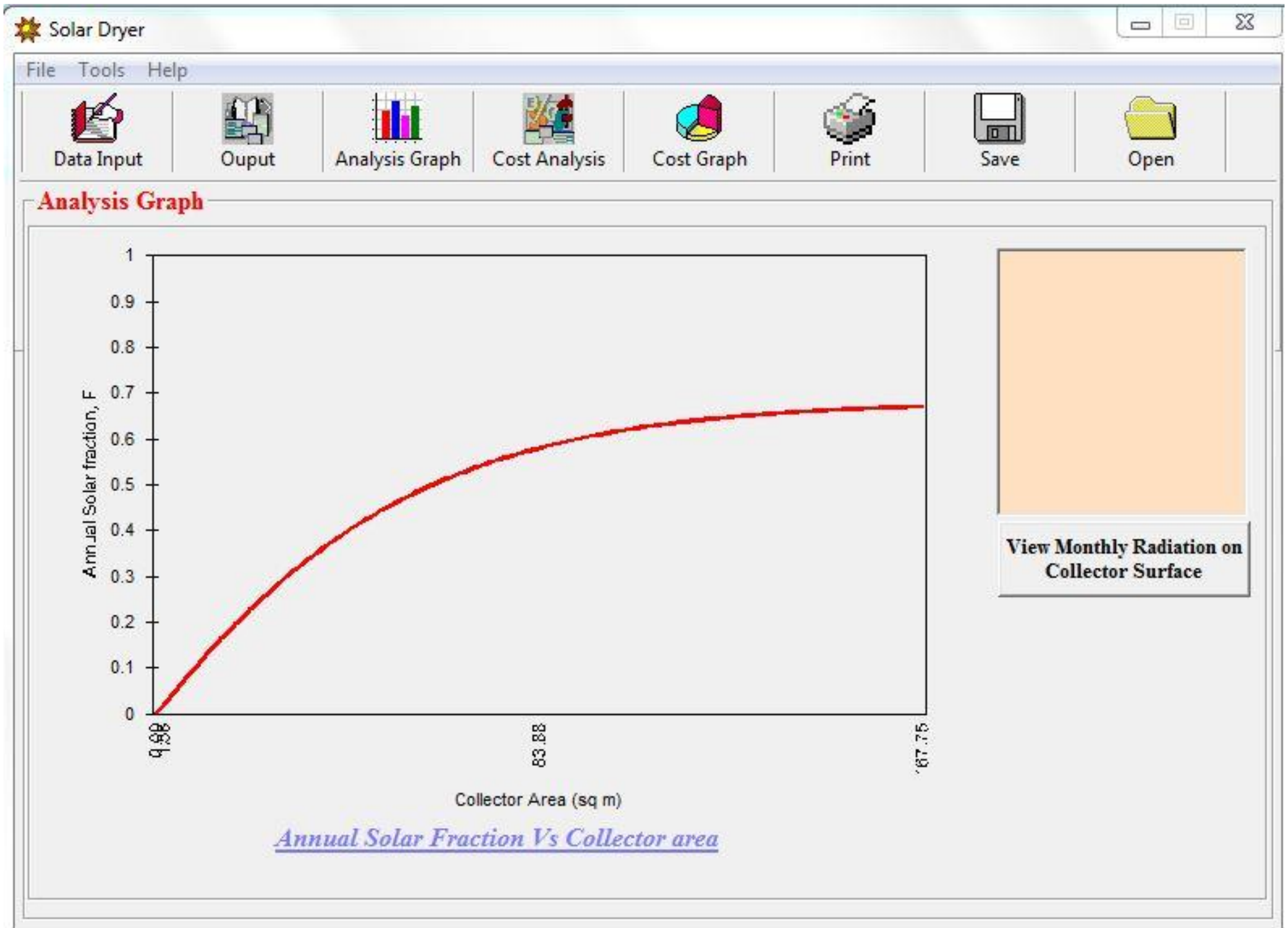

Fig.6 Graphical Analysis of Kano with 30% and 15% initial and final moisture content

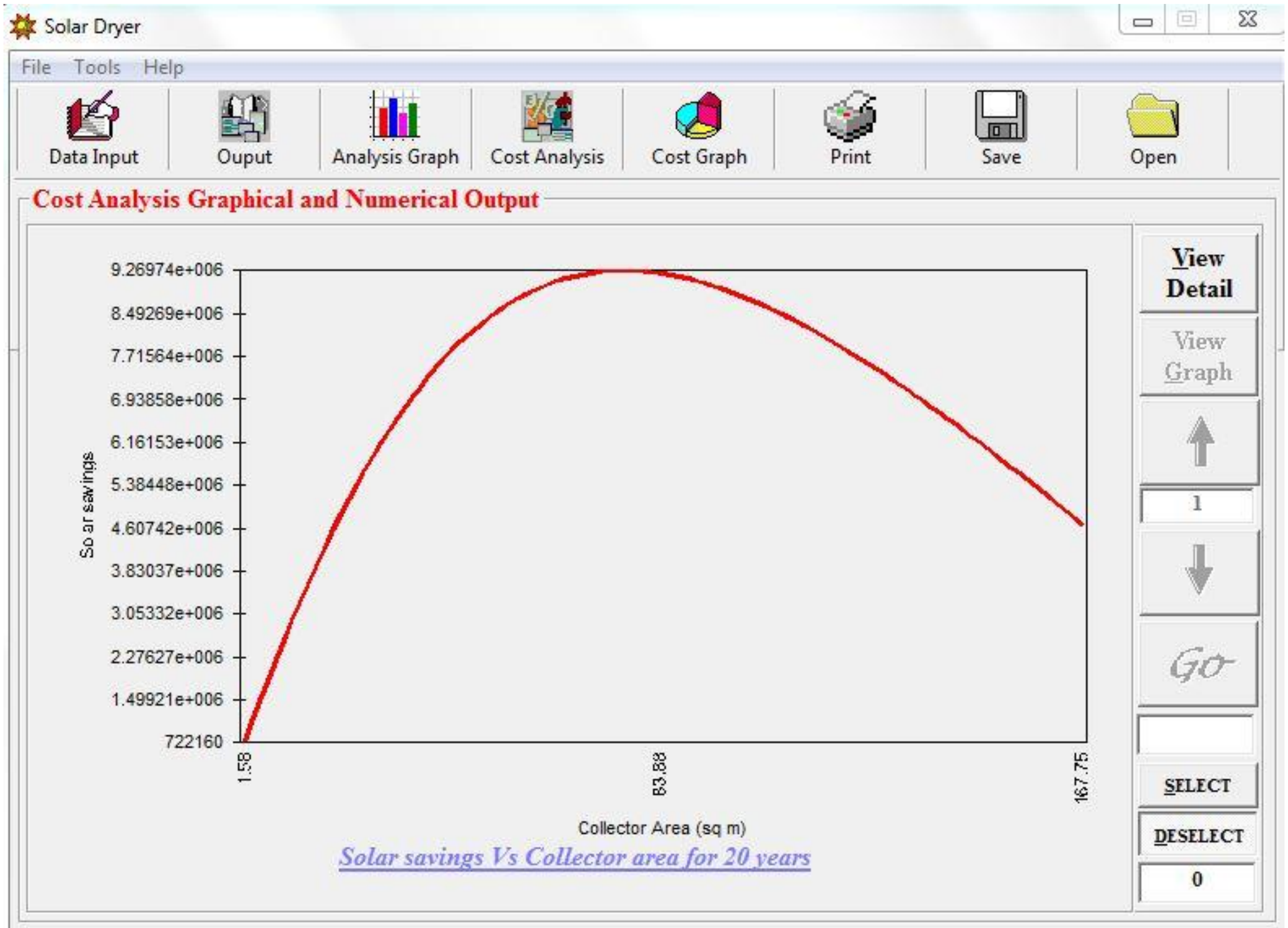

Fig.7. Graphical Analysis of Kano with 30% and 15% initial and final moisture content

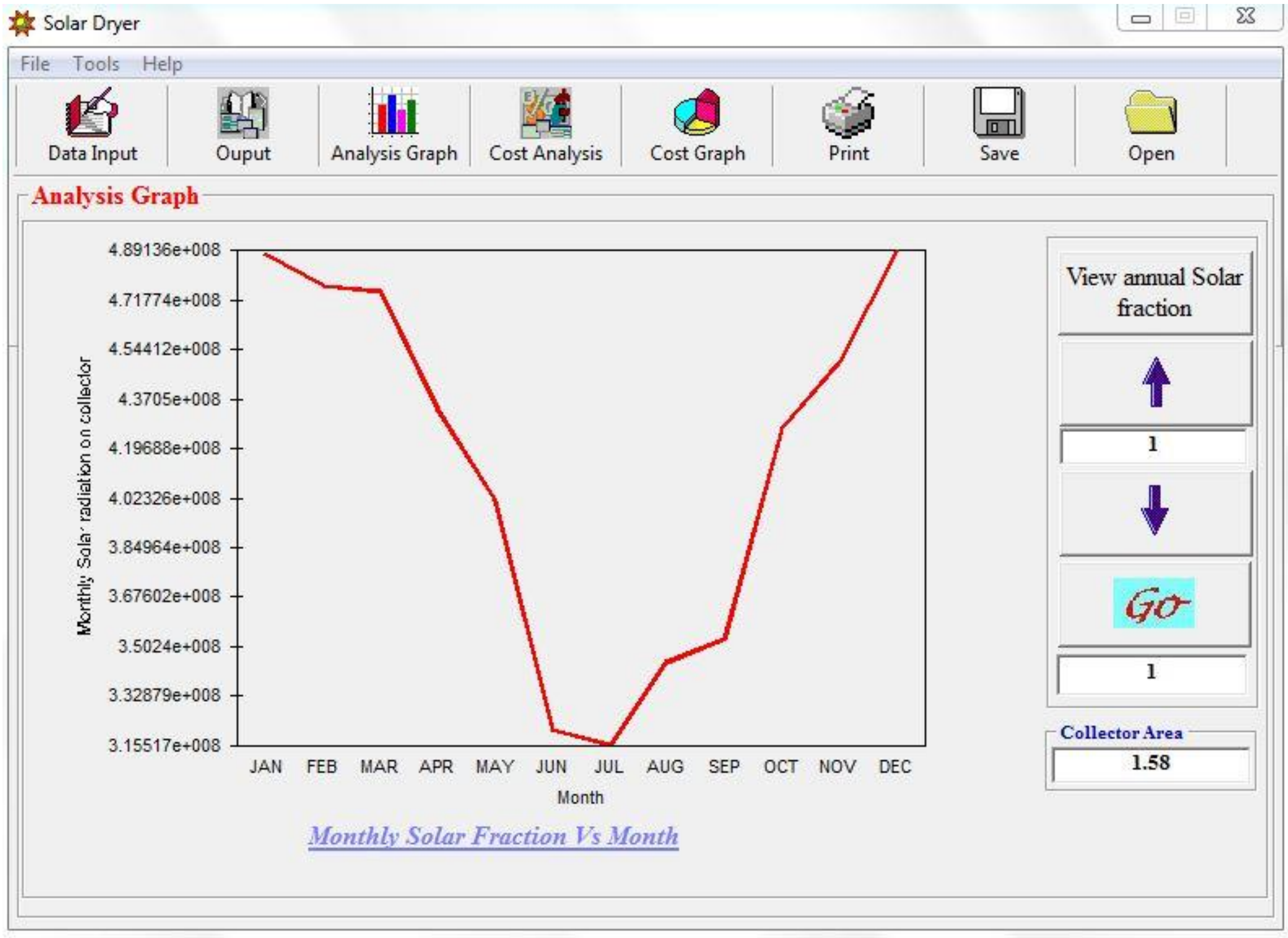

Fig.8. Graphical Analysis of Kano with 30% and 15% initial and final moisture content

The simulation software was used for simulation with different thermo properties of air as fluid, locations etc, and results were obtained for 50,000kg (50 tonnes) of agricultural produce per month.

Most agricultural produce exhibit about 25%-30% initial moisture content (wet-basis) before they are solar dried [6].When decreasing initial moisture content, i.e. 50%, 40%, 30%, 20% (wet basis) were used in the simulation, the fraction of energy supplied by solar increased gradually. The collector area in, m^2, required consequently reduced, and hence a reduction in the overall solar dryer cost. [6]

The lower the initial moisture content, of the produce, the higher the energy supplied by solar, and also the higher the fraction of energy supplied by solar.

Consequently, the much lower the initial moisture content the smaller the initial cost of investment, the shorter the pay-back time (years), and the lower the collector area required in m^2 with all other things kept constant.

For Ibadan location, with 50,000kg/month

(50 tonnes per month) of agricultural produce the average sunshine hours per month is about 159.8 hours. Therefore the drying rate will be 313kg per hour i.e. 0.313 tonnes per hour which is about 1.643 tonnes per day.

For Kano location, with the same 50,000kg (50 tonnes) per month of agricultural produce, the average sunshine hours per month is about 261.7hours. therefore the drying rate will be 191kg per hour i.e. 0.191 tonnes per hour which is about 1.64 tonnes per day.

For Port Harcourt location with the same 50,000kg produce the average sunshine hours per month is about 118 hours. Therefore the drying rate will be 424.3k per hour i.e. 0.42 tonne per hour which is about 1.624 tonnes per day.

A close observation of the drying rate of Ibadan, Kano and Port Harcourt of 50 tonnes of the produce revealed close and neighbouring values. Hence, a better way is to fix the drying rate in kg/hr and calculate the amount that can be dried in each location.

However, the large difference between any industrial solar dryer located at Ibadan, Kano and Port Harcourt will be the initial investment cost of equipment (to include solar collectors unit area cost), the solar savings for a given period of time and the pay-back period.

The total cost which include, the installation cost, the equipment cost and the operating costs and maintenance cost at Ibadan and Port Harcourt will surely be on the high side when compared to that in Kano. Hence a relative advantage at locations with high average sunshine hours per day to those with lesser or lower average sunshine hours per day. However, a better solar saving could be achieved with lower inflation and interest rates.

Also affecting is the air flow rate required for drying, as it was revealed during simulation, that higher air flow rates, keeping other things constant, means increase in the annual solar fraction but for larger fan/blower and consequently cost of purchase.

The simulation iteration stops when (i) The number of solar modules obtained can fully supply the energy needed for drying (ii) when the additional energy needed is less than 1/100 of the original energy supplied by the first solar module.

The simulation was done with input that represents industrial applications.

Cost analysis

In developing countries like Nigeria, items like mortgage interest rate, down payment and the likes, sounds unrealistic, hence the cost analysis is recommended to be adapted.

The C_A and C_E i.e. area dependent cost and area independent cost respectively which contribute to the overall cost of the installation have also been arbitrarily chosen with ratio of 1:3½. If a smaller initial moisture content is used, the collector area required for a solar fraction supply will be smaller and hence larger C_A/C_E. Smaller C_E will surely reduce C.

Therefore the larger C_A/C_E, the more reduced 'C' and hence, higher solar savings.

Recommendations

The selection of other materials for use in the design should also be based on their availability and affordability because nobody will want to buy any equipment that is too expensive and for which spare parts are not locally available. To help in performing economic analysis using this software, prices of solar air heating systems of different configurations can be obtained on the internet sites of international vendors and manufactures.

Though varieties of economic figures of merit like payback times, cash flow e.t.c, have been proposed and applied but the life cycle costing method is sufficiently the most inclusive since it take into account any level of detail the user wishes to include even, the dynamic nature of time value of money and hence recommended. The kinetics of moisture within the agricultural produce had not been dealt with in this paper.

Conclusion

Pre-investment, investment and operating cost that may be attached with industrial solar drying processes are actually functions of different meteorological data. These data are the essentials of optimum profit when the application of Solar drying equipment becomes pragmatically imperative. Although there are many values of solar collector that could easily support profitability but the optimal collector area needs to be examined and appropriately applied.

References

Duffie, J.A. Beckman W.A. (1980) Solar Thermal Engineering . John Willey & Sons Inc.

Fagbenle R.O. (1993) Estimation of Diffuse Solar Radiation in Ibadan, Nigeria. International Journal of Solar Energy,Vol. 13 ps. 145-153

Fagbenle R.O. (1990) Estimation of Total Solar Radiation in Nigeria Using Meteorological Data. Nigeria Journal of Renewable Energy. Vol. 1 pgs 1-8

Fagbenle,R.O. (1991).On Monthly Average Daily Extraterrestrial Solar Radiation for Nigeria Latitudes. Nigeria Journal of Renewable Energy. Vol. 2, No. 1, pgs. 1-8

Fagbenle,R.O.(2004-2005)Personal Consultation

Herick Otherno (1993).Design factors of small scale thermo-syphon solar crop dryers

Lasode Journal of Applied Science, Engineering and Technology vol. 4: No. 2 pgs. 32-43.

M.S. Soha, Ram Chandra (1994).Solar Drying system and their testing procedures Review. Energy convers. Management, Vol. 35, No. 3 pgs. 219-267