THE POTENTIAL FOR SOLAR ENERGY UTILISATION IN THE KENYAN FOOD PROCESSING INDUSTRY: WITH PARTICULAR REFERENCE TO SUITABLE FOOD MATERIALS AND PROCESSES; CLIMATIC LIMITATIONS; AND PROCESSES INVOLVING SOLAR WATER HEATING

By

Michael W. Okoth, B.Sc.(Eng.)(Lond.), A.C.G.I.

A THESIS
submitted in part fulfilment for the degree
of
MASTER OF SCIENCE
in the University of Nairobi

Department of Food Science and Technology

1983.

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

24th November 1983
Date

Michael W. Okoth

This thesis has been submitted for examination with our approval as University supervisors.

A. Williams
Dr. A. Williams

Kamaluddin Kassam
Dr. K. Kassam

24TH November 1983
Date

24th November 1983
Date

ACKNOWLEDGEMENTS

My special thanks go to Dr. A. Williams, who supervised this work, read and corrected the manuscript.

I also wish to thank Dr. K. Kassam who, as the second supervisor, offered some advice.

I very much wish to thank Mr. S.G. Kihara, a technician in the Department of Food Science and Technology, University of Nairobi, without whose assistance the experimental work would have been much more difficult.

My thanks are also due to Mr. G.M. Muchemi, Senior Instrument Officer, Meteorological Department, Nairobi, who calibrated the solarimeter - anemometer - recorder system and thereby enabled measurements of insolation and wind speed to be taken.

I gratefully acknowledge the assistance of the late Mr. J. Weima, Lecturer in Statistics, Department of Crop Science, University of Nairobi, in the statistical analysis of the experimental data.

I also wish to thank Miss N. Mwendia, who typed the thesis in her spare time.

Last, but not least, I very much thank the Swiss Federal Government for offering me a scholarship which enabled this work to be done and ETH-Zurich for donating the anemometer, solarimeter and recorder system.

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

The potential for the utilisation of solar energy in the Kenyan food processing industry was investigated. Initial surveys were carried out with regard to plant and animal food production and processing in Kenya; the availability of solar energy; food processes readily adaptable to using solar energy and the general economics of solar energy utilisation. It was found that Kenya has a large and growing food processing industry and an abundant supply of solar energy. Almost the whole country receives more than 18 MJ m^{-2} per day, on average. The results of the intensive literature survey which was carried out indicate that solar energy can be utilised for food dehydration, the provision of process heat and refrigeration.

The performance of a water heating flat-plate solar collector made by the author and three commercial water heating flat-plate solar collectors were tested. The three commercial solar collectors had glass covers and effective collector areas of 0.74, 1.5 and 1.85 m^2 while the self-made collector had a polyvinyl chloride (PVC) film cover and an effective area of 1.4 m^2. The experimental results conformed with the well known Hottel-Whillier-Bliss equation. According to this equation the performance of a solar collector is characterised by the product of the collector heat removal factor and the transmittance-absorptance product

($F_R(\tau\alpha)_e$) as well as the product of the collector heat removal factor and the heat loss coefficient (F_RU_L). The $F_R(\tau\alpha)_e$ values, obtained using the effective collector areas and the inlet water temperature, were 0.72, 0.78, 0.78 and 0.89 respectively for the commercial collectors and the self-made solar collector. The F_RU_L values were 9.08, 6.32, 9.61 and 13.14 W $m^{-2}K^{-1}$, respectively. The self-made solar collector had the highest $F_R(\tau\alpha)_e$ value because the PVC film had the highest transmittance, with regard to solar radiation. F_RU_L is a measure of the rate of heat loss from the solar collector. The solar collector with the lowest rate of heat loss had a special selective absorber surface and the outer surface of the glass cover was treated to minimise the transmittance, with regard to the longwave radiation from the absorber surface. The self-made solar collector had the highest rate of heat loss because the PVC film had the highest transmittance with regard to the longwave radiation emitted by the absorber.

The performance of a thermosyphon solar water heating system using the four flat-plate solar collectors, in turn, was tested. The storage tank had a capacity of 120 litres. The percentage of the total solar energy falling on the effective areas of the solar collectors between 12:00 noon and 3:00 p.m. which was transferred to the water in the storage tank was 46.6, 49.9, 41.0 and 52.6%, respectively for the three commercial solar collectors and the self-made collector. The rates of temperature rise, between 12:00 noon and 3:00 p.m., were 2.5, 2.4, 2.5 and 2.0°C $h^{-1}m^{-2}$, respectively. The rate of temperature rise is, however, determined by the insolation and therefore the variations shown above cannot be wholly attributed to the differences in the performance of the solar collectors.

It has thus been established that there is both the need and the potential for the utilisation of solar energy in the Kenyan food processing industry. The data obtained from the performance tests can be used to design solar water heating systems for the food industry in Kenya or other areas of similar climatic conditions.

1. INTRODUCTION

1.1. Global Energy Scene

An adequate supply of energy is a prerequisite to the continued growth of the world economy. The rapid growth of the world population necessitates continued utilisation of increasing amounts of energy in order to improve the standard of living, or even to maintain it at its present level.

Energy has to be available at a reasonable cost to sustain the development process. Moreover, energy production and utilisation processes of the future will have to contribute as little as possible to the menace of environmental pollution.

Using the estimated world reserves of fossil fuel given by 'Scientific American' (1) and the 1978 world rate of consumption of commercial energy (2), the author has estimated how long it will take before the known fossil fuel reserves are depleted. The estimates show that the coal reserves will be depleted in 254 to 381 years while petroleum and natural gas reserves will be depleted in 24 to 51 and 4[illegible] to 102 years, respectively. A recent report (3) indicates that "at present levels of consumption the world's proven oil reserves would dry up in a little over 30 years". It is thus evident that the world will sooner or later face a fossil fuel crisis. Either the supplies will be totally depleted or the remaining reserves will be too costly to exploit.

Added to the problems of availability and cost of fossil fuels is the problem of environmental pollution (5-8). Even if ample supplies of fossil fuels could be assured, a time might come when increased utilisation of fossil fuels cannot be allowed because of adverse effects on the environment. It might be argued that the use of appropriate pollution abatement technology will minimise the environmental impact of fossil fuels. Pollution abatement by its very nature, however, creates additional energy demand and thus compounds the problems of availability and cost of fossil fuels.

The general realisation of the finite nature of fossil fuel resources, as well as the environmental and safety constraints, has led to an examination of the possibility of utilising those energy resources which are non-depleting (renewable). A workshop on alternative energy strategies held in 1977 had this to say (4):

> "Research, development and demonstration of renewable energy systems should be given a high priority as soon as possible. They have a critically important role to play beyond the year 2000 as oil and natural gas decline further, particularly if nuclear energy and coal are limited by resources and/or environmental and safety constraints".

Which are the renewable sources of energy, and to what extent are they utilised? Gicquel (9), writing for the United Nations Conference on New and Renewable Sources of Energy held in Nairobi in 1981, noted that:

> "At present, new and renewable sources of energy account for approximately 15% of world commercial and non-commercial energy consumption. The only sources utilised to any appreciable extent are hydropower (1.7%) and especially fuelwood and charcoal (12 to 13%). Next come biomass conversion (0.8%), tar sands (0.15%), then geothermal power, draught animals, peat, oil shale, solar power, wind power and tidal power. Wave power and thermal gradient of the sea are virtually not utilised".

The status of these renewable energy sources was reviewed by various experts in preparation for the United Nations Conference on New and renewable sources of energy held in Nairobi in 1981 (10-19).

The development of renewable energy resources is most urgent for developing countries with no reserves of conventional energy sources. These countries continue to import increasing amounts of commercial energy, especially oil. Persistent problems, with regard to balance of payments, afflict these countries mainly because the price of the imported oil (and other fossil fuels) increases alarmingly while the prices of the products exported by these countries exhibit a tendency to decrease or fluctuate.

1.2. The Kenyan Energy Scene

Kenya imports all the crude oil, coal (and coke) and some hydroelectric power. Energy imports accounted for 22% of the total imports in 1977 (20). The share rose to 33.6 and 38.7% in 1980 and 1981, respectively (34).

1.2.1. Oil

Kenya's economic development is heavily dependent on petroleum products. In 1977, for instance, petroleum products accounted for 85% of the commercial energy consumption (20). During the period 1970-1977 the growth rate for the consumption of petroleum products was 6.4% (20). Table 1 gives a breakdown of oil consumption by sector in 1980.

Table 1. Oil Consumption in Kenya, 1980

Sector	Per cent
Agriculture	4
Transport	63
Power	7
Commercial & Industrial	22
Government	4
TOTAL	100

Source: Shakow et al., 1981 (Ref.21).

1.2.2. Coal

As noted above, all the coal is imported. Only 4.1.% of the total energy consumption in 1981 (excluding fuelwood and charcoal) came from coal (34). Nearly all the coal is used in industry to fire boilers and furnaces.

1.2.3. Electric Power

Electricity accounted for 13% of the commercial energy supply in 1980 (21). Seven per cent of the total refined petroleum products consumed in Kenya in 1980 was used to generate electricity (21). Hydro energy supplies 90% of the total electric power consumed in Kenya (22). The hydropower potential is estimated at 1200 MW out of which only 750 MW can be harnessed economically (23). On average, electricity demand growth rate is 8% and this means that even if the estimated hydropower potential were harnessed exclusively for the generation of electricity, it would not be able to meet the demand by the year 1993 (22, 23).

1.2.4. Woodfuel

Woodfuel is classified as a non-commercial energy source. It accounts for about 75% of all the energy requirements in Kenya (21, 23). The main use of woodfuel is in the household. Other uses include agricultural crop drying (tea, tobacco, bear brewing, etc.), pottery firing, fish smoking, etc. Estimates of the current annual consumption of woodfuel indicate a figure of the order of 30 million cubic metres (22 million tonnes of air dry wood) or 7 million tonnes of oil equivalent (21). Wood demand might exceed supply in the near future (24). According to a government report (23),

> "an area equivalent to about 2 million hectares may have to be planted with tree species between now and the turn of the century if Kenya's woodfuel requirements are to be met, to say nothing of the area needed to meet the requirements of other wood users".

1.2.5. Geothermal Energy

Several potential sites have been identified in the Rift Valley for geothermal power generation. Of these, Olkaria, Eburra and Lake Bogoria fields are the most important. The estimates of the geothermal energy potential of the Olkaria field range from 170 MW to 500 MW available over a period of 25 years (23).

1.2.6. Power Alcohol

One plant is already producing ethanol from molasses. Another one is under construction. The two plants will have a joint capacity of 120,000 litres per day. Large-scale power alcohol production would, however, compete directly with food production for land (25).

1.2.7. Biogas

Biogas is the combustible gas obtained by anaerobic fermentation of organic waste. Both vegetable matter and animal dung are used as substrates.

Muchiri (26) has estimated the potential for biogas production in the rural areas of Kenya as equal to 7,390 x 10^{10} kcal (309,641.000 GJ). Muchiri notes that this is more than the estimated total rural energy consumption in the year 2000.

Singh and Misiko (27) reported that there were more than 40 biogas plants operating in Kenya in 1980. Their capacity varied from 5.5 to 4500 cubic metres. The gas is mostly used for cooking and lighting in homes.

1.2.8. Wind Power

The potential for wind power utilisation exists in many parts of Kenya (26). Many windmills were in use in the past, especially on large-scale farms. Apart from generating electricity, wind power can be used directly for grain milling and water pumping. The potential for wind power is still very much underutilised.

1.2.9. Solar Energy

Kenya lies astride the equator. She has, as shall be seen, an abundant supply of solar energy. The Kenya

Government recognises that Kenya "has undisputed opportunity for the utilisation of solar energy to enhance its socio-economic development" (23). Solar energy has been used for crop drying from time immemorial. More recently, solar energy has been used for domestic and commercial water heating. On average, about 1000 units of the flat-plate-type solar water heating systems are sold each year (23). The impact of solar energy utilisation on the national economy is still minimal.

1.3. The Case for Solar Energy Utilisation in Kenya

There are a number of good reasons in favour of the development and widespread use of the solar energy resource in Kenya (28, 29):

(i) there is an abundant supply of solar energy;

(ii) it provides a truly renewable resource;

(iii) its use would open up an indigenous, relatively secure energy option;

(iv) its use would make possible the release of other fuels for premium use;

(v) a large part of the population lives in rural areas, the cost of providing reliable fuel transport and/or electric power transmission networks is excessive and as such, localised solar energy installations are cost effective;

(vi) solar energy technology is relatively unsophisticated compared to, say, nuclear engineering;

(vii) solar energy has no military potential and

(viii) solar energy is non-polluting.

1.4. The Need for the Utilisation of Solar Energy in the Kenyan Food Processing Industry.

As already indicated, the share of fuels (and lubricants), with regard to the total import bill, rose from 22.0% in 1977 to 33.6% in 1980 and 38.7% in 1981. Oil accounted for 78.1% of the total energy (excluding fuelwood and charcoal) consumed in 1981 (34). There is clearly a need to reduce the proportion of petroleum products in the total energy mix. With the expected growth in the national economy, the total energy consumption is bound to increase. One way of reducing the consumption of imported fuels is to institute energy conservation measures. This would reduce the total energy consumption by improving the efficiency of utilisation of the existing energy supplies. Clearly, only limited savings can be achieved by this means. Continued development and utilisation of renewable energy resources available locally would certainly go a long way to reducing the dependence on imported petroleum products. If for no other reason, the author's concern with the utilisation of solar energy in the Kenyan food processing industry stems from the fact that this industry takes a prominent position in the manufacturing sector. The manufacturing and agricultural sectors constituted 13.2

and 34.6%, respectively, of the total Gross Domestic Product (GDP) (at constant 1976 prices) in 1979 (30). The food processing industry (excluding beverages) contributed 33.1 (31), 39.0 (32), 44.4 (30) and 36.1% (30) of the total output (by value) from the manufacturing sector in 1972, 1976, 1977 and 1978, respectively. As shown in Table 1, the commercial and industrial sector accounted for 22% of the total oil consumption in Kenya in 1980. It can be seen that the food processing industry accounts for a sizeable proportion of the total oil consumption in Kenya. Indications are that the food processing industry will continue to grow. The utilisation of solar energy (and other renewable energy resources) will thus contribute significantly to alleviating Kenya's over-dependence on imported energy. More than this, it will open up means of food processing and preservation in areas which do not have modern facilities such as electricity. It will facilitate the development of small-scale rural industries and refrigeration systems. The benefits of these facilities would be enormous.

It is thus necessary to disseminate information on solar energy utilisation. In the words of Barbieri (33):

> "There is sufficient engineering expertise in most plants to be able to understand, operate and maintain any solar energy system. Decision-

makers in those plants, however, must know that solar energy is in fact an option. Information dissemination is a necessary element to diffuse solar energy technology, to achieve its widespread utilisation, and to educate potential users of the full range of solar energy system capabilities".

1.5. The Scope of the Study

In this study, the potential for solar energy utilisation in the Kenyan food processing industry is investigated. Solar photovoltaic systems which generate electricity from incident solar radiation are not considered. The author's concern is with solar thermal conversion systems which utilise solar radiation directly to heat water, air or a food product.

The work begins with a survey of food production and processing in Kenya. This makes it possible to identify the food materials and processing methods in Kenya that are most readily adaptable to solar energy use. The section on the availability of solar energy in Kenya helps to identify those regions within Kenya that could provide adequate conditions for solar energy utilisation. The food processes surveyed in detail are solar drying, the provision of solar process heat and solar refrigeration.

The experimental section is concerned with the performance testing of some solar water heating panels and a thermosyphon solar water heating system.

This study is not without its limitations. The major one is that it has not been possible to give a quantitative assessment of the potential for solar energy utilisation in Kenya. The second limitation is that in reviewing the literature on the economic feasibility for the diverse solar systems available, it was not possible to find any relevant study that had been carried out in Kenya.

2. LITERATURE SURVEY AND EVALUATION OF THE SOLAR POTENTIAL

2.1. FOOD PRODUCTION AND PROCESSING IN KENYA

2.1.1. Introduction

Kenya is largely an agricultural country. Agricultural production constitutes about one third of the Gross Domestic Product (34). It is necessary to know the food products available in various regions of Kenya, and the level of production of the food products. This information is useful in evaluating the potential for the utilisation of solar energy as an energy source in processing these products close to the respective growth regions of Kenya. A brief survey of the Kenyan food processing industry is also given as it is important to this thesis. The map of Kenya shown in Figure 1 will be useful.

2.1.2. Food Production in Kenya

The important farming areas of Kenya may be divided into three ecological regions, namely, the coastal region, the Lake Victoria Basin and the Highlands (35-39).

2.1.2.1. The Coastal Region

Intensive fruit and vegetable production is found along the coastal belt. The products include mangoes and coconuts.

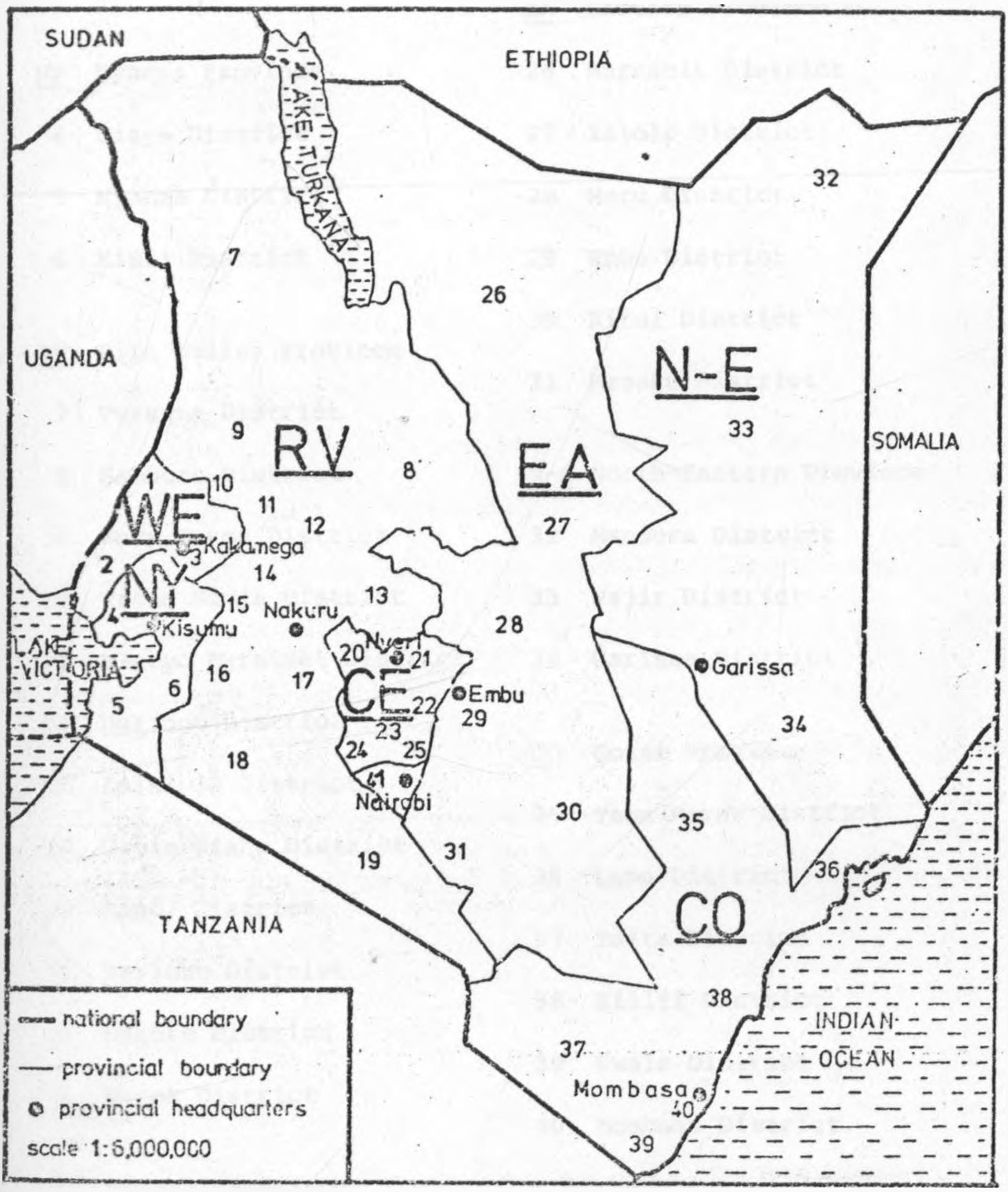


Fig. 1: Map of Kenya Showing Provinces and Districts.
Source: Nout 1981 (Ref. 291).

(Of the 570,000 km^2 total land area, only 159,000 km^2, that is, 28% of the total land area of Kenya has at least marginal potential for agriculture (292)).

Legend to Figure 1

WE	Western Province
1	Bungoma District
2	Busia District
3	Kakamega District
NY	Nyanza Province
4	Siaya District
5	Nyanza District
6	Kisii District
RV	Rift Valley Province
7	Turkana District
8	Samburu District
9	West Pokot District
10	Trans Nzoia District
11	Elgeyo Marakwet District
12	Baringo District
13	Laikipia District
14	Uasin Gishu District
15	Nandi District
16	Kericho District
17	Nakuru District
18	Narok District
CE	Central Province
20	Nyandarua District
21	Nyeri District
22	Kirinyaga District
23	Murang'a District
24	Kiambu District
25	Thika District
EA	Eastern Province
26	Marsabit District
27	Isiolo District
28	Meru District
29	Embu District
30	Kitui District
31	Masaku District
N-E	North-Eastern Province
32	Mandera District
33	Wajir District
34	Garissa District
CO	Coast Province
35	Tana River District
36	Lamu District
37	Taita District
38	Kilifi District
39	Kwale District
40	Mombasa District
41	Nairobi Area

Taita District is the most productive region. In the Taita lowlands, sheep, goats and indigenous zebu cattle are reared. Groundnuts, chillies, cassava and pigeon peas are also grown in this region. The main food crops in the Taita highlands are maize, beans, sweet potatoes and other vegetables. Some coffee is also grown in this region. Fruits produced in this region include apples, pineapples, passion fruit and macadamia nuts. Poultry, pigs and dairying enterprises can also be found.

2.1.2.2. The Lake Victoria Basin

Crops grown in this region include maize, millet, cassava, sorghum, rice, sugar cane, fruits and vegetables. Fruits produced in this region include bananas, passion fruits, pawpaws and a variety of citrus fruits while the vegetables include cabbages, collard greens, carrots, onions, lettuce, cow peas and cucumbers. Coffee, tea and potatoes are also produced in Kisii District. Livestock and poultry production can also be found in this region.

2.1.2.3. The Highlands

This is the most predominant agricultural zone in Kenya. Cereal crops such as wheat, maize, barley and oats are grown in this region. The main wheat growing areas are the Uasin Gishu Plateau and the Kinangop Plateau. Various fruits and vegetables are produced in this region. Coffee is the main plantation crop. Tea is particularly found in Kericho, Sotik, the Nandi Hills and the Limuru regions. Both beef and dairy cattle are found in this region. Pigs, sheep and goats are also reared.

2.1.2.4. Food Production Statistics

As of May 1979, there were an estimated 11,453.400 cattle, 8,282,000 goats, 4,299,000 sheep, 111,500 pigs and 26,862,000 poultry stock in Kenya (34). The total production of various food products in 1980 and 1981 is shown in Table 2. The total crop and milk production by small-holders in Kenya in the year 1978/79 can be seen in Table 3. Detailed information on food production in Kenya is to be found in the district and provincial annual reports of the Ministries of Agriculture and Livestock Development.

2.1.3. Food Processing

2.1.3.1. Definition

Salunkhe et al. (40) defined vegetable processing as comprising "those treatments which begin after harvest and end before consumption: handling, transportation, refrigeration, holding, washing, trimming, blanching, freezing, canning, drying, packaging, addition of chemicals, radiation, storage, and ultimately cooking or heating". This definition is valid for all foods if the word 'harvesting' is taken to include activities

Table 2. Total Production of Various Food Products in Kenya, 1980 and 1981.

Crop or Product	Unit	1980	1981
Coffee	'000 tonnes	91.3	90.7
Tea	"	89.9	90.9
Maize	"	1,620	2,070
Wheat	"	216	214
Sugar cane	"	3,951	3,822
White sugar	"	401	367
Fresh horticultural produce (export)	tonnes	22,266	23,352
Fish	tonnes	47,787	57,730

Source: Central Bureau of Statistics 1982 (Ref. 34).

Table 3. Crop and Milk Production by Small-holders in Kenya During the Farming Year 1978/79.

Crop or Product	Total ('000 tonnes)	Main Producing Provinces
Maize	1,541.7	Rift Valley, Central, Nyanza, Eastern, Western
Millet and Sorghum	166.5	Nyanza
Beans	573.3	Central, Eastern
Potatoes	810.0	Central, Rift Valley
Sweet Potatoes	197.0	Central, Western, Nyanza
Cassava	230.4	Nyanza, Western
Bananas	186.4	Western
Other fruits	111.6	Coast, Nyanza
Vegetables	442.8	All areas
Coffee (clean)	423.9	Central, Eastern, Nyanza
Tea	380.7	Central, Rift Valley, Nyanza
Milk (Million litres)	769.0	Rift Valley, Central

Source: Central Bureau of Statistics 1982 (Ref. 34).

such as slaughtering, milking and fishing.

2.1.3.2. Reasons for Food Processing

Fresh food products may be processed for a number of reasons. These include:

(i) the removal of inedible parts;
(ii) the extraction and purification of foodstuffs, for example, sugar and vegetable oils;
(iii) the change of physical form, for example, grinding;
(iv) the increase in palatability;
(v) the prolongation of shelf life.

2.1.3.3. Principles of Food Preservation

Excluding the activities of insects, parasites and rodents, there are three main causes of the deterioration of stored food products (41):

(i) the activities of microorganisms, particularly bacteria, yeasts and moulds;
(ii) chemical reactions mediated by endogenous food enzymes;
(iii) non-enzymatic chemical reactions.

The methods of food preservation are therefore mainly based on four principles:

(i) the lowering of temperature;
(ii) heat treatment;
(iii) the lowering of water activity;
(iv) altering the chemical composition

2.1.3.3.1. Lowering of Temperature

Lowering of temperature reduces the activity of microorganisms. The rates of deleterious chemical reactions, both enzymatic and non-enzymatic, are also decreased. Microbial activity is more or less completely brought to a standstill by frozen storage. The food preservation methods utilising the lowering of temperature to retard food deterioration are chilling and freezing (42, 43, 44). The recommended optimum conditions for various foods have to be maintained to enjoy the maximum benefits of chilling (42, 45, 46).

2.1.3.3.2. Heat Treatment

Enzymes and microorganisms have optimum temperatures for maximum activity. Beyond the optimum temperature the activity decreases. Complete inactivation of specific enzymes and microorganisms is attained by holding the food product for a suitable period at a high temperature. Food preservation methods which utilise heat treatment to inactivate enzymes and/or microorganisms are blanching (47), pasteurisation (48) and sterilisation (49).

2.1.3.3.3. Lowering of Water Activity

The water activity of foods has profound influence on their perishability. Water activity is defined as "the ratio of the water vapour pressure over a food to that over pure water at the same temperature" (50).

Microbial activity stops when the water activity of a food product is lowered below a certain value which depends on the microorganism in question. The lowering of water activity is achieved by the following processes: Freezing, freeze-drying (51), concentration (52, 53), drying (54) and the addition of sugar or salt (55).

2.1.3.3.4. Altering the Chemical Composition

Microorganisms are inactivated by adding chemical preservatives or acids (56, 57). The acids could also be produced in the food product by microbial activity.

2.1.4. Food Processing in Kenya

Products produced in the Kenyan food processing industry include meat and meat products, dairy products, canned fruits and vegetables, dried fruits and vegetables, jams and jellies, beverages, vegetable oils and fats, cereal products, sugar, fish, tea and coffee. Detailed information on various firms and their products is available in various directories (58, 59, 60). Tables 4 to 9 give a measure of the size of the Kenyan food processing industry. The Kenyan food processing industry has recently been the subject of a number of studies (61-65).

Table 4. Meat Processing by Kenya Meat Commission and Uplands Bacon Factory, 1978 - 1981.

KENYA MEAT COMMISSION	Unit	1978	1979	1980	1981
Intake of:					
Cattle and calves	'000 Head	68	68	56	61
Sheep	"	11	10	6	7
Lambs	"	-	-	-	1
Goats	"	70	2	1	1
Total production of Carcass Beef	Tonnes	8,890	7,634	6,438	8,410
UPLANDS BACON FACTORY					
Intake of pigs for:					
Bacon	'000 Head	34	29	20	12
Pork	"	4	5	5	2
Manufacturers	"	2	2	2	4

Source: Central Bureau of Statistics 1982 (Ref. 34).

Table 5. Milk Processed by the Kenya Co-operative Creameries Ltd., 1977 - 1981

Year	Recorded Milk Production ('000 litres)	Whole Milk and Cream ('000 litres)	Butter and Ghee (tonnes)	Cheese (tonnes)	Evaporated Milk (tonnes)	Dried Whole Milk Powder (tonnes)	Dried Skim-Milk Powder (tonnes)
1977	259,450	157,880	4,342	445	1,321	5,262	3,440
1978	269,796	185,557	3,871	253	489	4,236	2,956
1979	240,559	212,255	3,134	264	188	1,439	1,218
1980	186,885	186,892	2,174	150	44	128	80
1981	222,895	222,335	2,729	210	-	1,334	469

Source: Central Bureau of Statistics 1982 (Ref. 34).

Table 6. Production of Beverages, 1977 - 1981

Year	Spirits (litres)	Beer ('000 litres)	Mineral Waters ('000 litres)	Fruit Squashes* ('000 litres)
1977	420,180	195,160	99,411	3,000
1978	407,796	221,365	108,019	6,381
1979	415,694	212,712	127,926	6,486
1980	462,956	232,424	142,953	-
1981	609,763	248,264	171,800	-

Source: Central Bureau of Statistics 1982 (Ref. 34).

* Source: Central Bureau of Statistics 1980 (Ref. 30).

Table 7. Export of Some Fruit and Vegetable Products (in Kg)

Product	1978	1979
Passion Fruit Juice	444,800	373,913
Pineapple Juice	2,064,200	1,846,311
Tomato Juice	7,000	20,104
Other Fruit and Vegetable Juices	191,700	2,524,905
Tinned Pineapple	42,081,900	41,048,499
Dehydrated Vegetables (excluding leguminous Vegetables)	949,600	1,339,958
Tomato Puree	15,300	4,785

Source: Customs and Excise Department 1978 and 1979
(Taken from Ref. 61).

Table 8. Production of Some Cereal Products (in tonnes)

Product	1977	1978	1979
Sifted Maize Meal	195,544	227,148	255,726
Wheat Flour	149,441	156,910	141,169
Rice	20,077	183,470	225,990
Bread	95,703	102,781	80,815
Biscuits	1,684	2,638	2,947

Source: Central Bureau of Statistics 1980 (Ref. 30).

Table 9. Location and Capacity of Existing Oil Mills

Location	No. of Factories	Maximum Processing Capacity (tonnes)
Mombasa	4	31,800
Nakuru	3	49,500
Kisumu	1	12,000
Voi	1	4,500
Malakisi	1	10,500
Nairobi	1	42,000
Total	11	150,300

Source: Nyamwaya 1979 (Ref. 66)

2.2. AVAILABILITY OF SOLAR ENERGY IN KENYA

2.2.1. Introduction

Above the earth's atmosphere the flux of solar radiation is approximately 1400 W m^{-2}. However, by the time it reaches the earth's surface it has been reduced to between 1050 and 0 W m^{-2} (67). This reduction is due to reflection back into outer space and absorption or scattering by molecules; this is especially so with the scattering by water droplets in the clouds and by dust particles. The intensity of the radiation reaching the earth's surface at any one time thus varies from place to place. In addition to this geographical variation, there is also seasonal and diurnal variation of solar radiation intensity at a particular place.

Reliable solar radiation data is required for the design and prediction of the long-term performance of any solar energy system.

2.2.2. Definitions Related to Solar Radiation

The following distinctions are usually made with regard to solar radiation (28, 68, 69).

(i) Direct solar radiation: This is the energy coming directly from the sun without deflection by dust or clouds. It is also called "beam radiation".

(ii) Diffuse solar radiation: This is the energy arriving from the sun after scattering or reflection by dust or water droplets and by gas molecules of the atmosphere. It comes from all directions and is also known as "sky radiation".

(iii) Global solar radiation: This is the sum of the direct and diffuse solar radiation fluxes incident on a horizontal surface facing upwards. It is sometimes called "total radiation".

2.2.3. Measurement of Solar Radiation

A pyranometer (also called a solarimeter) is used for measuring global radiation on a horizontal surface. An instrument used for measuring the direct component of solar radiation on a surface at right angles to the solar rays is called a pyrheliometer.

A pyranometer is usually a thermopile exposed under a glass hemisphere whereas in a pyrheliometer the thermopile is exposed at the end of a tube pointing at the sun.

Thermopile instruments contain a large number of thermocouple junctions in series. The 'hot' junctions are painted black and the 'cold' junctions are either painted white or attached to a heat sink. The temperature difference is translated into an electromotive force the magnitude of which is a measure of the intensity of the radiation falling on the black junctions.

Instruments with silicon solar cells are also in use.

Pyranometers are also used to measure diffuse radiation using a shading ring or disc (70). Various types of pyranometers are described in the literature (70-73).

A Gunn-Bellani radiometer does not give instantaneous radiation intensity but hourly or daily global insolation (71, 74).

2.2.4. Measurement of the Duration of Sunshine

The most common instrument for measuring the duration of sunshine is the Campbell-Stokes recorder (73, 74, 75). It consists of a glass sphere which focuses the solar rays on to a sensitized paper, thereby causing a burn to appear on the paper whenever the heat rays are powerful enough (75). The times during which burning occurs are taken as periods of "bright sunshine".

Other sunshine recorders exist. The main one, used in the USA, consist of mercury in a tube (73). The mercury expands in response to the heat from solar radiation and thus causes an electrical switch to close. Modified cameras which use photographic paper to record the sun's light rays also exist (73).

2.2.5. Estimation of Solar Radiation from the Duration of Sunshine.

It often happens that only records of the duration of sunshine are available. Empirical relationships have been used to estimate solar radiation from the duration of sunshine data (76-82). The relationship between solar radiation and the duration of sunshine is usually of the form proposed by Ångström (83):

$$Q = Q_m \ (a + b \ S/S_m) \ \ldots\ldots\ldots\ldots \ \text{Eqn 2.1}$$

where - Q is the daily total global solar radiation and S the corresponding duration of sunshine in hours.

- Q_m is the mean daily total global solar radiation in the absence of cloud obtained from the tabulated values calculated by Schüepp (84) for standard atmospheric conditions (2 cm of precipitable water, pressure 1000 mb, ozone content 0.34 cm NTP, and zero turbidity).

- S_m is the mean maximum daily duration of sunshine recordable; it is the time between sunrise and sunset minus 0.4 h, during which time the sun is too low to burn the recorder paper.

- a and b are dimensionless regression parameters.

A model using temperature, relative humidity and sunshine data has been developed (85, 86). It should be noted that the duration of sunshine can be estimated from the observed cloudiness values in the absence of data from a sunshine recorder (76, 79).

2.2.6. Available Solar Radiation in Kenya

To date, measurements of global radiation by Gunn-Bellani radiometers have been made at 58 stations in Kenya (87).Available radiation data has been used by Okoola (87) as well as Obasi and Rao (88) to prepare radiation maps for Kenya. They used regression equations relating global radiation to sunshine hours or cloudiness to generate radiation data where no records were available.

2.2.6.1. Distribution of Global Solar Radiation in Kenya.

While Okoola (87) presented solar radiation maps for January, April, July and October only, Obasi and Rao (88) presented maps for all the months of the year. Figure 2 shows all stations in which solar data is currently being recorded in Kenya. The author follows Okoola (87) in taking the months of January, April, July and October as representative of the main seasons of Kenya.

In January most of the country has radiation values greater than 21 MJ m^{-2} per day (see Figure 3).

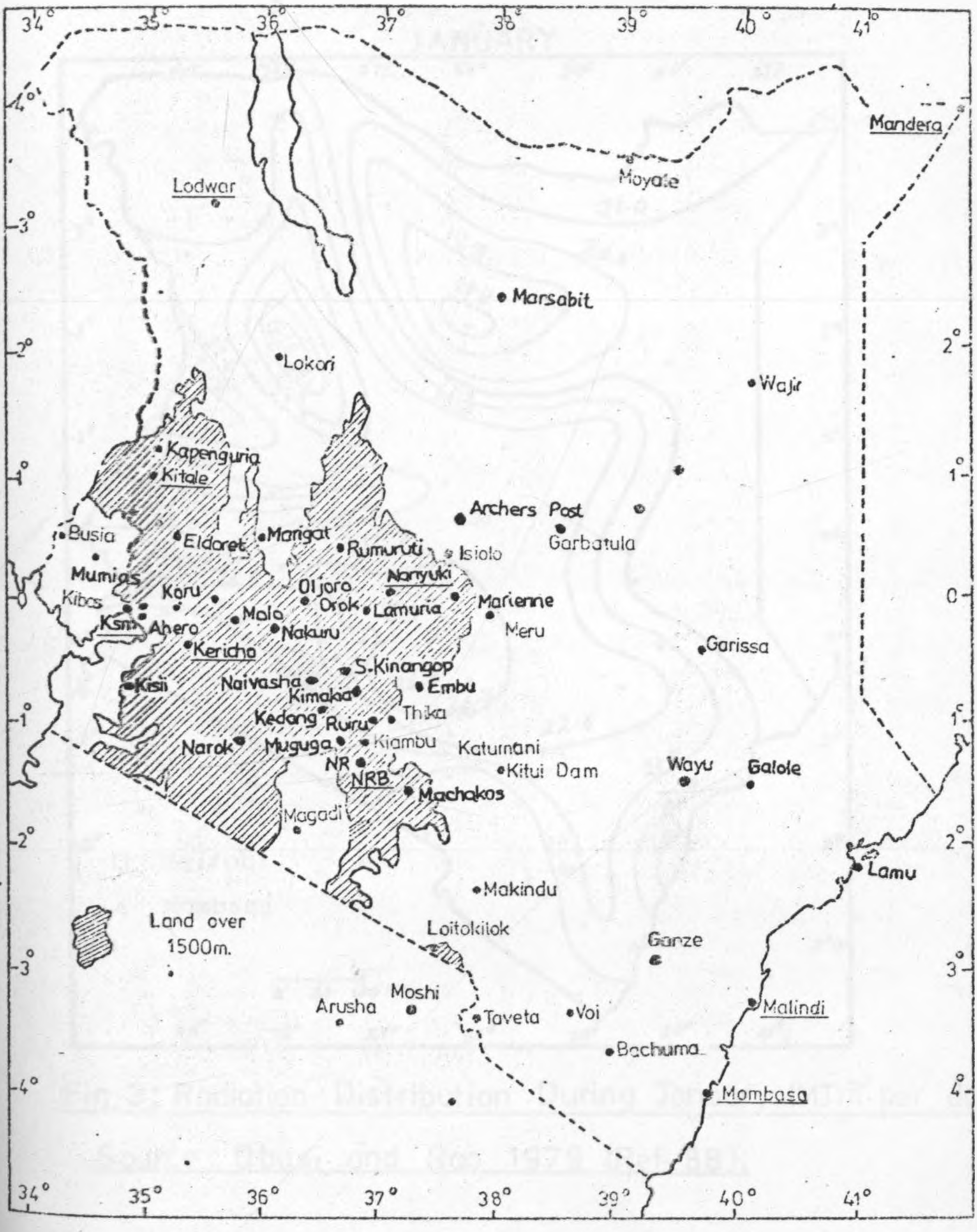
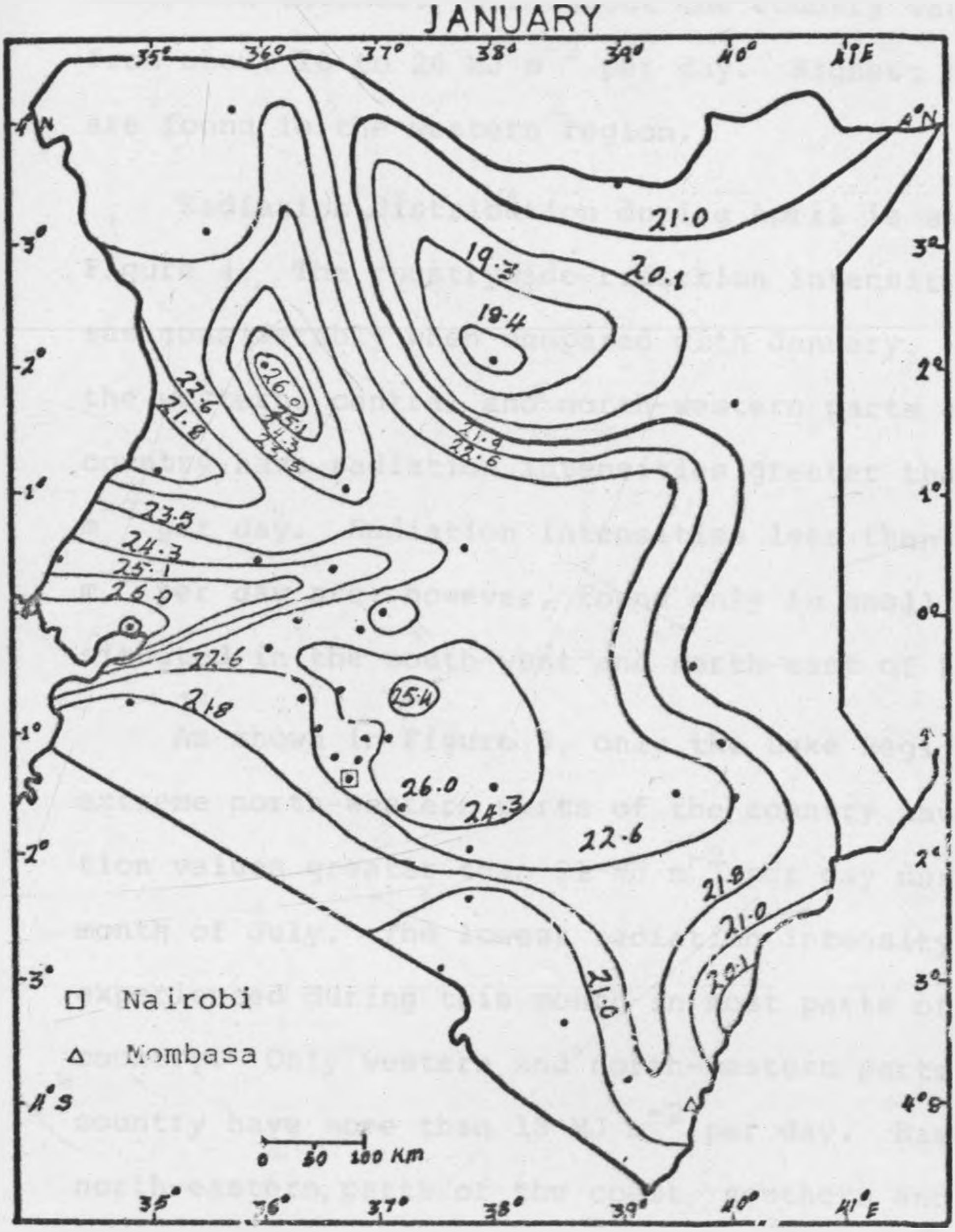


Fig. 2: Stations in which Solar Data is Currently Being Recorded in Kenya.
Source: Okoola 1982 (Ref. 87).



JANUARY

Fig. 3: Radiation Distribution During January (MJm^{-2} per day)

Source: Obasi and Rao 1979 (Ref 88).

Lower values are found in parts of the coast, south-west, northern and eastern regions. The mean solar radiation intensity throughout the country varies from about 18 to 26 MJ m^{-2} per day. Highest values are found in the western region.

Radiation distribution during April is shown in Figure 4. The countrywide radiation intensity decreases considerably when compared with January. Only the western, central and north-western parts of the country have radiation intensities greater than 21 MJ m^{-2} per day. Radiation intensities less than 18 MJ m^{-2} per day are, however, found only in small areas situated in the south-west and north-east of Kenya.

As shown in Figure 5, only the Lake Region and extreme north-western parts of the country have radiation values greater than 21 MJ m^{-2} per day during the month of July. The lowest radiation intensity is experienced during this month in most parts of the country. Only western and north-western parts of the country have more than 18 MJ m^{-2} per day. Eastern, north-eastern, parts of the coast, southern and south-western regions of the country experience less than 16 MJ m^{-2} per day.

In October, as shown in Figure 6, only the eastern, north-eastern and coastal parts of Kenya receive less than 21 MJ m^{-2} per day. The highest radiation intensities are received in the Lake Region (24 to 26 MJ m^{-2}

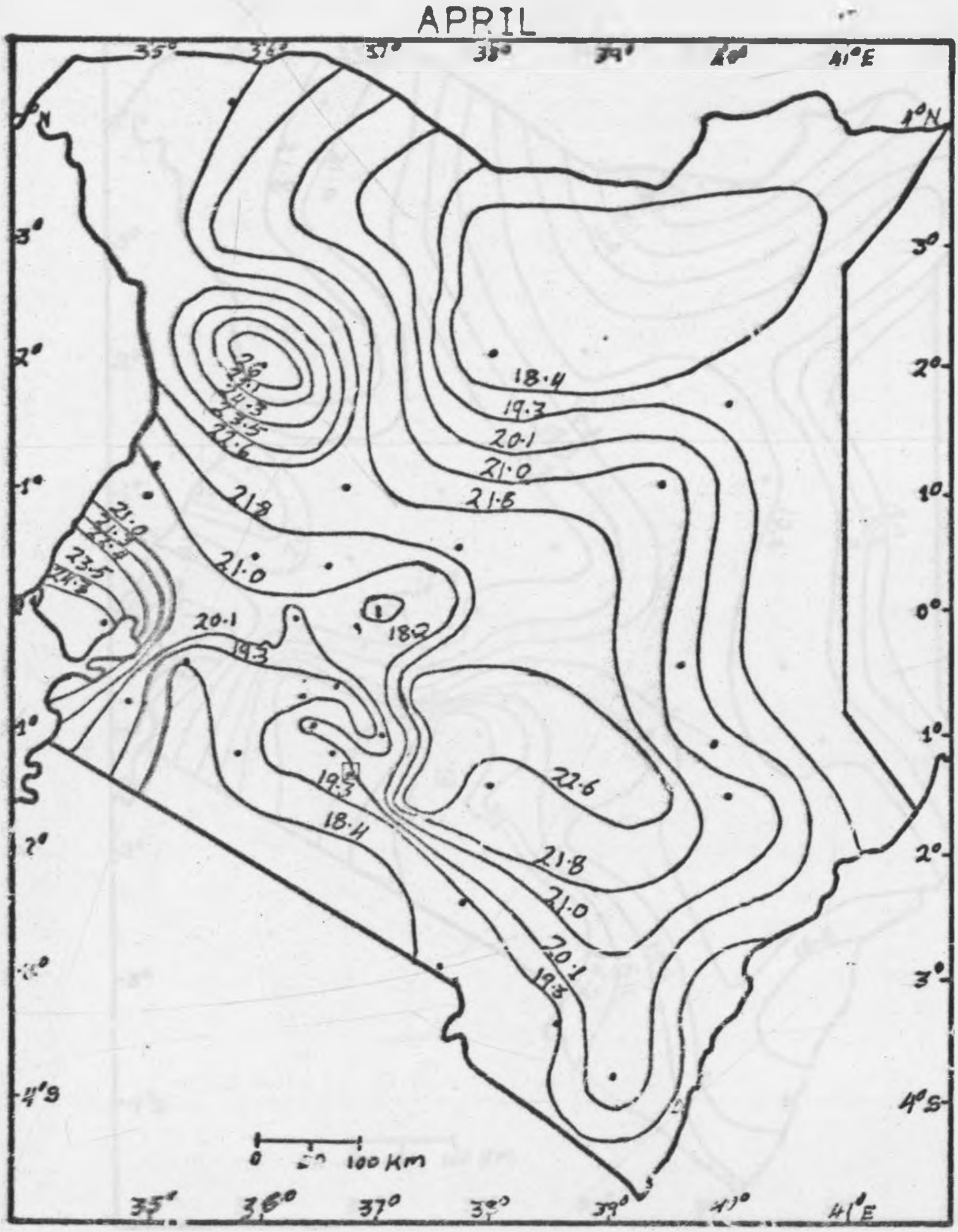


Fig.4. Radiation Distribution During April (MJ m^{-2} per day)

Source: Obasi and Rao 1979 (Ref 88).

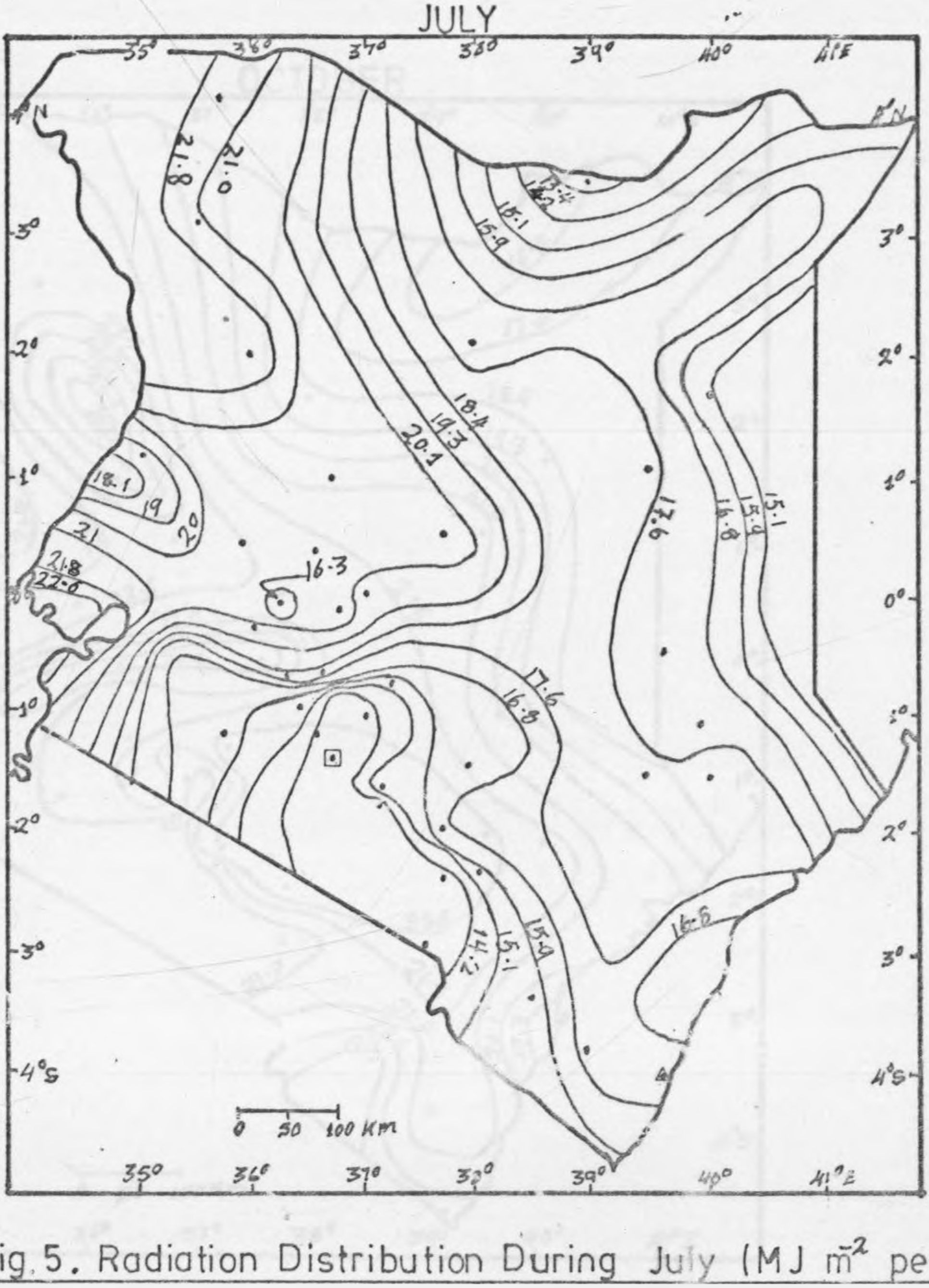


Fig. 5. Radiation Distribution During July (MJ m^{-2} per day)

Source. Obasi and Rao 1979 (Ref 88)

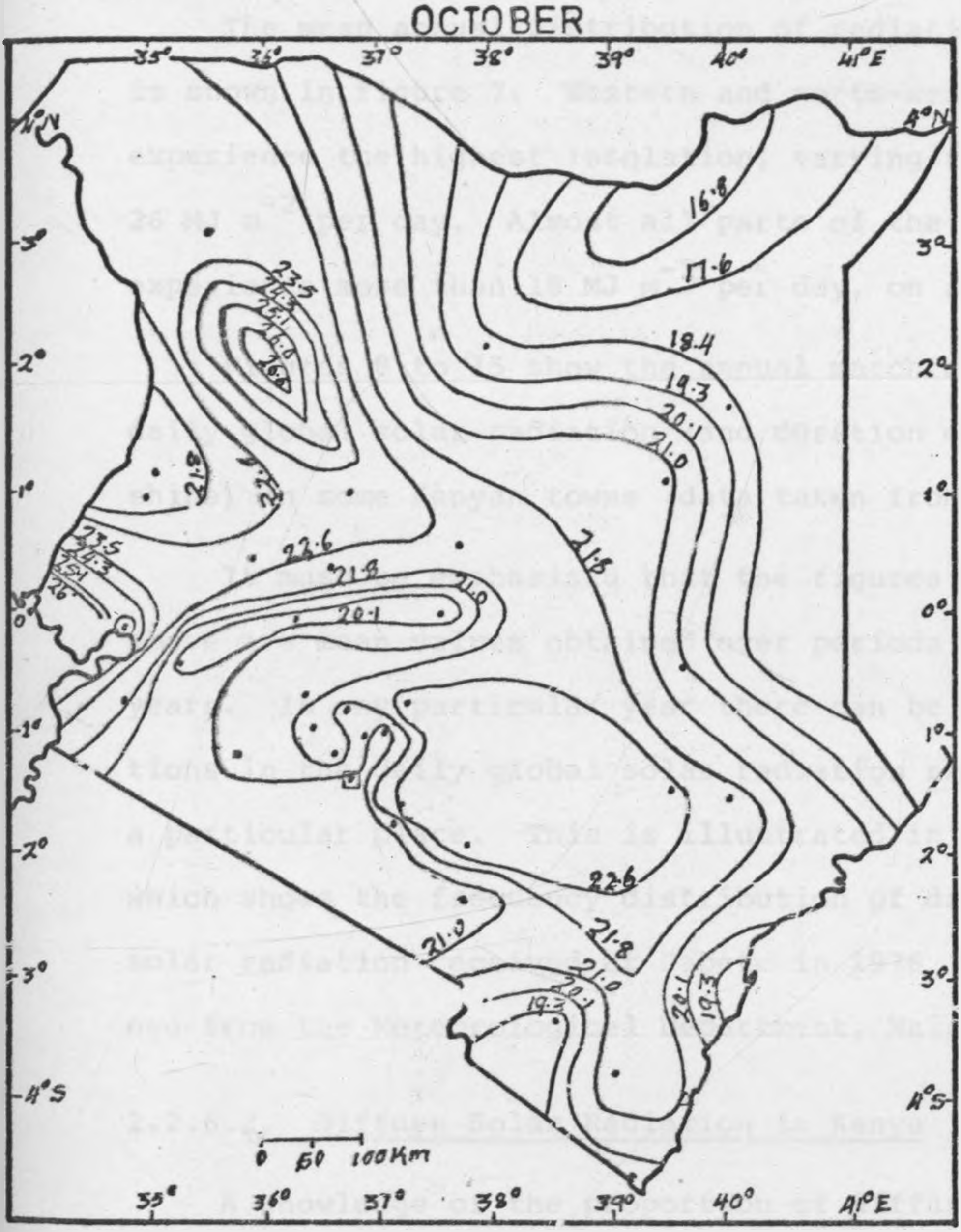


Fig. 6. Radiation Distribution During October (MJ m^{-2} per day)
Source: Obasi and Rao 1979 (Ref 88).

per day). There is hardly a place in Kenya receiving less than 16 MJ m^{-2} per day.

The mean annual distribution of radiation in Kenya is shown in Figure 7. Western and north-western Kenya experience the highest insolation, varying from 22 to 26 MJ m^{-2} per day. Almost all parts of the country experience more than 18 MJ m^{-2} per day, on average.

Figures 8 to 15 show the annual march of mean daily global solar radiation (and duration of sunshine) in some Kenyan towns (data taken from Ref. 290).

It must be emphasised that the figures mentioned above are mean values obtained over periods of several years. In any particular year there can be wide variations in the daily global solar radiation received at a particular place. This is illustrated in Figure 16 which shows the frequency distribution of daily global solar radiation received at Kabete in 1976 (data obtained from the Meteorological Department, Nairobi).

2.2.6.2. Diffuse Solar Radiation in Kenya

A knowledge of the proportion of diffuse radiation in the total radiation received at a particular place on earth is important in planning for systematic utilisation of solar energy as the diffuse radiation is largely unused by concentrating collector systems. To the author's knowledge, routine measurements of diffuse solar radiation are available only at the

ANNUAL

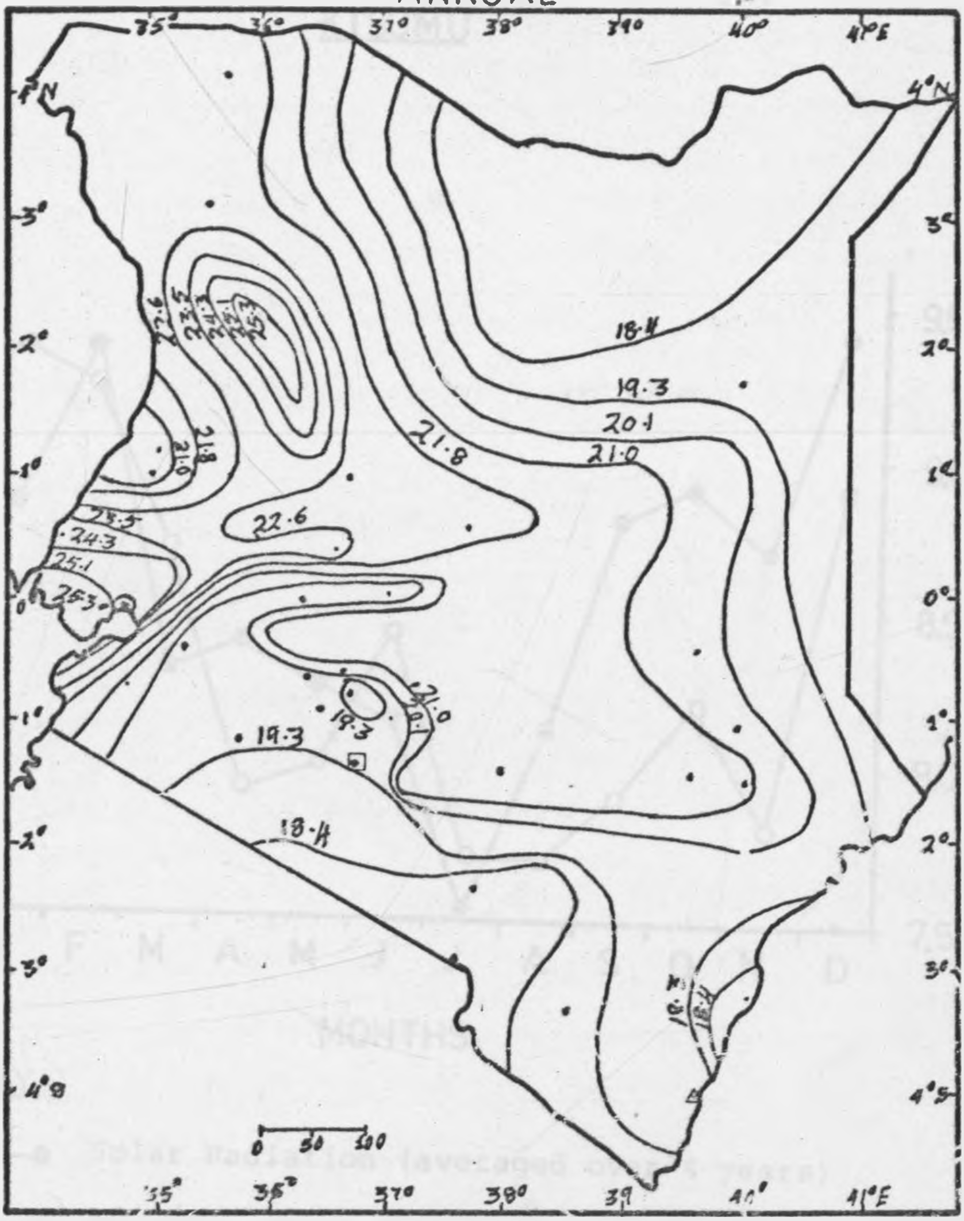
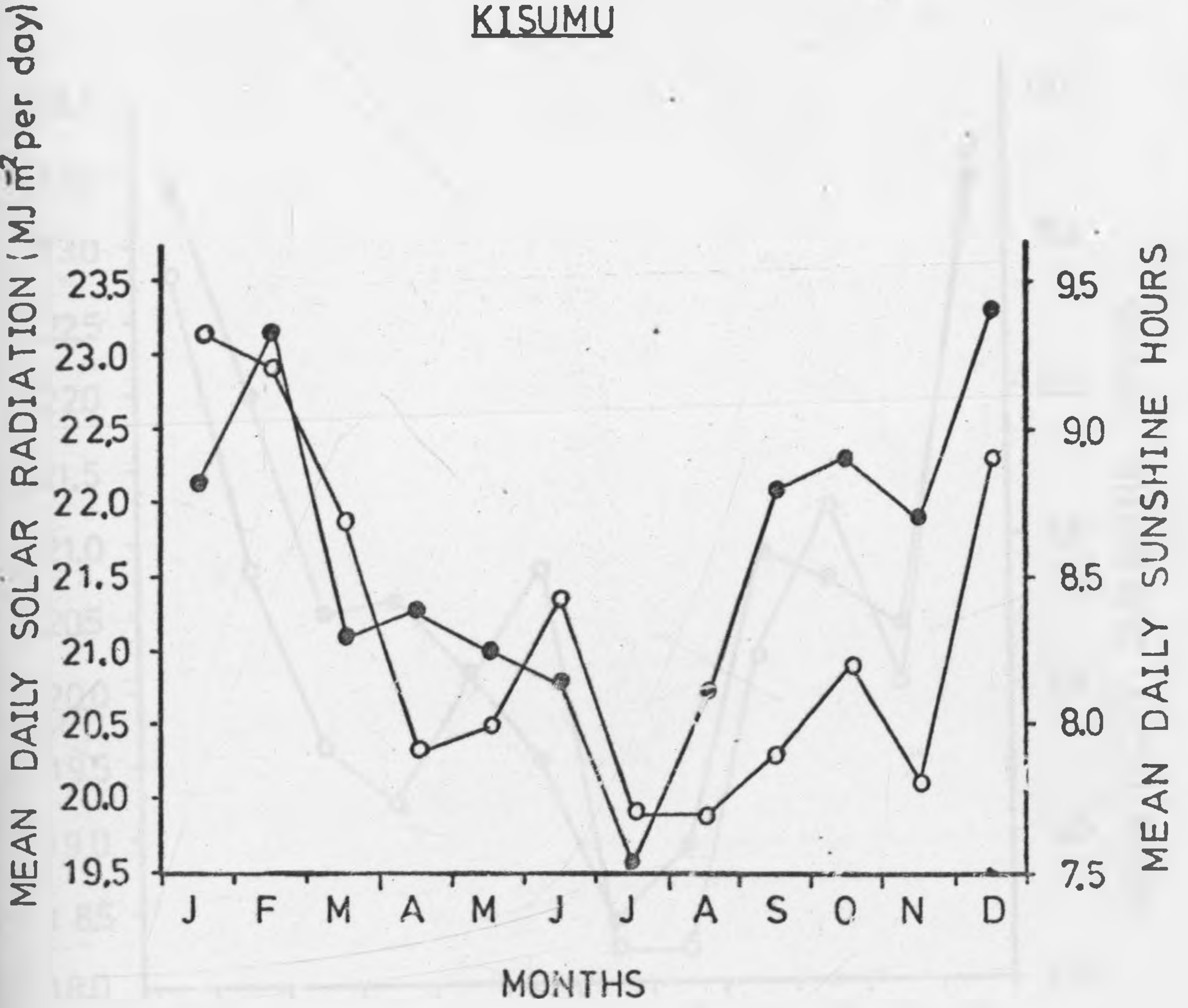


Fig.7. Annual Distribution of Radiation(MJ m^{-2} per day)

Source: Obasi and Rao 1979 (Ref 88).



KEY

●—● Solar Radiation (averaged over 4 years)

○—○ Sunshine Hours (averaged over 13 years)

Fig. 8. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Kisumu

KITALE

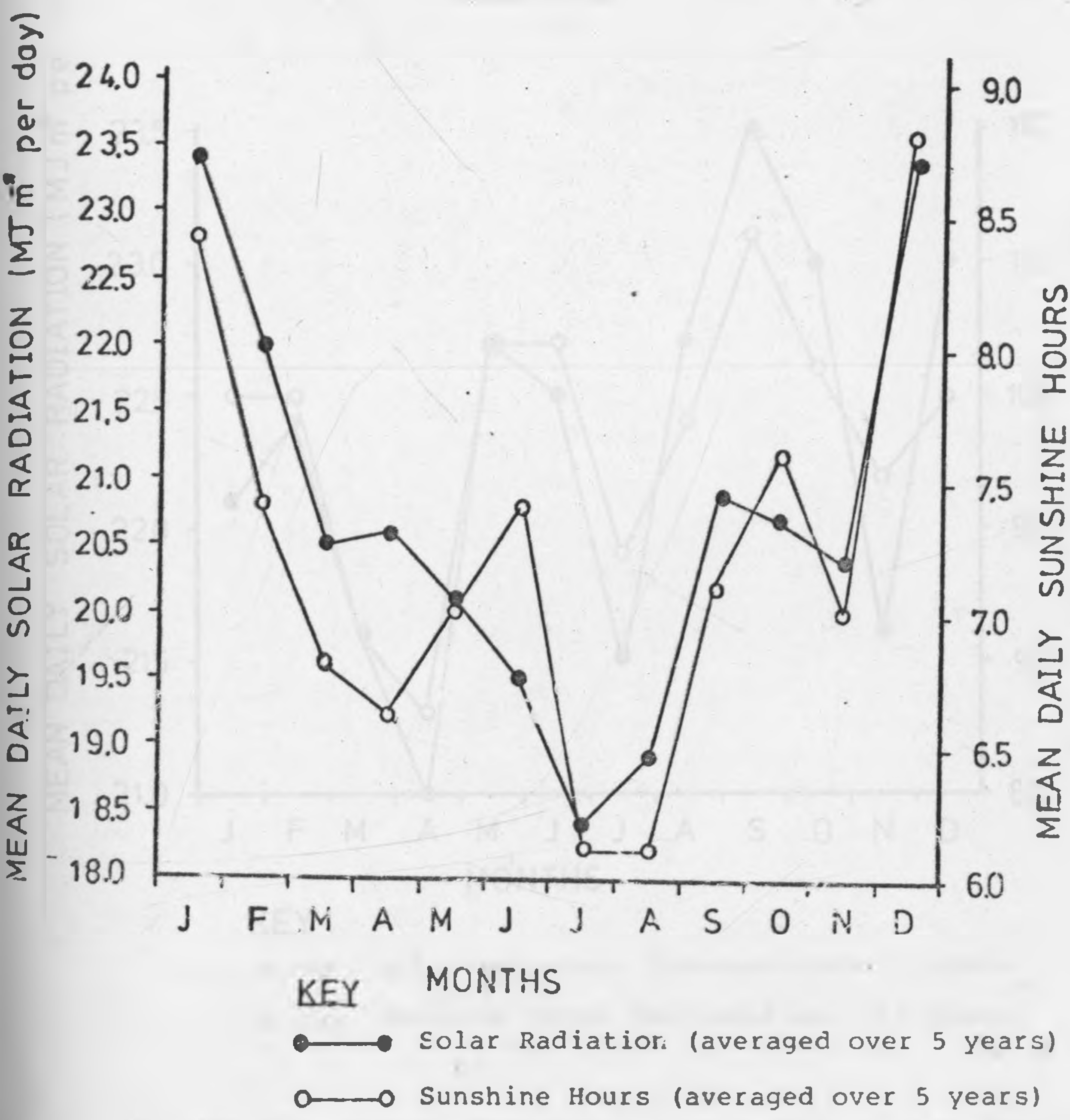


Fig. 9. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Kitale.

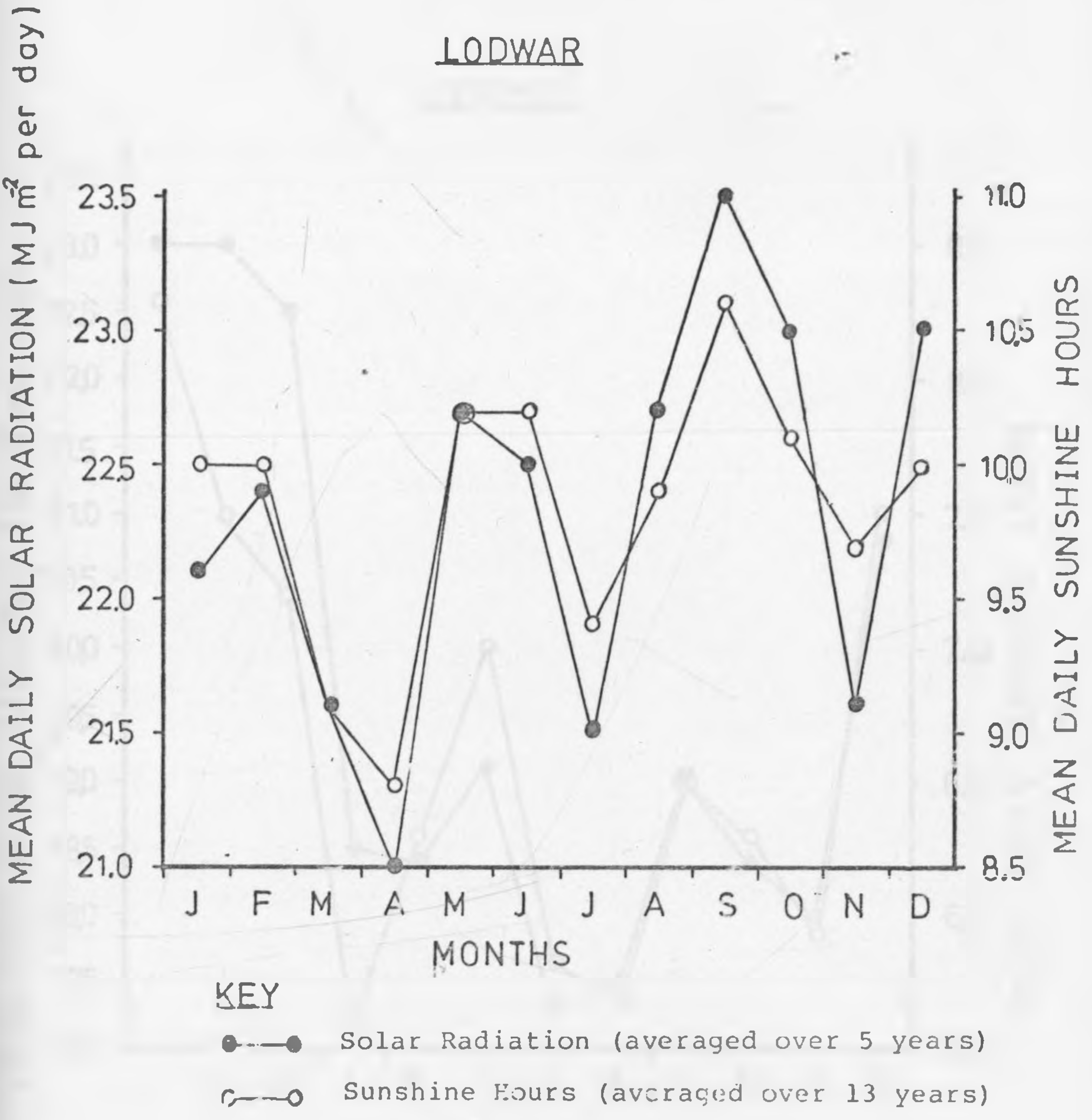


Fig.10: The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Lodwar

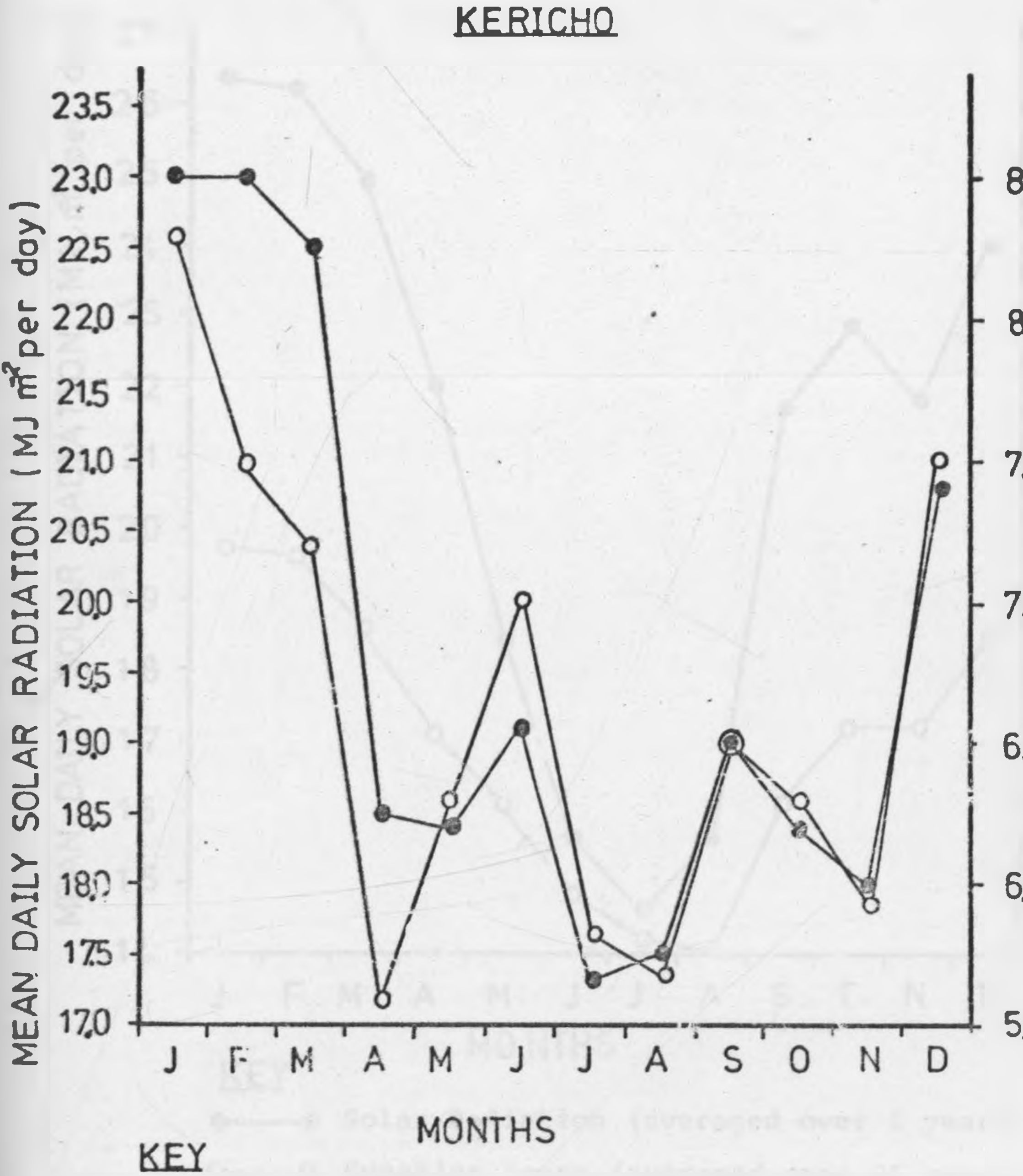


Fig. 11. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Kericho.

KABETE, NAIROBI.

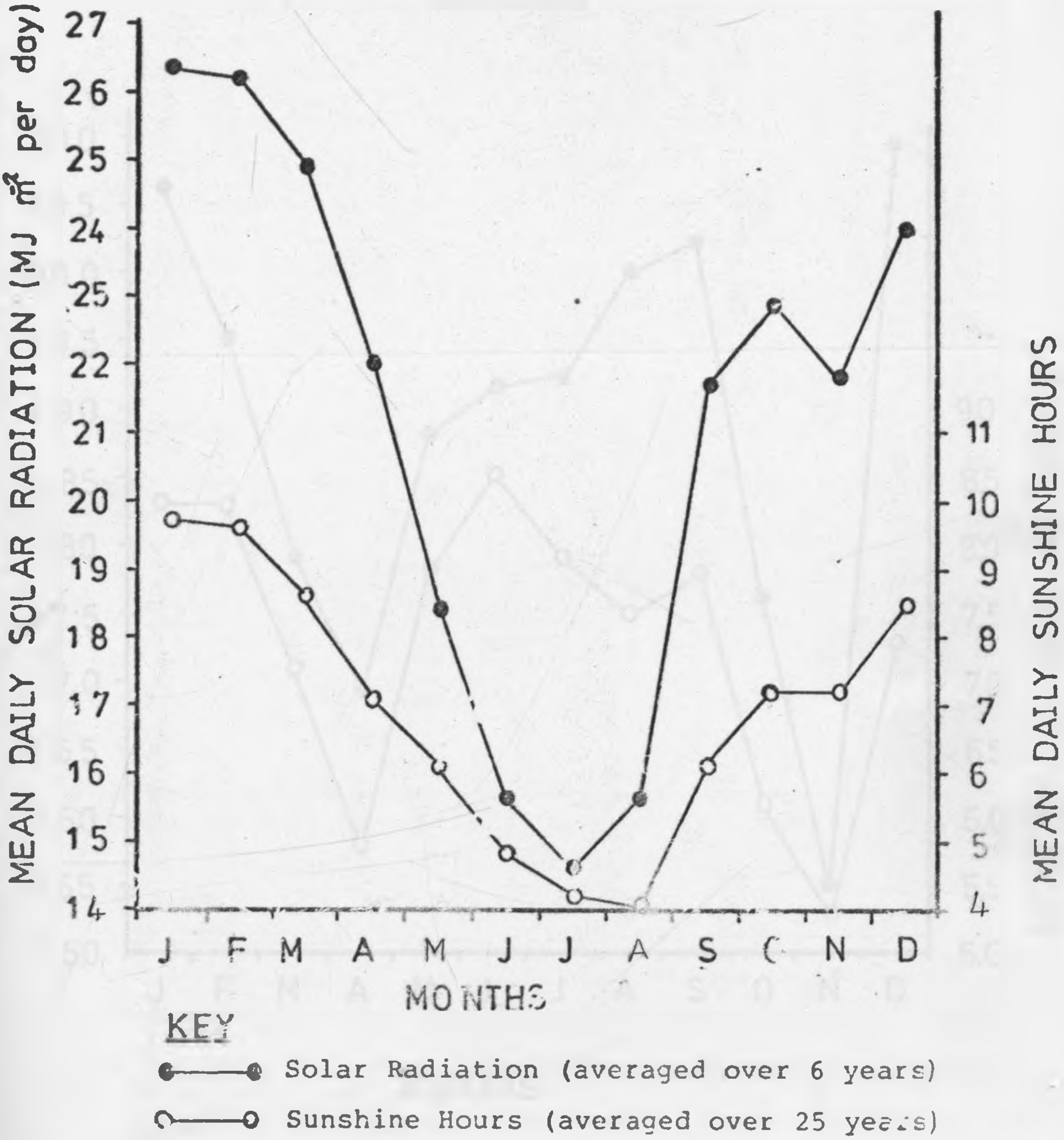
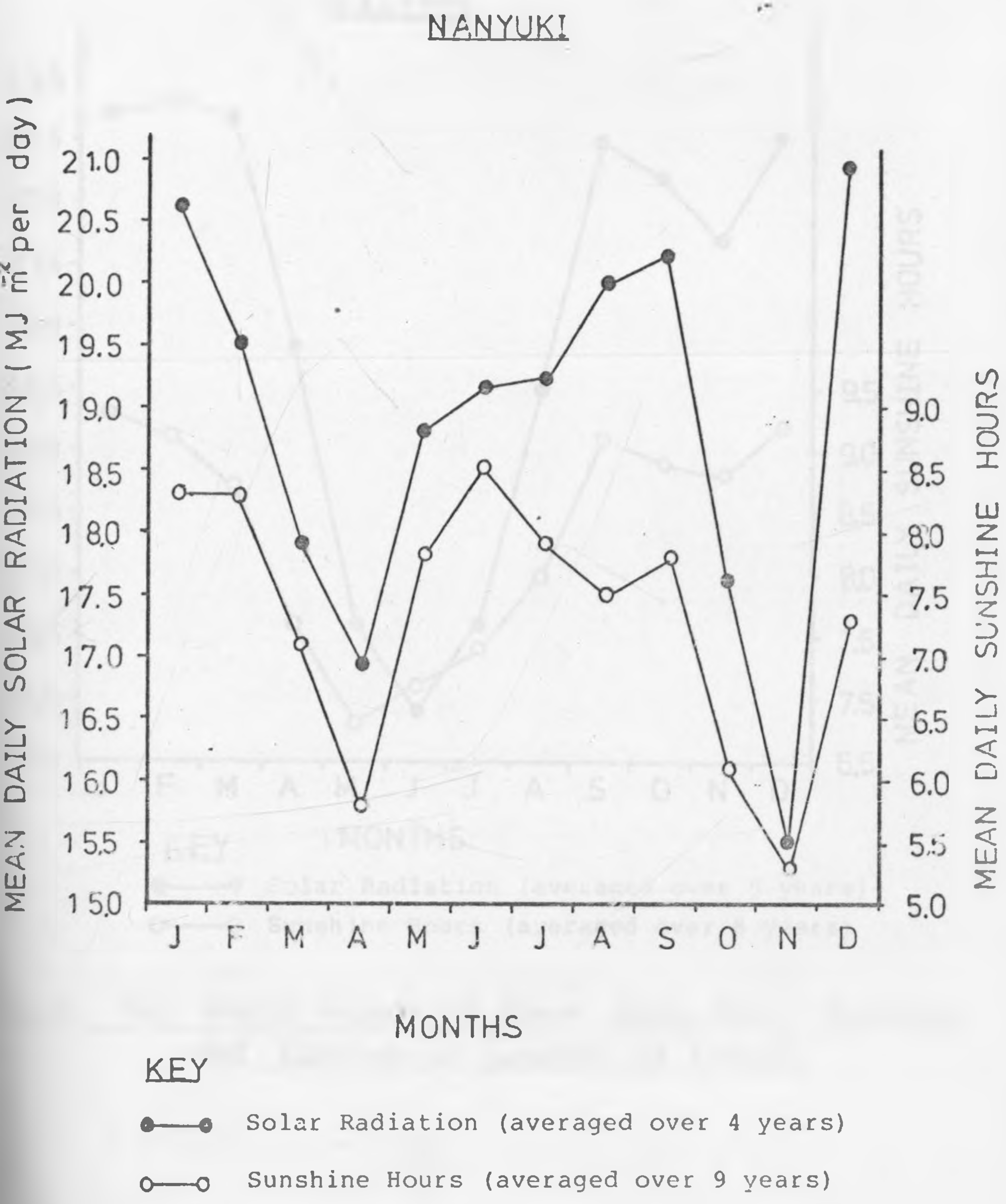


Fig.12. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Kabete. Nairobi.



NANYUKI

Fig. 13. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Nanyuki.

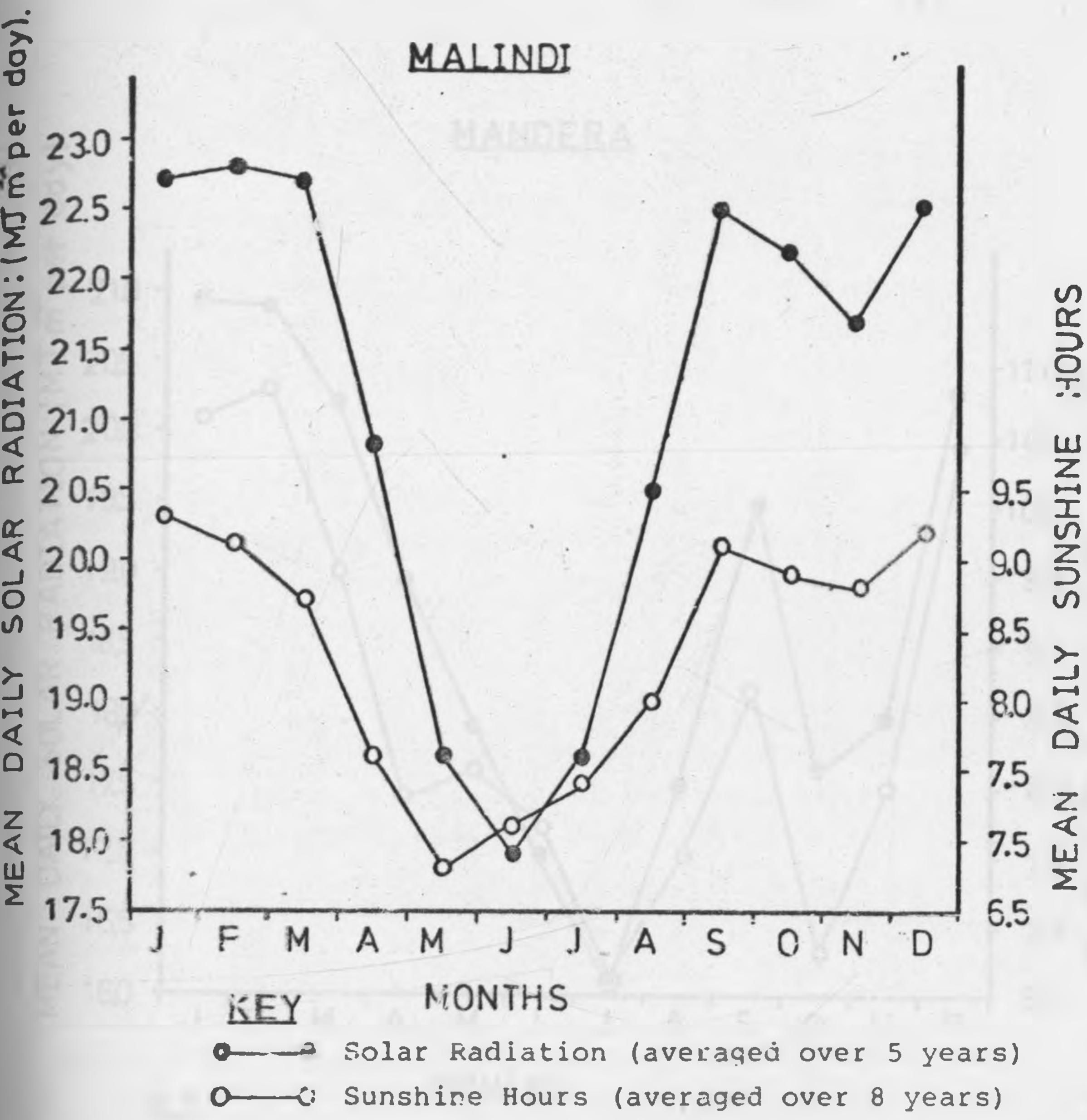


Fig.14. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Malindi.

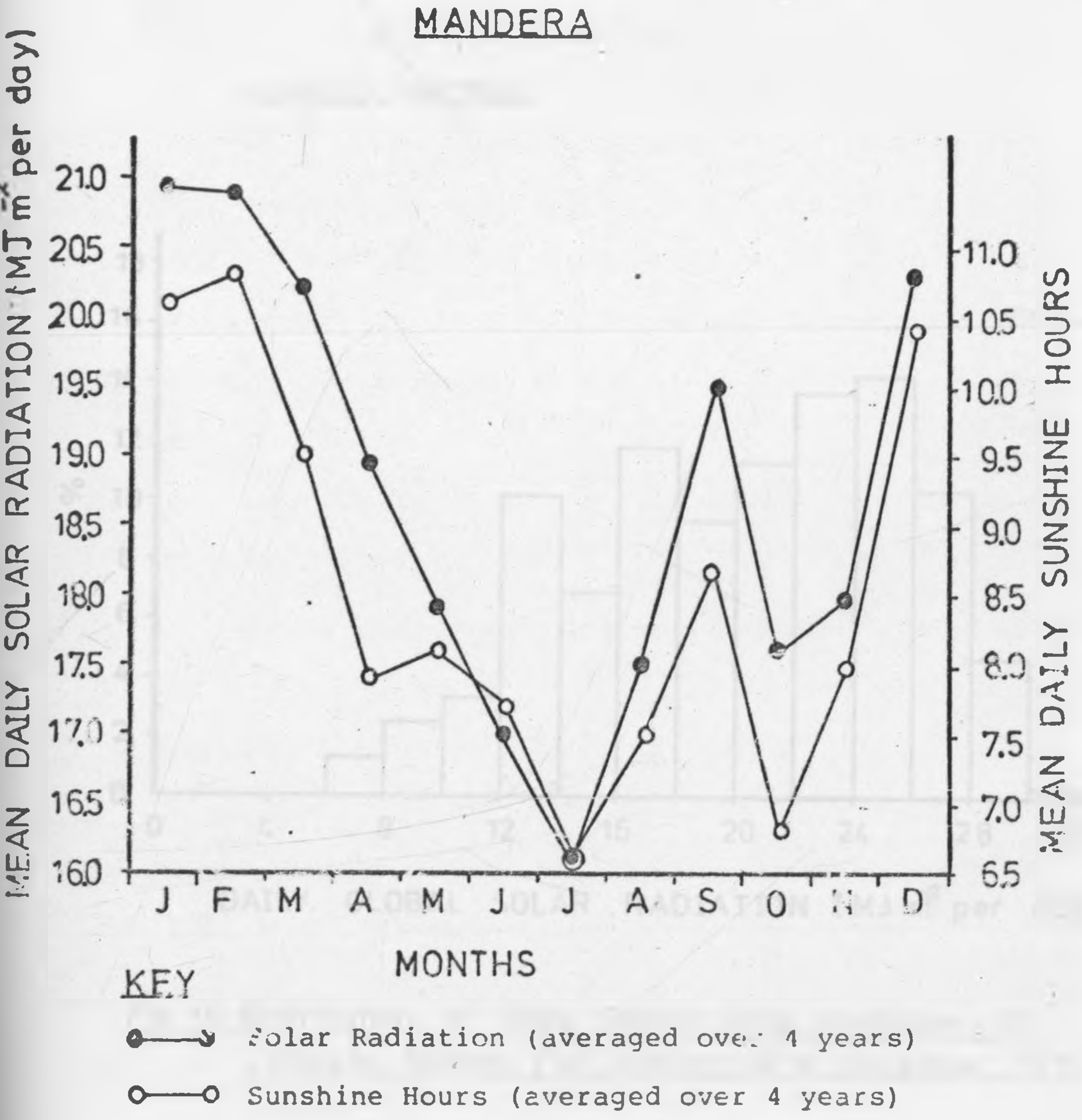


Fig. 15. The Annual March of Mean Daily Solar Radiation and Duration of Sunshine at Mandera.

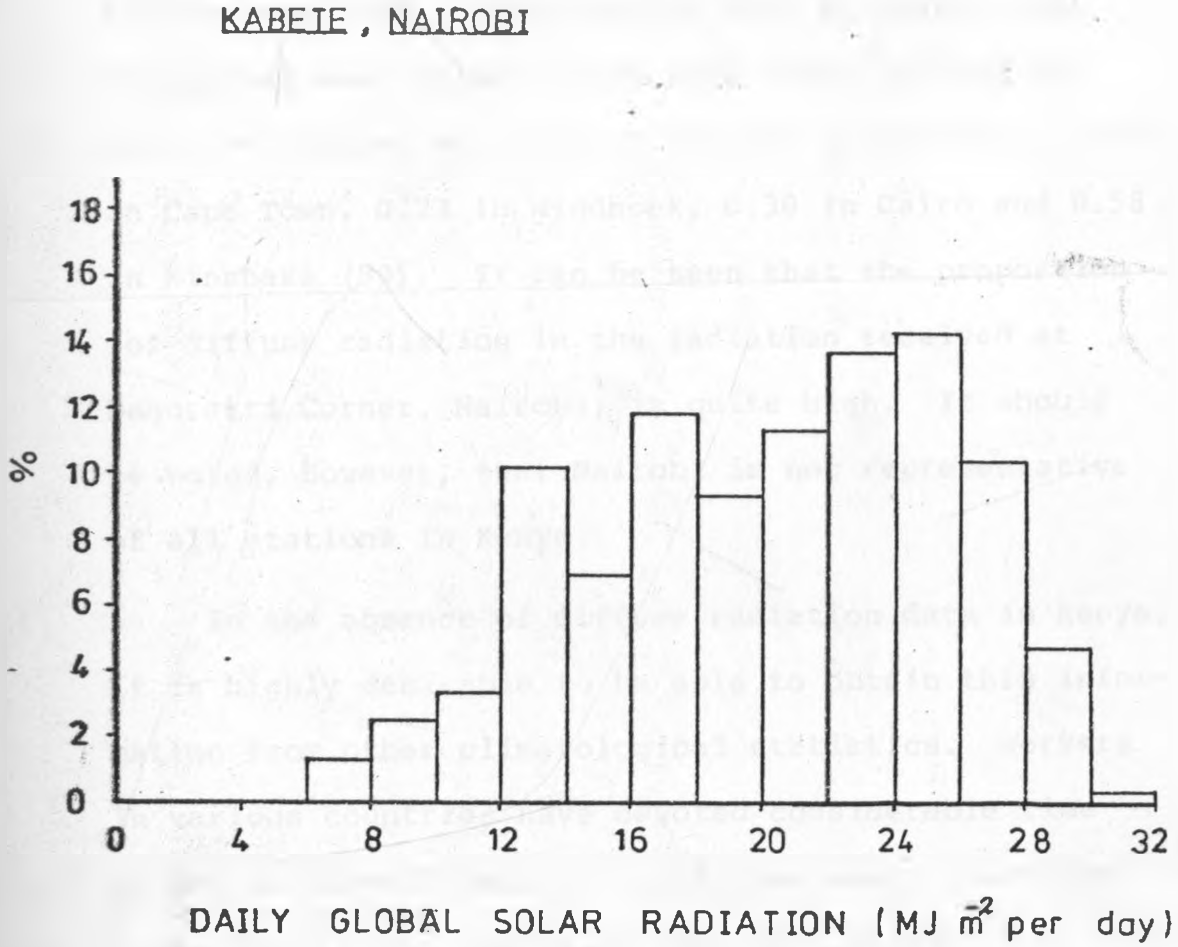


Fig. 16. Distribution of Daily Global Solar Radiation at Kabete, Nairobi (1st January—31 st December 1976)

Meteorological Department Headquarters, Dagoretti Corner, Nairobi. The mean value of the ratio of diffuse to global solar radiation at Dagoretti Corner varies from 0.23 in February to 0.72 in August (89). The annual mean value of the same ratio is 0.44 at Dagoretti Corner as compared to 0.31 in Bulawayo, 0.29 in Cape Town, 0.23 in Windhoek, 0.30 in Cairo and 0.58 in Kinshasa (89). It can be seen that the proportion of diffuse radiation in the radiation received at Dagoretti Corner, Nairobi, is quite high. It should be noted, however, that Nairobi is not representative of all stations in Kenya.

In the absence of diffuse radiation data in Kenya, it is highly desirable to be able to obtain this information from other climatological statistics. Workers in various countries have devoted considerable time to the problem of estimating diffuse solar radiation from global solar radiation data (80, 90-95).

2.2.6.3. Duration of Sunshine in Kenya

Figure 17 shows the mean number of sunshine hours per day over Kenya in January. Most parts of the country experience an average of over 8 hours of sunshine per day. The lowest values occur in a small area just to the south of Lake Victoria and average 6 to 7 hours of sunshine per day.

The mean number of sunshine hours per day over

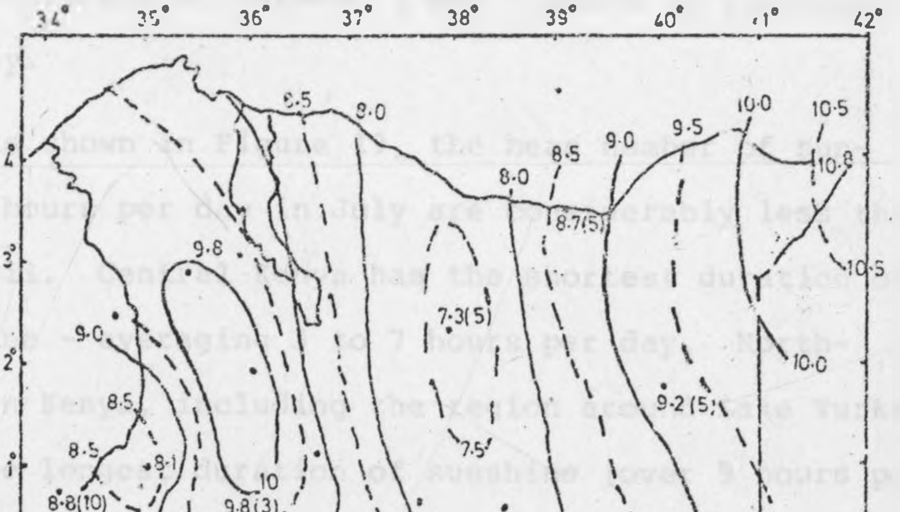


Fig. 17: Mean Number of Sunshine Hours per day over Kenya in January (averaged over ten years or as shown in brackets). Source: Okoola 1982 (Ref. 87).

Kenya for the month of April is shown in Figure 18. The lowest values are found in central Kenya and range from about 5 to 7 hours per day. Eastern, coast and north-western regions experience over 8 hours of sunshine per day, on average. The Lake Victoria region has an average of between 6 and 7 hours of sunshine per day.

As shown in Figure 19, the mean number of sunshine hours per day in July are considerably less than in April. Central Kenya has the shortest duration of sunshine - averaging 3 to 7 hours per day. North-western Kenya, including the region around Lake Turkana, has the longest duration of sunshine (over 9 hours per day). The average duration of sunshine in eastern and north-eastern parts of Kenya vary from 5 to 8 hours per day. Western Kenya has between 6 and 7 while the coastal region has between 7 and 8 hours of sunshine per day, on average.

Figure 20 shows that most parts of the country have on average over 8 hours of sunshine per day in October. There is hardly a place in the country experiencing less than 6 hours of sunshine per day.

Finally, Figure 21 shows the mean number of sunshine hours per day over Kenya for the whole year. Both eastern and north-western Kenya have annual mean durations of sunshine greater than 8 hours per day. The lowest values are found in central Kenya and vary from about 5.5 to 7.7 hours of sunshine per day.

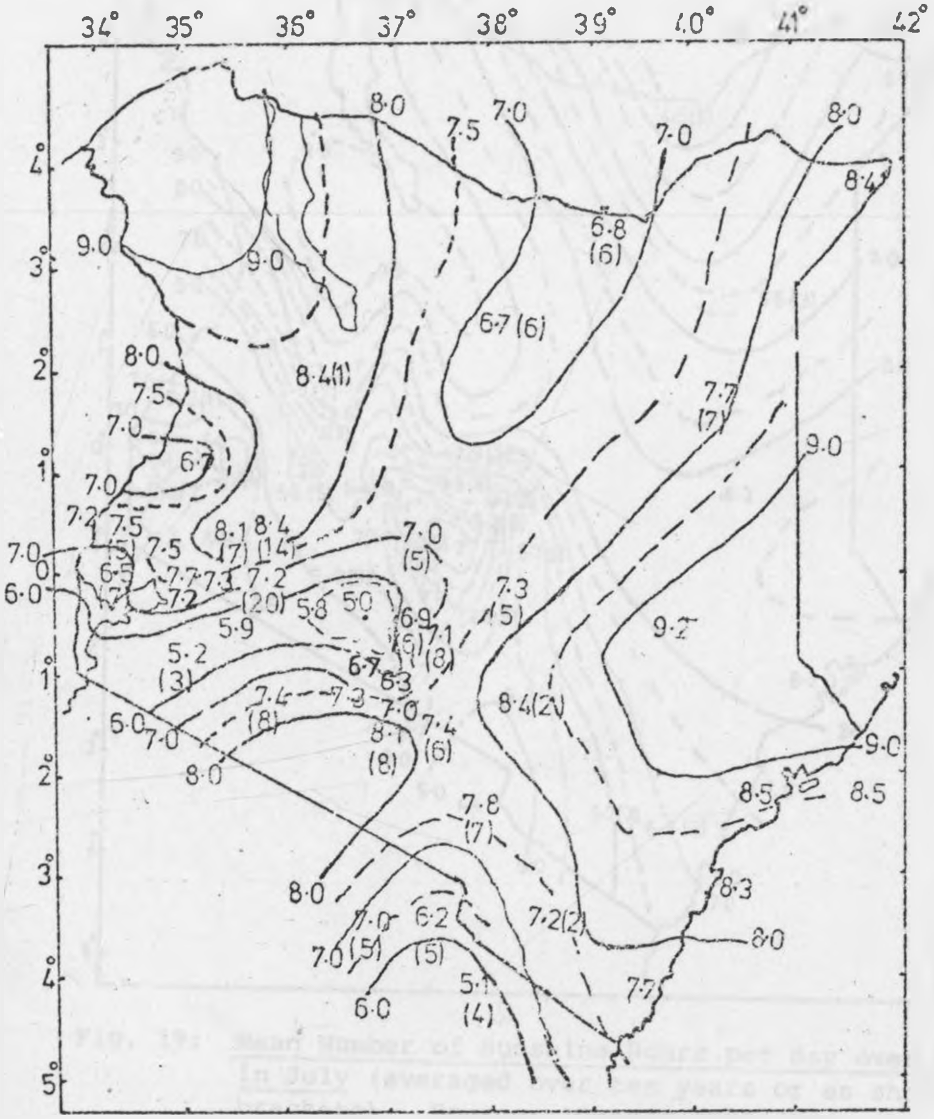


Fig. 18: Mean Number of Sunshine Hours per day over Kenya in April (averaged over ten years or as shown in brackets).
Source: Okoola 1982 (Ref. 87).

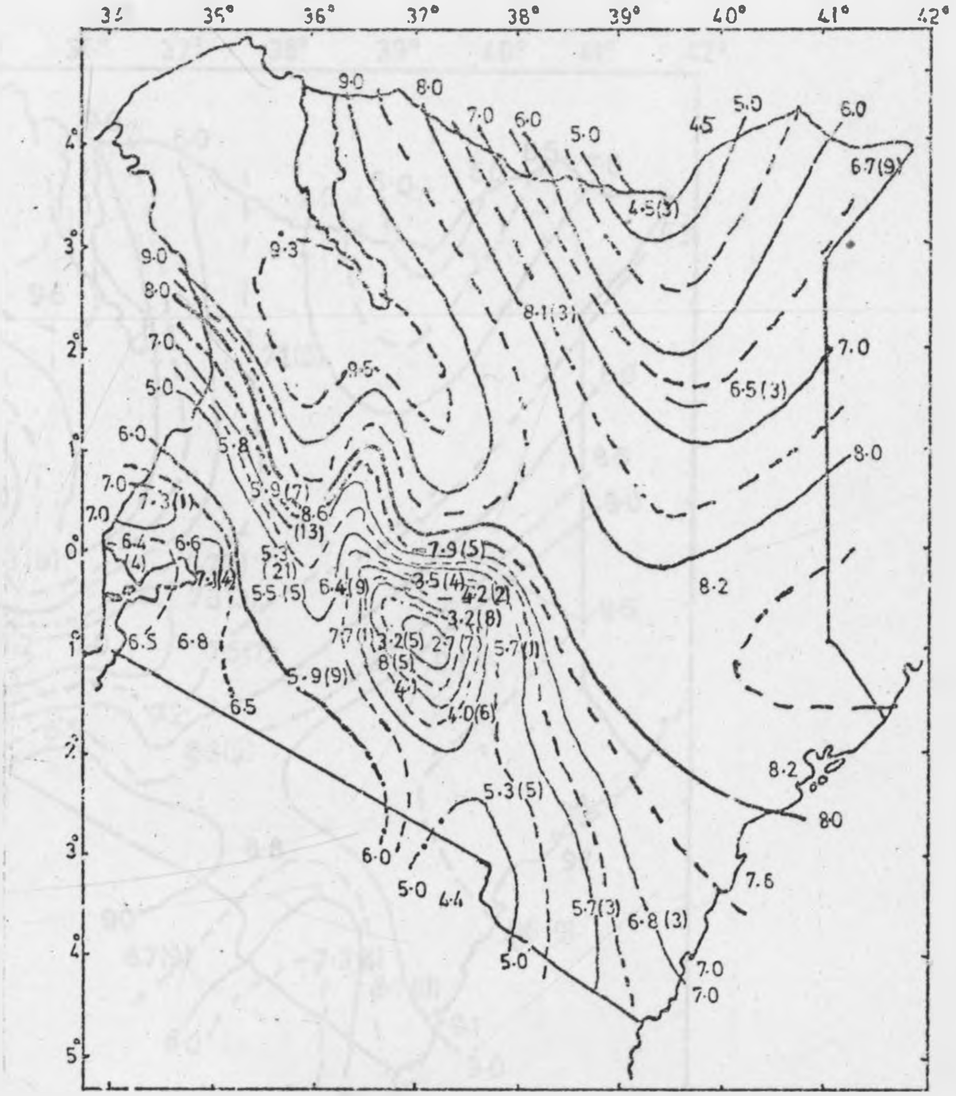


Fig. 19: Mean Number of Sunshine Hours per day over Kenya in July (averaged over ten years or as shown in brackets). Source: Okoola 1982 (Ref. 87).

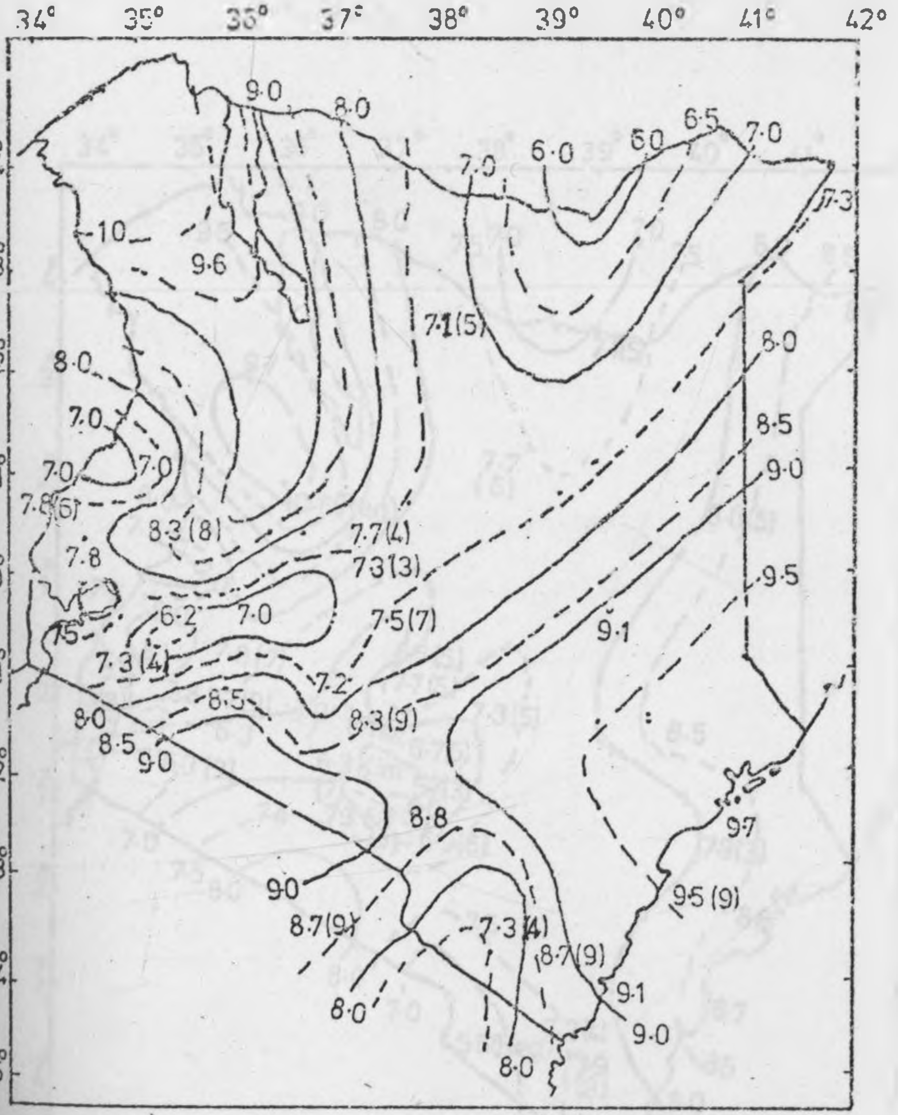


Fig. 20: Mean Number of Sunshine Hours per day over Kenya in October (averaged over 10 years or as shown in brackets). Source: Okoola 1982 (Ref. 87).

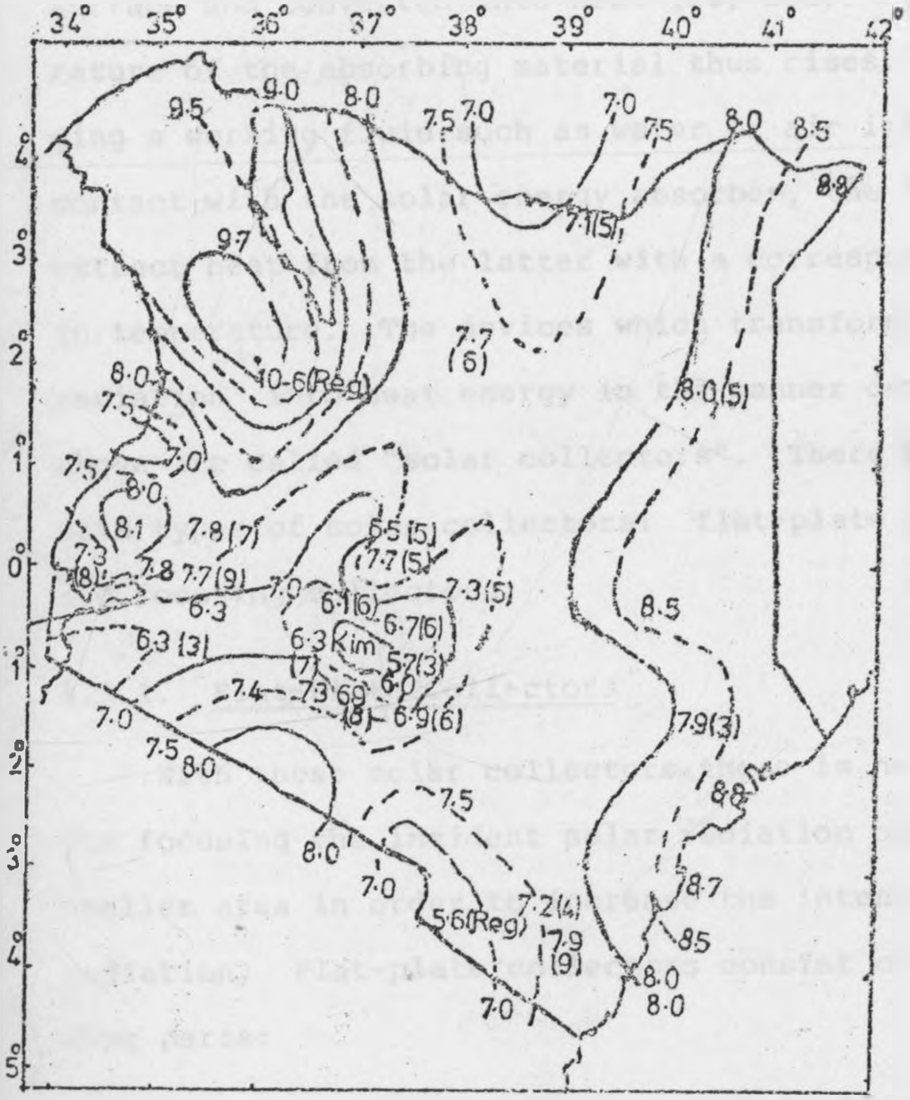


Fig. 21: Mean Number of Sunshine Hours per day over Kenya for the Whole Year (averaged over ten years or as shown in brackets). Source: Okoola 1982 (Ref. 87).

2.3. THERMAL CONVERSION OF SOLAR ENERGY

Solar energy can be transformed into heat energy to heat, for instance, air or water which can then be used in various ways (67, 96-101). Solar radiation is absorbed by a suitable material having a black surface and converted into heat (28, 102). The temperature of the absorbing material thus rises. By bringing a working fluid such as water or air into thermal contact with the solar energy absorber, the former extract heat from the latter with a corresponding rise in temperature. The devices which transform solar radiation into heat energy in the manner described above are called "solar collectors". There are two main types of solar collectors: flat-plate collectors and focusing collectors.

2.3.1. Flat-Plate Collectors

With these solar collectors there is no provision for focusing the incident solar radiation onto a smaller area in order to increase the intensity of the radiation. Flat-plate collectors consist of the following parts:

(i) An absorber, usually made of sheet metal (iron, copper or aluminium), with the exposed surface painted black to absorb the incoming radiation.

(ii) One or more transparent covers placed over the absorber to reduce the heat loss by convection and radiation (103).

(iii) A means of transferring the heat collected to the working fluid, that is, a heat exchanger to ensure thermal contact between the working fluid and the absorber.

(iv) Insulation in order to reduce heat losses from the sides and bottom surface of the absorber.

(v) A suitable casing.

Apart from the transmittance of the transparent cover, the performance of a flat-plate collector is influenced by the absorptivity: emissivity ratio (of the absorber surface) and the rate of heat loss from the absorber. Most of the heat loss is by conduction, convection and radiation through the front transparant cover. The following methods have been used to improve the efficiency of flat-plate collectors:

(i) the use of selective coatings such as black chrome, black copper oxide and black nickel on the absorber surface (104, 105);

(ii) the use of heat reflecting glass covers to reflect the emitted longwave radiation back to the absorber;

(iii) the insertion of honeycomb structures between the absorber plate and the transparent cover to suppress the convective heat loss (80, 106);

(iv) the complete removal of air (by evacuation) to eliminate free convective and conductive heat losses (105, 106).

For low temperature applications (say, no more than 80°C), flat-plate collectors have some advantages over concentrating collectors:

(i) No complicated mechanisms for tracking the apparent diurnal motion of the sun are required.

(ii) They are simple in construction.

(iii) They are relatively cheap.

(iv) They utilise both diffuse and direct solar radiation. Concentrating collectors (also called focusing collectors) utilise only direct solar radiation.

2.3.2. Focusing Collectors

In these collectors, the parallel rays of the sun are focused onto a smaller area in order to increase the intensity of the radiation. A black absorber in thermal contact with the working fluid is placed at the focus. The heat generated by the focused radiation is thus transferred to the working fluid.

The focusing may be accomplished by single or multiple reflective (mirror-like) or refractive (lens) elements (107-111). A mechanism for tracking the sun is usually required.

Concentrating collectors offer an attractive means of providing thermal energy at temperatures above 100^{o}C, with the following advantages (108):

(i) The smaller absorber size reduces thermal losses when compared with a flat-plate collector of equivalent aperture. This improves the efficiency of solar energy utilisation at a given collection and heat delivery temperature.

(ii) Weight can be reduced by replacing a large flat-plate absorber with a light reflective or refractive element and a smaller absorber.

(iii) The energy delivery temperature can be raised and closely matched to a system's needs for process heat.

2.3.3. Thermal Storage of Solar Energy

One of the major problems to be overcome in utilising solar energy in continuous processes is its intermittent nature. It is not available in sufficient quantity during cloudy spells and at night. Some degree of storage is therefore required in any application of solar energy. In thermal applications of solar energy the problem becomes that of heat storage. The simplest way to store thermal energy is as sensible heat, heating a suitable material to a higher temperature. Usually water or rocks are used as storage media (28, 112, 113). The disadvantage of sensible heat stores is that they tend to be large and heavy and containment costs can be high (28). The alternative system, latent heat storage, makes use of the fact that certain substances undergoing a phase change absorb large amounts of heat energy which they release when the reverse phase change occurs. Dean (112) observed that salt hydrates are ideal materials for latent heat storage. Telkes (114) designed a solar house in the late 1940's for which Glauber's salt ($Na_2SO_4.10H_2O$) was used for thermal storage. These systems are, however, not yet as well developed as sensible heat storage systems.

2.4. UTILISATION OF SOLAR ENERGY IN FOOD PROCESSING INDUSTRY

2.4.1. Introduction

It has been shown in Section 2.1 that Kenya has a diversified food processing industry. The food preservation methods used in the Kenyan food processing industry include pasteurisation, sterilisation, evaporation, drying, chilling and freezing. Other processing operations include blanching (of food products) as well as cleaning and rinsing of processing equipment. All the processing operations mentioned above have one thing in common: they require energy input in the form of heat (if absorption-type refrigerators are used for chilling and freezing).

It is shown here that there is a need to provide at least part of this energy input using suitable solar energy systems. Both the technical and economic feasibility of utilising solar energy for heating in the food processing industry are investigated. The applications considered include drying, the provision of industrial process heat (for processes other than drying) and refrigeration.

2.4.2. DRYING

2.4.2.1. The Need for Solar Drying

The sun has been used to dry food products such as cereals, pulses, meat, fish, fruits and vegetables from time immemorial. The food products are simply spread on the ground or on platforms and turned regularly until drying is complete. The process is labour intensive and requires little capital. This form of drying, however, presents several problems (115):

(i) The drying period is long and depends on the climatic conditions.

(ii) The quality of the dried product is dependent on the climatic and environmental conditions, for example:

  (a) drying is adversely affected by rain and storm;

  (b) pollution and dust adversely affect the quality of the dried product.

(iii) It is difficult to maintain a dried product of standard quality.

(iv) The product being dried is open to infestation by insects and intrusion by animals.

It is for these reasons that artificial drying is increasingly being used in the food industry. A common procedure is to pass heated air through the food material being dried. The air is heated using conventional energy resources such as wood and fossil fuels.

The high and ever increasing costs of fossil fuels and other conventional primary energy resources, and their inevitable scarcity, have prompted the use of artificial driers utilising solar energy as the energy source (115).

2.4.2.2. Solar Air Heaters

These are solar collectors through which air passes.Two basic categories of solar air heating collectors are discernible. The first category have non-porous absorbers whereas the second category have porous absorbers through which the air passes. A general description of solar collectors has been given in Section 2.3. Nydegger (116) has described a tubular black polythene collector for air heating. Selcuk (117) has discussed the performance of various air heating collectors.

2.4.2.3. Solar Driers

There are two types of solar driers in use. In one system the material being dried is in direct contact with the incident solar radiation. The second system, on the other hand, has the material being dried under shade with solar heated air passing through it. Movement of air through the material being dried is essential as the evaporated water has to be carried away by air. The air movement is achieved by wind ventilation, natural convection or forced ventilation by means of fans. Various types of solar driers have been described in the literature (115, 118, 119).

2.4.2.4. The Potential for Solar Drying in Kenya

2.4.2.4.1. Introduction

The possibility of utilising solar energy for the dehydration of some food products in Kenya is examined. The drying air temperatures suitable for various food products are examined with a view to showing that these temperatures could be attained using simple solar devices mentioned above.

Some crops are harvested at certain times of the year only. The harvesting dates sometimes vary from one region to another. The harvesting dates of some crops are presented here with a view to ascertaining whether the harvesting dates coincide with periods of adequate insolation for solar drying. The harvesting dates are obtained from a publication of the Government of Kenya (120).

2.4.2.4.2. Coffee

In Kenya, coffee-beans are either sun-dried (121-124) or mechanically dried (125-129). Mechanical drying involves passing heated air through the coffee-beans. Fuel oil, diesel or electricity are used as the main supply of the requisite energy (127).

Karigi and Kihara (130) reported that coffee-beans can withstand a maximum air temperature of about 40°C without quality impairment. They, however, noted that in some cases an initial maximum temperature of 60°C can be used for 2 hours and the drying subsequently continued at a temperature of 40°C.

Mitchell (131) reported that air temperatures of 50 to 60°C are used in some estates in Brazil.

An approximate guide is given by Sivetz and Desrosier (128). They indicate that coffee-beans can tolerate a temperature of 40°C for a day or two, 50°C for a few hours, and 60°C for less than an hour without damage.

The main coffee growing areas are in Central and Eastern Provinces. Coffee harvesting seasons in Central Province fall mainly around June and November/December. In Eastern Province the harvesting is mainly in the months of May to August and November to December. Meru and Embu Districts have harvesting times during the period January to March.

*There is plenty of sunshine in the coffee growing regions between November and March. This is the period of maximum insolation. On the other hand, the period May to August is not so well endowed with solar radiation, especially in Central Province. In designing a solar coffee drier, one has therefore to note that an auxiliary heater utilising conventional energy resources has to be used during periods of insuffient insolation. The potential for the utilisation of solar energy for coffee drying in Kenya is, however, certainly there.

2.4.2.4.3. Tea

Tea processing involves withering, rolling, roll-breaking, fermentation and firing (drying) (132-134). Fermented tea contains 58-60% moisture on a wet basis and has to be dried to 3-4% moisture content (on a wet basis) (135). Drying is achieved by passing hot air through the fermented tea. Eden (132) notes that inlet air temperatures usually range from 82 to 94°C although Karigi and Kihara (130), in their survey of tea drying in Kenya, found that inlet air temperatures ranging from 104 to 110°C are often used. The energy used in drying is obtained via oil, coal or wood (130).

The main tea growing area is Kericho, followed by Nandi Hills and then Limuru (136). Tea leaf picking is carried out throughout the year.

One sees a potential for solar-assisted drying. Looking at Kericho, for instance, the period December to March is particularly well suited to solar drying. Mean daily solar radiation received varies from about 21 to 23 MJ m^{-2} per day and duration of sunshine varies from 7.5 to 8.3 hours per day, on average. Solar energy would still make a significant contribution to the total energy required for drying during the remaining months as the duration of sunshine averages 5.6 to 7 hours per day. It has been estimated that up to 75% of the annual energy required for tea drying and withering in Kenya could be provided by solar energy (137).

2.4.2.4.4. Fish

In view of the inadequacy of refrigeration facilities in Kenya, drying is the most common method of fish preservation (144). It has been reported that bacterial action stops when the water content of fish falls below 25% on a wet weight basis and that mould growth ceases when the water content falls below 15% on a wet weight basis (138).

The commonly used methods of fish drying in Kenya are: (a) combined drying and smoking over fire; (b) sun-drying and (c) frying in oil. Apart from sun-drying, these methods require a reliable supply of fuel. They are also very labour intensive. Smoking and frying are therefore not suitable for large-scale operations. Sun-drying is, thus, the simplest and most economical method of fish preservation. Usually, split or unsplit fish are placed on the sand or rocks and turned regularly until they dry. This form of drying, however, has all the disadvantages mentioned in Section 2.4.2.1. In particular, insect infestation has been identified as a serious problem (139, 140).

Clearly, controlled drying is necessary if losses are to be minimised. Tunnel driers have been found suitable for fish drying (138, 141, 142). A fan and an air heater are required. Hot water or steam are the most typical heating media, but electric and infrared heating have also been used (138). Waterman (138) has given the following drying conditions: (a) an air velocity of 1 to 2 m s^{-1}; (b) an air temperature of 27 to 43°C and (c) a relative humidity of 45 to 55%. Balachandran (143) established the optimum drying conditions for some Indian fish as follows: (a) an air temperature of 45 to 50°C; (b) a relative humidity of 55 to 65% and (c) an air velocity of 1.67 to 2.0 m s^{-1}.

To the author's knowledge, tunnel driers are not currently used for fish drying in Kenya. Their adoption would greatly benefit the fish industry as the problems of poor quality and losses would be minimised. The energy cost need not be a hindrance as the temperatures mentioned above are easily attainable with simple solar air heaters.

The use of other types of solar driers as an alternative to traditional sun-drying has been investigated by various workers and found promising (145-148).

The bulk of the fish in Kenya is obtained from Lake Victoria, Lake Turkana and the Indian Ocean along the Kenya Coast (144, 149). These fishing areas happen to be the regions with the highest insolation in Kenya. They have abundant sunshine throughout the year. Fishing is done all the year round although the highest catch is obtained after the rains (144). It is thus evident that the fishing industry in Kenya is ideally suited to the utilisation of solar energy.

2.4.2.4.5. Fruits and Vegetables

The most ancient method of drying fruits and vegetables is sun-drying and it is still in use in many parts of the world (150). The food material is placed on trays and exposed to the sunshine. The later stages of drying proceed in the shade. Jackson and Mohammed (151) have given detailed instructions on the sun-drying of specific fruits and vegetables.

The disadvantages of sun-drying of fruits and vegetables have already been mentioned. Drying systems utilising heated air have been described in the literature (150). It is important to maintain the inlet air temperature at acceptable levels in order to avoid damage to the fruit or vegetable product. Duckworth (152) has indicated that the maximum air temperature for fruit lies between 60 and 77°C, depending on the material being dried. He noted that higher inlet air temperatures up to 99°C, or even higher, can be used in the dehydration of vegetables, when compared with fruits. Malik and

Dhingra (153), however, stated that, in general, the inlet air temperature for dehydration of fruits and vegetables should not exceed 71 to 77^{o}C.

Suitable solar collectors can be used to heat air to the temperatures mentioned above. Tests carried out in Syria revealed that solar dehydrated fruit compared quite favourably with the traditional sun-dried samples, they had a better taste as well as other attributes (154). Gomez (155) used a simple solar drier to dry mangoes, pawpaws, pumpkins and cowpea leaf in Kenya. She obtained dehydrated products of acceptable nutritional and organoleptic quality.

Solar dehydration is suitable for those fruits and vegetables whose production seasons coincide with the periods of high insolation. Of the many vegetables that can be dried in Kenya the author mentions here potatoes and carrots.

Potatoes are mainly grown in Central, Eastern and Rift Valley Provinces. In the Central Province, potatoes are harvested during the months of June to August and December to February. The harvesting dates in the Eastern Province are in June/July and December to February. The harvesting time for potatoes in the Rift Valley Province falls in July/August and November/December.

The period November to February happens to be the period of maximum insolation in all the potato producing regions. In contrast, much less solar radiation is received in June and July. Potatoes can, however, be kept in good condition for up to two months (156). The potential for solar dehydration of potatoes in Kenya is therefore much greater when compared with other vegetables.

The production of carrots is most significant in the Central and Eastern Provinces of Kenya. The harvesting dates are in June to August and January to March. There is certainly sufficient sunshine for solar dehydration during the period January to March. The material harvested in June, July and August would have to rely on conventional energy sources on cloudy days.

A wide variety of fruits can also be dried using solar driers in Kenya. For instance, Kilifi and Kwale Districts, which have abundant sunshine, produce grape-fruits which are very suitable for solar drying.

Solar drying of fruits and vegetables to extend their shelf-life would greatly help the horticultural industry in Kenya. Disposal of the excess produce at harvesting time has been recognised as a major problem (156, 157). The farmers are forced to sell at throw-away prices due to the lack of suitable storage facilities.

2.4.2.4.6. Cereals

The author considers maize and wheat only. Maize and wheat are grown on both small-scale and large-scale farms in Kenya. These crops have traditionally been dried in the sun. Sun-drying has serious limitations, especially on large-scale farms where a large amount of product has to be dried at one go. Some large-scale farms have facilities for artificial drying (158). Artificial drying basically involves passing heated air through a bed of maize or wheat. The advantages of artificial drying of cereal grains when compared with sun-drying have been given by Brooker et al. (159). Various types of artificial driers are described in the literature (159-163). There are two types of artificial drying, namely low temperature drying and high temperature drying.

In low temperature drying, the air temperature is raised above ambient by about 5 to 10°C and drying is completed in 3-14 days. However, with high temperature drying, air temperatures are raised above ambient by 15 to 60°C and drying is completed in several minutes (161).

Recommended maximum drying air temperatures have been given in the literature (54, 162, 164, 165). The maximum drying air temperature for milling wheat is 66°C and 60°C for moisture contents less than 25% and greater than 25%, on a wet basis, respectively. Grain for stock feed can withstand maximum drying air temperatures in the range of 82 to 104°C.

The high fuel costs hamper widespread use of artificial maize and wheat driers in Kenya. The rather low drying temperatures mentioned above can be attained by fairly simple solar air heaters.

In most parts of the Central Province of Kenya, the harvesting dates for hybrid maize fall within the period December to March. This is also the period of maximum insolation.

The harvesting dates for hybrid maize in the Rift Valley Province extend from September to January, with the exception of Kericho District where harvesting occurs in July to August. It is clear that there is no shortage of solar energy in the Rift Valley Province between September and January. As shown in Section 2.2, Kericho District has sufficient sunshine for solar drying in July and August as the mean daily sunshine hours are not less than 5.5.

Maize is harvested in Nyanza and Western Provinces around August/September and December/January. These regions enjoy high insolation throughout the year and thus offer great potential for solar dehydration.

The main wheat producing region is the Rift Valley Province. The wheat harvesting season runs from September to January. This is evidently a period of adequate solar energy for wheat drying.

2.4.2.5. <u>The Economic Feasibility of Solar Drying Systems</u>.

Kaminskas (166), in 1974, carried out an extensive feasibility study of the implications of using solar energy in fruit and vegetable dehydration. His findings, although outdated, are shown in Table 10.

Table 10. <u>Cost of Solar Energy for Dehydration Compared to Conventional Energy Sources</u>.

% Utilisation of Solar Energy	Cost* (US $/GJ)
10	2.36
20	2.64
30	7.83
50	10.66
Liquid Propane (No Solar Energy)	3.58
Natural Gas (No Solar Energy)	0.19 - 2.17
Electricity (No Solar Energy)	2.17 - 9.25

Source: Adapted from Kaminskas 1974 (Ref. 167)

* Assumes: 200 days per year operation
10% interest rate
10-year equipment life.

Kaminskas (166) did the work mentioned above at California Polytechnic State University, USA. It is noteworthy that even in 1974 the capital investment costs necessary to collect solar energy at a 20 to 30% solar utilisation was not much higher than the cost of some conventional energy sources. Most certainly, the picture is now much more favourable for the utilisation of solar energy.

Work done by Troeger and Butler (167), in 1978, on peanut drying in the USA showed that the use of solar energy to reduce fossil fuel consumption for peanut drying was feasible.

In 1978, Heid (168) compared solar drying costs with the costs of owning and operating conventional grain driers in the Midwest of the United States of America. He concluded that "sun-powered systems represent an investment choice for some grain producers, especially if fossil fuels (became) scarce and more expensive".

The costs of drying grain with ambient and solar-heated air in Canada were compared by Fraser and Muir (169) in 1980. They found that electricity costs were lower with solar-heated air than with unheated ambient air but total costs were higher for solar drying. They observed that if the cost of electricity doubled and the cost of other inputs increased by 50%, then the total drying costs using ambient air or solar-heated air would be about the same. It has to be noted that apart from natural sun-drying, ambient air drying is the least energy intensive drying system. The only energy input is electric power to drive the fan.

Bose (170) reported in 1980 that the use of solar energy for drying was economically attractive in India. He recommended solar drying systems incorporating auxiliary heating by conventional means.

Singh et al. (171) identified conditions under which solar-assisted food dehydration becomes feasible. For a given set of economic parameters, there is an optimum collector area for maximum life cycle savings. The economic feasibility was found to be very much dependent on the location of the plant, that is, climatic conditions, and the type of load.

2.4.3. INDUSTRIAL PROCESS HEAT

2.4.3.1. Introduction

Here the author is concerned with energy use in food processing plants. In particular, only process heat is considered. Industrial process heat is defined here as the energy used in a food processing plant in the form of thermal energy rather than in the form of power.

As noted by Proctor and Morse (172), in the food processing industry heat is typically generated in a central boiler house at a temperature higher than that required for any of the processes in the plant, and then reticulated as 99°C water or steam at 125-170°C to the individual processes, most of which operate at much lower temperatures. A study of the energy use in a sector of the Australian food processing industry showed that over 70% of the process heat is used below 100°C and very little above 150°C (172).

It is clear that solar energy can be used to provide process heat in the food processing industry. It has been estimated that in the United Kingdom 35% of the low temperature water and process heating below 80°C could economically be satisfied with solar energy as compared to 10% of process heat in the temperature range 80 to 120°C (173).

The use of solar energy to provide industrial process heat is attractive because "industrial process heat loads are fairly constant over the year and an installed solar system might be expected to yield useful energy throughout the year" (174). This statement is not true for single product food processing plants if the products in question are available in certain seasons only. This is especially to be found in crop drying installations which the author is not concerned with here. Another attraction of solar process heat systems is that they can be designed to provide heat at exactly the end-use temperature required by a process, thereby raising thermodynamic efficiency (174).

2.4.3.2. Potential Applications of Solar Thermal Systems.

Solar energy could be used in a variety of industries where the generation of hot water (or low pressure steam) is required. Hot water is extensively used in the food processing industry for a variety of applications. The most prevalent of these are washing and rinsing (175). It has been reported in the literature that the temperature of water for cleaning and rinsing in food processing plants varies from 38 to 82°C (176-179). The processing temperatures of various food process operations are shown in Table 11. It can be seen that the processing temperatures of many food

Table 11. Processing Temperatures of Various Food Process Operations.

Operation	Temperature, °C	Reference
Milk Pasteurisation		
- Batch	63	179
- HTST	72	179
Juice Pasteurisation	77-87	179
Cheese Manufacture		
- Milk warming	28-31	179
- Curd cooking	38-50	179
Beer Manufacture		
- Mashing	38-77	179
- Pasteurisation	60	179
Meat Processing		
- Scalding	125-135	179
- Smoking	125-135	179
Canning	115-130	179
Fruits and Vegetables		
- Blanching	85-100	47
- Brine syrup heating	93	192
- Commercial sterilisation	100-121	192

products are below 100°C. These low temperatures can easily be attained by flat-plate solar collectors.

Intertechnology Corporation (105) has carried out a comprehensive analysis of the potential of solar energy to provide industrial process heat in a wide sector of the food processing industry in the United States. The food processing industries covered in their study included meat packing and processed meats, poultry dressing plants, cheese, condensed and evaporated milk, fluid milk, canned specialty products, canned fruits and vegetables, bakery products, cane sugar, animal and vegetable fats and oils, malt beveranges, bottled and canned soft drinks. It should be noted that all these industries are available in Kenya. The Intertchnology Corporation study found that there is a potential for solar energy use in all these industries. The proportion of the total heat load which can be economically provided by solar energy was found to vary from 5% to 74%.

Singh et al. (180) studied the compatibility of solar energy with fluid milk processing energy demands. They found that apart from providing heat for the pasteurisation of milk, solar energy could be used for heating water for cleaning and feed water to the boiler. They found that the percentage of the total process heat demand which can be met by solar energy depends on the location of the plant. For example, a 400 m^2

flat-plate collector was found to meet 29% and 34% of the total process heat demand in similar plants in Madison and Fresno (USA), respectively.

The solar water heating system of the Michigan State University milk processing plant was studied over one complete year (179). The system utilised 116 m^2 of flat-plate collectors. It operated successfully and its maintenance requirements were found to be minimal. The system's yearly efficiency, with respect to the utilisation of the incoming solar energy, was found to be 46% and it was able to supply about 56% of the yearly process heat demand.

An evacuated tube solar collector was used by Davis et al. (181) in Washington (USA) to pasteurise milk and grape fruit juice directly, by pumping the liquid food through the collector. Grape fruit juice and milk were heated to 75°C and 68°C, respectively. The milk discharge temperature was kept at 68 ± 2 °C by a microprocessor control system described by Harrel et al. (182). Adequate pasteurisation was achieved even on days with intermittent cloud cover.

Bachmann and Leuenberger (183) have reported the use of a simple system utilising solar heated water to produce cheese and butter oil. The system consisted of two flat-plate solar collectors, an insulated hot water tank and a double-jacketted, insulated cheese vat. The system had an efficiency of 40-50%, this being the proportion of the available solar radiation that was transferred to the water. By 1979, the system had been in successful operation in Afghanistan for three years.

Commonwealth, Scientific and Industrial Research Organisation (CSIRO) of Australia has undertaken a demonstration programme to explore the application of solar heat generating systems in industry. The performance of can warming and beer pasteurising installations have been reported by Read (184).

In the can warming process in New South Wales, filled cans of soft drink were heated by sprays of hot water (50 to 60°C), raising the can temperature from 3°C to a temperature above the ambient dew point, to prevent moisture condensing on the cans before packing. The solar water heating system consisted of 94 m^2 of flat-plate solar collectors and a 20 m^3 storage tank. The solar system was able to provide 44% of the total heat load during the test period from September 1977 to February 1979.

A beer pasteurising installation in Adelaide used 178 m^2 of selective flat-plate solar collectors with glass covers having a low iron content. Two tanks having a total capacity of 52,000 l were used to store heated water. The sytem collected 30 to 46% of the incoming solar radiation.

Wells (185) reported in 1982 that a 110 m^2 solar hot water system installed by Cadbury Schweppes Pty Ltd. in a factory at Claremont, Tasmania, was expected to provide an estimated 75% of the annual energy demand previously supplied by a 14 kW electric hot water system.

Heat pumps are increasingly being used to raise the temperature of low-grade heat energy source to a more useful level (186). It is conceivable that when economical heat pump systems become available they will be used with flat-plate solar collectors to obtain water at higher temperatures than would be possible with flat-plate solar collectors alone. Schuler et al. (187) have used a solar energy system with heat pump augmentation to provide industrial process heat in north-eastern Ohio, USA. They were able to maintain the temperature of the cleaning solution at 77°C even when solar energy was not available.

The above cases show that the use of solar energy to provide industrial process heat in the food processing industry is technically feasible. There is certainly a potential for the use of solar energy systems in Kenya as most parts of the country receive large amounts of solar energy throughout the year.

2.4.3.3. The Economics of Solar Process Heat

The installation of solar energy systems requires fairly high initial investment. The justification for these systems is the savings in conventional fuel as a result of the use of solar energy throughout the system's life as compared to the extra investment.

The economic feasibility of solar water heating in milk processing plants in the midwestern United States was investigated by Thomas et al. (188). The results indicated that under 1977 economic conditions and a 20-year payback period it was economically justifiable to replace 30 to 40% of the electric energy demand for warm water in large dairy plants by solar energy.

Work done by Brown and Stadjuhar (174) in 1978 showed that a solar-assisted process heat system was a viable investment in Denver, Colorado when the backup fuel was electric energy costing US $7.39/GJ.

Singh et al. (180), in their 1978 study of the compatibility of solar energy with fluid milk processing energy demands in the USA, did not find positive savings (at fixed collector area cost of US $200/m^2 and 10% discount rate) when the backup fuel costs less than US $5/GJ. They found that there is an optimum collector area for each fuel cost at which the present worth of solar savings is a maximum.

Barbieri (33) noted in 1979 that most solar energy systems were not competitive when compared with conventional energy sources. He was referring specifically to the United States of America. He saw as an impediment to the use of solar energy, the fact that industry typically requires a 3 to 5 year payback time on capital expenditures. He saw the number of days that a process needs energy as the most important characteristic affecting economic viability and predicted that production lines which operate 12 months per year will be the first to find solar energy attractive.

In a study (reported in 1980) of solar water heating for the food industry in the United States, Mintzias (189) found that a solar water heater with an optimised collector area results in positive savings for most of the geographical locations in the USA.

The major conclusion of work done by Bakker-Arkema et al. (179) in Michigan State University (reported in 1980) is that "solar energy does have promise for heating water in food processing plants". They noted that solar energy was even then cheaper than electrical energy.

Davis et al. (181), in their study of the solar pasteurisation of fruit juice and milk, found that under 1981 economic conditions a payback time of approximately ten years may be expected for a US $200/$m^2$ solar pasteuriser in the Columbia Plateau region of Washington, USA.

The economics of solar water heating in canning, dairy and meat processing operations was evaluated by Singh et al. (190) in 1982. They found that life cycle savings and optimum collector area are dependent on the type of food processing operations and location. The payback time (near the optimum collector area) varied from 12 to 15 years.

The effects of storage volume per unit collector area, and collector type, on the thermal and economic feasibility of solar water heating in the food processing industry were examined by Singh et al. (191) in 1982. It was found that parabolic trough collectors had better thermal and economic performance than flat-plate collectors. The performance of the system was not affected considerably by the storage volume to collector area ratio in the range 40 l m^{-2} to 100 l m^{-2}. The performance was considerably reduced when the storage volume to collector area ratio was less than 40 l m^{-2}.

2.4.4. REFRIGERATION

2.4.4.1. The Need for Refrigeration

As already indicated, the lowering of temperature is effective in controlling microbial and enzymatic activity in food products. Perishable foods such as fruits and vegetables, milk, fish and meat require refrigeration facilities to extend their shelf-life. Adequate refrigeration facilities will facilitate the transportation and marketing of these products.

2.4.4.2. The Current Status of Refrigeration in Kenya

The extent to which refrigeration is used in preserving meat, milk, fruit and vegetables, and fish in Kenya is briefly reviewed.

2.4.4.2.1. Meat

Most of the meat consumed in Kenya is obtained from small slaughter-houses which have no facilities for chilling (193). Most butcheries also have no cooling facilities. The Kenya Meat Commission, however, has refrigeration facilities in its plants at Nakuru, Mombasa and Athi River (63). The lack of refrigeration facilities presents major constraints to the Kenyan meat industry (193, 194).

2.4.4.2.2. Milk

The Kenya Cooperative Creameries (KCC) has cooling facilities in its factories. There are also cooling facilities in some of the KCC milk collection centres (195). Most of the primary dairy co-operative societies have no milk cooling facilities and the evening milk cannot be collected by the KCC the following morning because of quality deterioration (195-197). The lack of refrigeration facilities (and unhygienic handling) results in some milk being rejected by the KCC. It was reported, for instance, that out of the 35 million litres of milk taken to the KCC in Trans Nzoia District in 1981, 565,000 litres were rejected (198). This represents 1.6% loss. Reported losses by Kakamega Dairy Co-operative Society Ltd. were 2, 3.5 and 0.8% in 1978, 1979 and 1980, respectively (199). Losses in Meru District amounted to 6% in 1981 (200).

Clearly, the Kenyan dairy industry could benefit from the provision of more refrigeration facilities.

2.4.4.2.3. Fruits and Vegetables

Except in very few modern supermarkets, fruits and vegetables are not refrigerated in Kenyan markets. Some refrigeration of fruits and vegetables does certainly occur in homes with domestic refrigerators. But even these are to be found mostly in the urban areas. The marketing of fruits and vegetables would be greatly enhanced if refrigeration facilities were more widely available. It has been noted, for instance, that vegetables sent to Mombasa by rail from Voi frequently rot on the way (201). The provision of adequate refrigeration facilities would certainly minimise the losses referred to by Saint-Hilaire and Shah (61).

2.4.4.2.4. Fish

Some firms have facilities for refrigerated storage, transport and marketing of fish (63). However, the bulk of fish marketing is done by small-scale traders who have no refrigeration facilities at their disposal. Ice plants are not available in the rural areas where most of the trade occurs. Lack of refrigeration facilities combined with inadequate transport facilities make the marketing of fish very difficult. The dangers of quality deterioration and spoilage continue to plague the fresh fish industry in Kenya (202). It was recently reported, for instance, that Lake Naivasha Fisheries Co-operative Society lost over 3,700 fish worth over KShs.11,000 at a go due to rotting (203). A study (204) of the hygienic quality of marketed fish in Kenya revealed high levels of bacterial counts. This was attributed to the lack of refrigeration facilities.

2.4.4.3. The Need for Solar Refrigeration

It has been shown that there is a need for more refrigeration facilities in Kenya. Most of the existing refrigerators are of the vapour-compression type which require electric power for operation. A few absorption-type refrigerators utilising kerosene are also available (205). Vapour-compression refrigerators can only be used in areas with a supply of electricity. Unfortunately, electricity is not yet available in most of the rural areas of Kenya. Absorption refrigerators could be used in all parts of the country. Considerations of availability and cost of fuel (not to mention the initial capital outlay) would, however, hamper their widespread use.

Operating costs are an increasingly important aspect of refrigeration. In a recent survey (206) of 14 of the 21 sectors of the food, drink and tobacco industry in the United Kingdom, it was found that refrigeration accounted for over 17% of the electrical energy used for processing in all the fourteen sectors.

Newell (207) reported that cooling milk uses over 40% of the electricity consumption in milk parlours and dairies in the United Kingdom. He noted that cooling milk in a refrigerated bulk tank consumes on average 20 kWh per 1000 litres of milk cooled.

Barlow (208) reported that 9.8% of the average energy consumption in a brewery is used in chilling and conditioning.

It has been reported that refrigeration accounted for 3% of the total primary energy used in the USA in 1973 (209).

Household refrigerators and freezers in the Federal Republic of Germany consumed about 2% of the primary energy used in 1977 (210).

Lorentzen (211) estimated the energy consumption by refrigerators to vary from 2 to 20% of the electricity production of any one country. He cited the figures for Norway and Denmark as being 2 to 2.5 and 20% of the total electricity production, respectively.

The use of solar energy to power refrigerators would reduce the operating costs of refrigeration systems. Moreover, solar powered refrigerators can be used even in remote rural areas without electricity supply. The use of solar energy for refrigeration is attractive because refrigeration is most needed during periods of high solar radiation intensity.

2.4.4.4. Solar Refrigeration: A State-of-the-Art Review.

2.4.4.4.1. Types of Solar Refrigerators

Solar energy can be used to operate the refrigeration systems mentioned below:

(i) Vapour-Compression Refrigeration System: Solar energy is used as the source of power for the compressor of a conventional vapour-compression refrigeration system (212-216). Concentrating solar collectors are used to produce steam which drives a steam engine or turbine coupled to a conventional compressor. Alternatively, the compressor is powered by electricity generated by a solar photovoltaic system (217, 218).

(ii) Steam Jet Refrigeration System: The steam generated by solar energy is used to operate a steam jet refrigeration system (219-221).

(iii) Thermoelectric Refrigeration System: Solar energy is utilised to raise the temperature of the 'hot' junctions of a thermocouple system thereby generating electrical power for the operation of a thermoelectric refrigerator (222-224). In a thermoelectric refrigerator cooling is achieved by passing an electric curre through a thermocouple circuit (Peltier effect).

(iv) Absorption Refrigeration System: Solar energy provides the heat energy required to operate an absorption refrigeration system (225).

2.4.4.4.2. Solar Absorption Refrigerators

Absorption refrigeration systems are most readily adaptable to the utilisation of solar energy. They can utilise low temperature heat which can be supplied using inexpensive flat-plate collectors. The use of flat-plate collectors has the added advantage that good performance is attainable even on cloudy days when concentrating collectors would be largely inoperative.

As described by Farber (226), solar absorption refrigeration systems are classified into two types: intermittent and continuous systems.

2.4.4.4.2.1. Intermittent Solar Refrigeration Systems

An intermittent solar refrigeration system basically consists of two tanks connected by a pipe, with a control valve on the pipe. One tank (generator/absorber) contains the absorbent plus refrigerant while the second tank (condenser/evaporator) receives the condensed refrigerant. An Ammonia/water system is used as an illustration (Figure 22).

During the charging period ammonia is driven out of solution by heating with solar-heated water or direct solar heating. The ammonia vapour is condensed in the other tank using air or water as the cooling medium.

During the refrigeration period the heat supply is stopped, the water/ammonia solution cooled, the liquid ammonia allowed to vapourise (while extracting heat from the material being cooled) and the ammonia vapour reabsorbed by the ammonia/water solution.

Favre and Leibundgut (227, 228) have developed a unique system in which the evaporator unit contains ammonia/water solution rather than liquid ammonia.

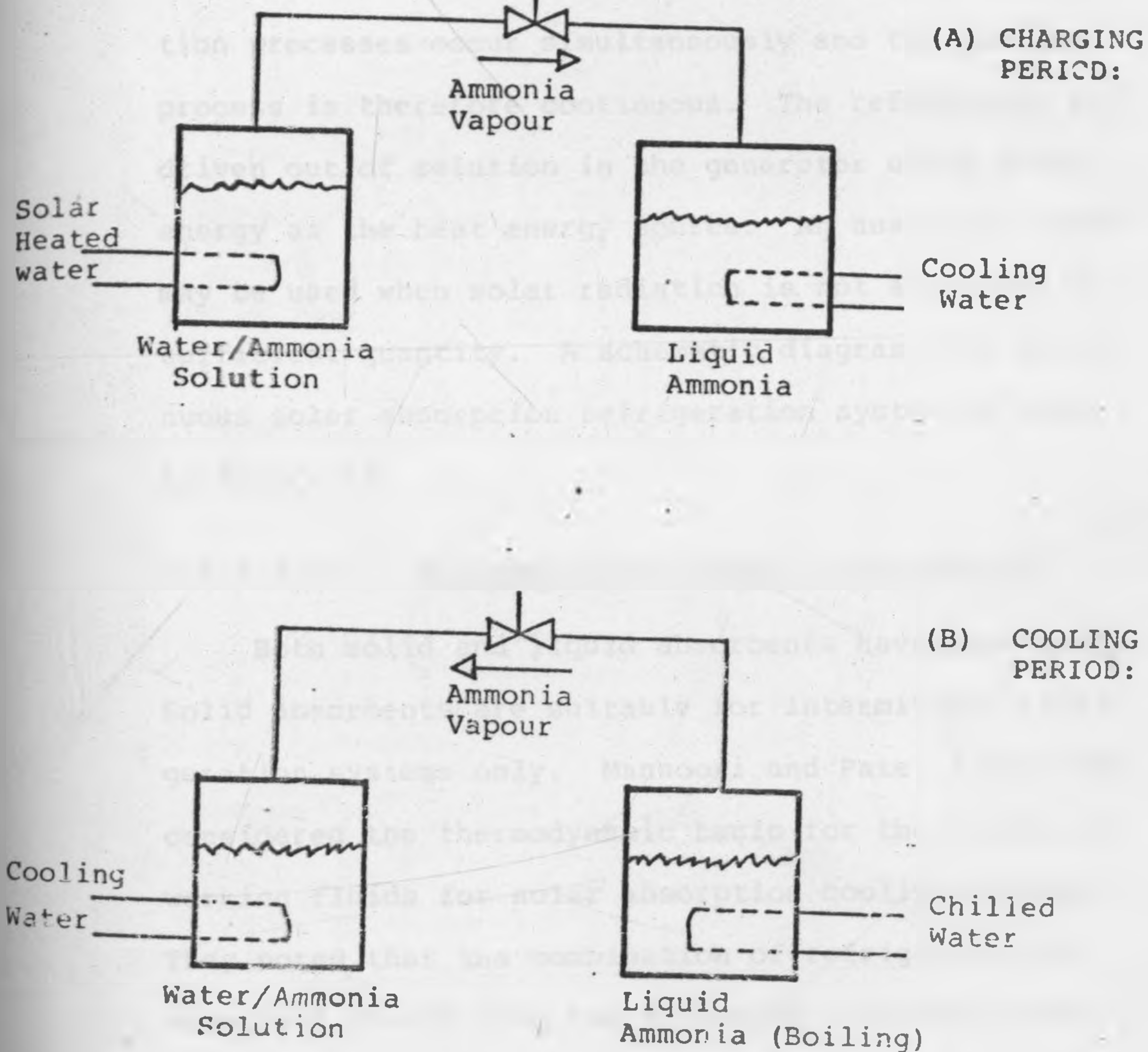


Fig. 22. Intermittent Ammonia/Water Refrigeration System

2.4.4.4.2.2. Continuous Solar Refrigeration Systems

In these systems, the refrigeration and regeneration processes occur simultaneously and the cooling process is therefore continuous. The refrigerant is driven out of solution in the generator using solar energy as the heat energy source. An auxiliary heater may be used when solar radiation is not available in sufficient quantity. A schematic diagram of a continuous solar absorption refrigeration system is shown in Figure 23.

2.4.4.4.2.3. Absorbent/Refrigerant Combinations

Both solid and liquid absorbents have been used. Solid absorbents are suitable for intermittent refrigeration systems only. Mansoori and Patel (229) have considered the thermodynamic basis for the choice of working fluids for solar absorption cooling systems. They noted that the combination of refrigerant and absorbent should have the following characteristics in order to qualify for use in absorption solar cooling systems:

(i) High equilibrium solubility at the required temperature and pressure in the absorber.

(ii) Rapid absorption of the refrigerant.

(iii) Pure refrigerant vapour should be obtained from a rich solution as easily as possible.

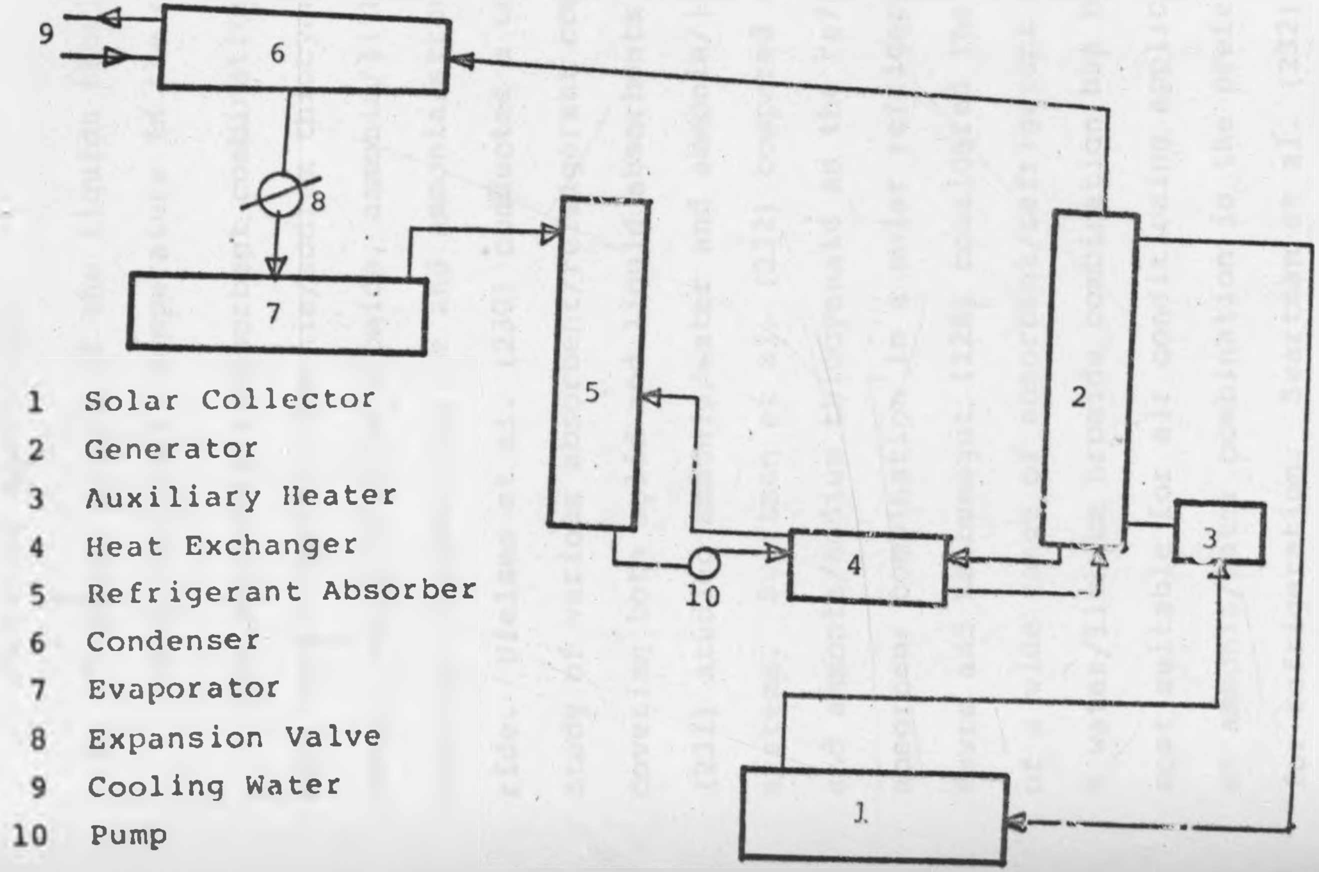


Fig. 23 Continuous Solar Refrigeration System.

(iv) The absorbent should be non-volatile or very much less volatile than the refrigerant.

(v) The solutions should have low viscosities under operating conditions.

(vi) Freezing points of the liquids should be lower than the lowest temperature in the cycle.

The refrigerant/absorbent combinations which have been tried include ammonia/sodium thiocyanate, ammonia/water, water/lithium bromide, ammonia/lithium nitrate, ammonia/calcium chloride and ammonia/strontium chloride. Nielsen et al. (230) conducted a comparative study of various absorbent/refrigerant combinations covering both solid and liquid absorbents. Chinnappa (231) studied ammonia/water and ammonia/lithium nitrate systems. Swartman et al. (232) compared ammonia/water and ammonia/sodium thiocyanate as the refrigerant/absorbent combination in a solar refrigeration system. Favre and Leibundgut (228) considered the suitability of a wide range of absorbent/refrigerant combinations. A water/lithium bromide combination has been found most suitable for air conditioning applications while an ammonia/water combination is the preferred choice for refrigeration. Swartman et al. (232) found the optimum initial ammonia concentration in an ammonia/water intermittent system to be 64.0%.

2.4.4.4.2.4. Performance of Solar Absorption Refrigerators.

2.4.4.4.2.4.1. Intermittent Systems

Williams et al. (233) reported the results of experiments with an intermittent ammonia/water food cooler utilising a concentrating solar collector. The evaporator was placed in a 2.25 cu.ft. (0.064 m^3) box during refrigeration periods. The system was able to maintain the temperature of water in the box at approximately 17.8°C below the ambient temperature. The overall coefficient of performance (COP_r), defined as the ratio of the cooling obtainable to the amount of solar energy received by the collector, showed a maximum value of approximately 0.14.

An ammonia/water solar refrigeration system using a flat-plate collector as the generator and absorber was designed, built and tested by Swartman and Swaminathan (234-236). This system was able to condense, on average, about 3.2 kg of ammonia during 6 hours of regeneration when the average solar radiation intensity was 1.1 langleys/min (766W m^{-2}). The lowest temperature in the evaporator was -12°C.

Chinnappa (237) tested an ammonia/water intermittent refrigerator incorporating a flat-plate collector (1.63 m^2) at Colombo in Sri Lanka. His results showed that 1 lb (0.454 kg) of ice can be produced on a clear day for every 3 to 4 square feet

(0.279 to 0.372 m^2) of collector surface.

Swartman et al. (232) operated an intermittent solar refrigeration system using both ammonia/water and ammonia/sodium thiocyanate as working substances. A minimum evaporator temperature of -13°C was obtained with an ammonia/water system on a day when a maximum solution temperature of 85°C was attained. For the ammonia/sodium thiocyanate system a minimum evaporator temperature of -12°C was attained with a maximum solution temperature of 97°C. The ammonia/water system attained a maximum COP_r of 0.14 at an ammonia concentration of 70%.

A solar adsorption refrigerator employing ammonia and calcium chloride was tested by Muradov and Shadiev (238) at Bukhara State Pedagogical Institute (USSR). A negative temperature (°C) was established in the evaporator within 1 to 2 hours of the start of the refrigeration process and was maintained for 8 hours.

The Asian Institute of Technology (Bangkok) constructed and tested a prototype refrigerator using a 1.44 m^2 flat-plate solar collector (239). The refrigerator produced 6 kg of ice in one day and was able to keep 3.5 kg of fruit below 15°C while the ambient temperature reached 37°C.

Exell (240) reported the performance of an intermittent ammonia/water refrigeration system, tested in Thailand, utilising a 1.95 m^2 flat-plate collector with a mirror booster. On a day when the total radiation falling directly on the collector was 28.2 MJ, the total radiation received was raised to 38.6 MJ by the mirror booster. Freezing temperatures were attained in the ice-box 1½ hours after the start of the refrigeration operation, and 5.18 kg of ice was produced from 7.5 kg of water initially at 29°C. The COP_r was 0.073.

An intermittent ammonia/calcium chloride solar refrigeration system installed in Sudan provided up to 16 kg of ice per day (241).

2.4.4.4.2.4.2. Continuous Systems

A thermodynamic analysis of a continuous ammonia/water absorption refrigeration system by Farber (242) showed that a temperature of -7°C can easily be attained in the evaporator with the generator operating at 71°C.

A continuous ammonia/water solar refrigeration system was built at the University of Florida in 1970 (243). It used a 1.49 m^2 flat-plate solar collector. On average, about 42,200 kJ of solar energy was collected and 18.1 kg of ice produced per day. That is to say, a COP_r of about 0.1 was attained and 12.1 kg of ice produced per m^2 of collector surface per day. Swartman (244) remarked in 1973 that this was then the most successful solar refrigeration system.

Maksudow and Wachidow (245) reported the performance of a continuous ammonia/water absorption refrigerator built at Samarkand (USSR). The cooler unit had two separate evaporators. The first was part of a normal continuous solar absorption refrigerator which operated during the day time. The second evaporator was connected to a solar collector, condenser, a liquid ammonia storage tank and an expansion valve. The liquid ammonia generated during the day time by this second unit was stored for cooling at night. Flat-plate collectors were used. It was reported that this system was able to keep the temperature of the cooler at 0-6°C throughout the day. The accumulated ice helped to maintain low temperatures when refrigeration was difficult to maintain during periods of insufficient solar radiation.

A continuous ammonia/water solar refrigeration system to chill 400 l of milk per day to 4°C was reported to be under construction in Mexico in 1981 (246). The system uses 15 m^2 of flat-plate collectors.

2.4.4.4.3. The Economics of Solar Refrigeration

There has been no systematic development of solar powered refrigeration units (247). Up-to-date information on the economics of prototype machines is very scanty.

Trombe and Föex (248) presented an "economic balance sheet" of ice manufacture using an absorption machine in 1961. They estimated the cost of ice to be of the order of 0.9 to 1.4 US cents per pound (2.0 to 3.08 US cents per kg).

Chung and Duffie (249) estimated the cost of ice production by a solar refrigerator to be of the order of US $3.92 per tonne (in 1961).

In another study, Swartman and Swaminathan (234) estimated the cost of manufacturing ice using a solar powered intermittent absorption refrigerating system to be of the order of 1.3 US cents per lb (2.86 US cents per kg) in 1971. They concluded that "comparing this cost to the usual cost of ice in the range of 2 to 4 US cents per lb (4.4 to 8.8 US cents per kg) in tropical countries such as India, intermittent solar refrigeration is attractive".

The ice produced by Exell's solar refrigeration system (240) was estimated to cost US $0.05 per kg (in 1977); this was three times the retail price and four times the ex-factory price of ice in Bangkok.

The cost of cooling a catch of 500 kg of fish in Tanzania using ammonia/water solar absorption refrigeration system was estimated in 1977 (250). The cold storage unit was assumed to be 2.5 m long, 1 m wide and 1 m deep. The cost of the absorption refrigeration machine was estimated by scaling down the costs of available machines; these were larger than required by a factor of 3 to 4. Assuming a 5-year equipment life, it was found that the cost of solar refrigeration was TShs 1.06 per kWh heat input (electricity cost was TShs 0.30 per kWh in 1977).

A comparison of the costs of different solar cooling systems in Sudan in 1981 has been presented by Grallert (251)(Table 12).

It was reported in 1982 that solar powered (photovoltaic) refrigerators could turn out to be a viable option in the future (252). The price of a conventional refrigerator, and the costs of operating it for ten years, was estimated to be US $1,750 while the cost of a solar refrigerator was estimated to be US $5,000, the latter price was expected to drop to under US $2,000 in 1984.

The author has estimated the cost of producing one pound (0.454 kg) of ice by a conventional 20 cu.ft. freezer in Kenya. Approximately 60 kWh of electrical energy is required to produce one ton (1.02 tonnes) of ice by a conventional ice plant (253). Electricity costs KShs 0.60 per kWh in Kenya. The electric power consumed in producing one ton (1 02 tonnes) of ice in Kenya therefore costs KShs 36 (this is equivalent to 1.6 Kenya cents per lb or 3.5 Kenya cents per kg of ice). The capital cost of operating a 20 cu.ft. freezer to produce 1 ton (1.02 tonnes) of ice is estimated from the data given in the literature to be KShs 83 (254). The cost of producing one pound (0.454 kg) of ice in Kenya by a 20 cu.ft. freezer is thus approximately 5.3 Kenya cents (0.4 US cents).

Table 12. Comparison of the Costs of Refrigeration in Sudan in 1981 using Solar Refrigerators with a Standard Refrigeration Duty of 50 kW.

Collector Type*	Type of Refrigerator	Cost of Cooling (DM/kWh) +		Collector Price DM/M^2
		Cold storage at 0°C	Frozen storage (-20/-30°C)	
1	Continuous NH_3/H_2O absorption refrigerator	4.2	-	220
2	Continuous NH_3/H_2O absorption refrigerator	3.1	8.0	850
3	Continuous NH_3/H_2O absorption refrigerator	3.3	8.1	1000
4	Compression refrigerator driven by a steam turbine	5.9	13.8	2000
5	Compression refrigerator	4.9	15.5	2640

Source: Adapted from Grallert 1982 (Ref.50)

* Collector type:

1 Cheap collector with single glazing and selective absorber
2 Partly evacuated flat-plate collector: single glazing and selective absorber
3 Evacuated glass-tube collector with selective absorber
4 Parabolic collector with a concentrating power of 200
5 Silicon cell electricity generator (Polycrystalline)

\+ Deutsche marks required to produce a refrigeration effect of 1 kWh (1 DM was equivalent to 4.0 Kenya Shillings in 1981).

2.5. TESTING THE THERMAL PERFORMANCE OF SOLAR COLLECTORS

2.5.1. Introduction

The subject of solar collector testing procedures is still an issue for considerable debate (255-261). A number of standard testing procedures have been proposed (262-266). Thermal performance testing of solar collectors is useful in two ways. Firstly, it is an aid in selecting a suitable solar collector for a given duty. Secondly, it provides information necessary in designing and predicting the performance of a solar energy system (255, 267-270).

2.5.2. Theoretical Basis for a Standard Test

At steady state, the useful energy extracted from a collector by the working fluid plus the heat lost to the surroundings equals the solar energy absorbed by the collector plate (of a flat-plate collector). This can be expressed as:

$$q_u/A + U_L\ (\bar{t}_p - t_a) = I\ (\tau\alpha)_e \qquad \text{..... Eqn 2.2}$$

where:

q_u = rate of useful energy extraction from the solar collector, W;

A = collector cross-sectional area, m^2;

U_L = heat loss coefficient of collector, W m^{-2} K^{-1};

$\bar{t}_p$ = average temperature of the collector's absorber surface, K;

t_a = ambient air temperature, K;

I = insolation in plane of collector, W m^{-2};

$(\tau\alpha)_e$ = effective transmittance - absorptance product for the solar collector.

The efficiency (η) of a solar collector is defined as the amount of useful energy extracted from the collector as a percentage of the solar energy incident upon the collector during the same period, that is,

$$\eta = (q_u/A)/I \qquad \text{...... Eqn 2.3}$$

The rate of useful energy extraction from a solar collector, q_u, is given by:

$$q_u = \dot{m}\, c_p (t_o - t_i) \qquad \text{..... Eqn 2.4}$$

where:

$\dot{m}$ = mass flow-rate of the working fluid, kg s^{-1};

c_p = specific heat of the fluid, J kg^{-1} K^{-1};

t_o = outlet temperature of the fluid, K;

t_i = inlet temperature of the fluid, K.

Equation 2.2 can be rewritten as:

$$\eta = (\tau\alpha)_e - U_L (\bar{t}_p - t_a)/I \qquad \text{..... Eqn 2.5}$$

In practice, the average temperature of the collector's absorber surface, $\bar{t}_p$, is not known. It is therefore useful to replace $\bar{t}_p$ in Eqn 2.5 with the average fluid temperature and introduce an efficiency factor F' (101, 271, 272):

$$\eta = F' ((\tau\alpha)_e - U_L (t_m - t_a)/I) \qquad \text{...... Eqn 2.6}$$

where

$$t_m = (t_i + t_o)/2$$

The collector efficiency factor F' can be interpreted to mean the ratio of the useful energy gain to the useful energy gain if the collector absorbing surface had been at the mean fluid temperature. It is essentially a constant for a given collector design and fluid flow-rate (101).

Assuming that the heat loss coefficient, U_L, is constant, a plot of η vs $(t_m - t_a)/I$ is a straight line whose gradient is $-F'U_L$ and intercept on the vertical axis is $F'(\tau\alpha)_e$.

It has, however, been found more convenient to replace $\bar{t}_p$ in Eqn 2.5 with the inlet fluid temperature, t_i, instead of the mean fluid temperature, t_m, and to introduce a factor F_R(273):

$$\eta = F_R((\tau\alpha)_e - U_L(t_i - t_a)/I) \qquad \text{...... Eqn 2.7}$$

This is the Hottel-Whillier-Bliss equation.
F_R, the collector heat removal factor, has been defined as the ratio of the actual rate of heat transfer to the working fluid to the rate of heat transfer if the collector absorbing surface had been at the inlet fluid temperature (100).

A plot of η vs $(t_i - t_a)/I$ is a straight line whose gradient is $-F_RU_L$ and intercept $F_R(\tau\alpha)_e$.

In designing a solar collector, the aim is to have an efficiency curve whose intercept is as high as possible and gradient, $-F_RU_L$, as small, in magnitude, as possible. That is to say, the solar collector should be able to absorb as much of the incoming solar radiation as possible with minimal heat losses to the surroundings.

In selecting a solar collector for a given duty, a look at the efficiency curves of the various collectors would indicate which collector is most efficient with respect to thermal conversion of solar radiation. Thermal conversion efficiency is, however, not the sole criterion on which to base ones selection of a suitable solar collector. Other factors such as price, durability and maintenance costs are also important.

2.6. THERMOSYPHON SOLAR WATER HEATING SYSTEMS

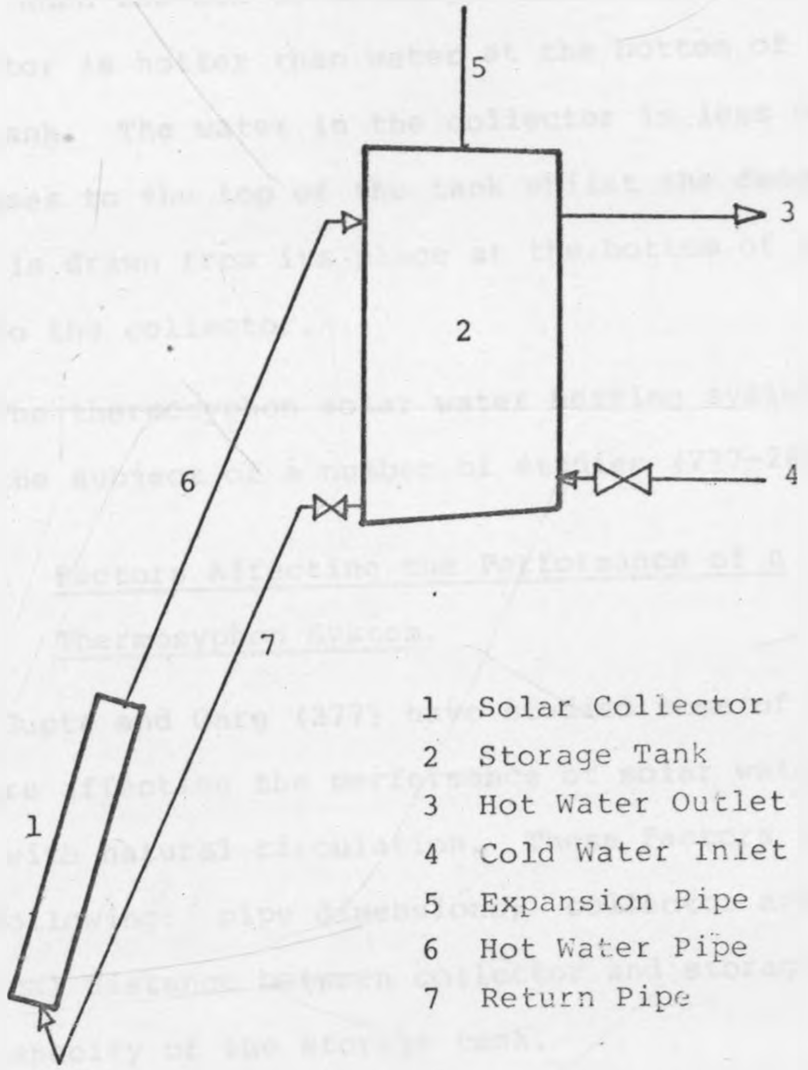
2.6.1. Introduction

In view of the necessity for some degree of heat storage in solar heating systems, solar heated water usually first goes to an insulated storage tank from which it is either withdrawn or heat extracted by a second fluid stream passing through a heat exchanger in thermal contact with the hot water. Thus, there is a need for circulation of water from the solar collectors to the storage tank. If the storage tank initially contains cold water, the water has to circulate through the solar collectors for quite some time before a desired temperature is attained.

The water circulation is achieved either by the use of a pump (104, 274) or by the use of thermosyphon effect. A system utilising a pump has the following advantages over a thermosyphon system (104). (a) there is much more freedom when it comes to locating the system components and (b) the system collects more energy than a comparable thermosyphon system. A pumped system, however, has to have a source of electricity and is more expensive than a comparable thermosyphon system.

2.6.2. The Thermosyphon System

The thermosyphon solar water heating system is shown schematically in Figure 24. The system operates



1 Solar Collector
2 Storage Tank
3 Hot Water Outlet
4 Cold Water Inlet
5 Expansion Pipe
6 Hot Water Pipe
7 Return Pipe

Fig. 24. A Thermosyphon Solar Water Heating System (Schematic).

by natural circulation of water (96, 97, 104, 275, 276). When the sun is shining, water in the solar collector is hotter than water at the bottom of the storage tank. The water in the collector is less dense and rises to the top of the tank whilst the denser water is drawn from its place at the bottom of the tank to the collector.

The thermosyphon solar water heating system has been the subject of a number of studies (277-282).

2.6.3. Factors Affecting the Performance of a Thermosyphon System.

Gupta and Garg (277) have studied some of the factors affecting the performance of solar water heaters with natural circulation. These factors include the following: pipe dimensions; collector area; vertical distance between collector and storage tank; and capacity of the storage tank.

The water flow-rate is affected by the sizes and lengths of the circulation pipes, the smoothness of their walls, the gradualness of the transitions from one size to another, the gentleness of curvature around corners, and the number and type of valves in the system. The flow-rate is higher for larger diameter pipes and, consequently, the temperature difference between the water at the top of the storage tank and the water at the bottom of the storage tank is much less than for the case of smaller diameter pipes.

The collector area determines the capacity (the amount of hot water produced in a given time) of the system for a given output temperature. Usually, the collector area is determined by the required capacity of the system. The area required for a given duty depends on the climatic regime and the type of collector being used.

The distance between the collector's top level and the bottom of the tank influences the performance of the system. The bottom of the tank should be at least 30 cm above the top level of the collector; the greater the height difference is, the faster the flow will be (96). However, the circulation rate drops when the height of the tank above the collector is increased above 4 m (104).

The capacity of the storage tank determines the rate of temperature rise. For a given collector area, the bigger the tank the slower the rate of temperature rise.

2.7. CONCLUSIONS FROM THE LITERATURE SURVEY

A wide variety of plant and animal food materials are produced in Kenya. The most important food producing areas are the Highlands, the Lake Victoria Basin and the Coastal Region. The food crops grown in Kenya include coffee, tea, maize, wheat, millet, sorghum, cassava, beans, and a wide variety of fruits and vegetables. Cattle, sheep, goats and poultry are also found in Kenya. There is therefore plenty of meat and milk. Fish are also caught from the lakes and the Indian Ocean.

A relatively large and diversified food processing industry exists in Kenya. Processed foods such as meat and meat products, dairy products, fish, canned fruits and vegetables, dried fruits and vegetables, jams and jellies, beverages, vegetable oils and fats, cereal products, sugar, tea and coffee are produced.

Kenya has an abundant supply of solar energy. The mean number of sunshine hours per day over Kenya for the whole year vary from about 6 hours in some parts of Central Province to over 9 hours in northwestern Kenya. Almost the whole country receives an annual average radiation of more than 18 MJ m^{-2} per day. Even in July, when the lowest insolation levels are obtained in most parts of the country, the bulk of the country still receives more than 16 MJ M^{-2}

per day, on average. In general, the lowest radiation values are experienced during the period between May and August.

The solar energy resource could be used to provide thermal energy for the food processing industry in Kenya. Almost all food materials produced in Kenya lend themselves most readily to processes involving partial or total energy supply in the form of solar energy. The food processing operations identified as suitable for the utilisation of solar energy are food drying, the provision of industrial process heat (for processes other than drying) and refrigeration.

Drying is one of the processing methods used for food preservation in Kenya. Very often, the traditional method of sun-drying results in food products of poor quality. Moreover, a large area is required for drying and the process is slow. The widespread use of the conventional artificial driers is hampered by the cost and availability of energy supplies. There is a need for artificial driers which utilise solar energy as the energy source. The food products suitable for solar drying in Kenya include coffee-beans, tea leaves, cereal grains, pulses, cassava, fruits and vegetables, and fish. One would expect solar drying systems to be economically feasible in Kenya as studies done in India and some parts of the USA have shown that these systems are economically attractive.

Hot water is extensively used in the food processing industry for a variety of applications, the most prevalent applications being washing and rinsing. As most of the water is used at temperatures below 100°C, solar energy can easily be used to heat water for use in the Kenyan food processing industry. Studies carried out in the USA have shown that the use of solar energy to provide part of the energy required for water heating in the food processing industry is both technically and economically feasible. Payback times varying from 10 to 20 years have been indicated. Solar water heating systems could perform even better in Kenya.

There are inadequate refrigeration facilities in Kenya. Almost all the available refrigerators are of the vapour-compression-type and require conventionally generated electric power. There is a need for the development of cheap refrigeration systems which utilise solar energy. Although a number of experimental solar refrigeration units have been tested in various countries, no commercial units have been produced to date. Solar refrigeration is technically feasible. Up to 4.2 and 12.1 kg of ice have been produced per square metre of flat-plate-type solar collector in one day by intermittent absorption-type solar refrigeration systems and continuous absorption-type solar refrigeration systems, respectively. A maximum overall coefficient of performance (COP_r) equal to 0.14 has been obtained. Economically, the conventional refrigeration systems are still cheaper than the solar refrigeration systems in places where conventional energy sources are readily available. However, with continued research and development as well as the adoption of mass production techniques, the costs of solar refrigeration systems are expected to come down Solar powered refrigerators could turn out to be a viable option in the near future. The use of solar refrigeration systems in remote rural areas could be cost effective even now.

In order to design and predict the performance of solar energy systems, a knowledge of the thermal performance of solar collectors is required. It is also necessary to know how solar energy systems (not solar collectors alone) perform in practice. To the author's knowledge, no information is available on th thermal performance of various solar collectors in Kenya. As to the performance of solar energy systems a number of thermosyphon solar water heaters have been installed in Kenya to provide hot water in homes and hotels. However, the performance of these system has not been systematically monitored. The remainder of this thesis therefore deals with the performance testing of some flat-plate solar collectors and a thermosyphon solar water heating system done by the author in the Department of Food Science and Technology (DFST), University of Nairobi (Kabete).

3. EQUIPMENT AND EXPERIMENTAL METHODS

3.1. EQUIPMENT

3.1.1. Solar Collectors

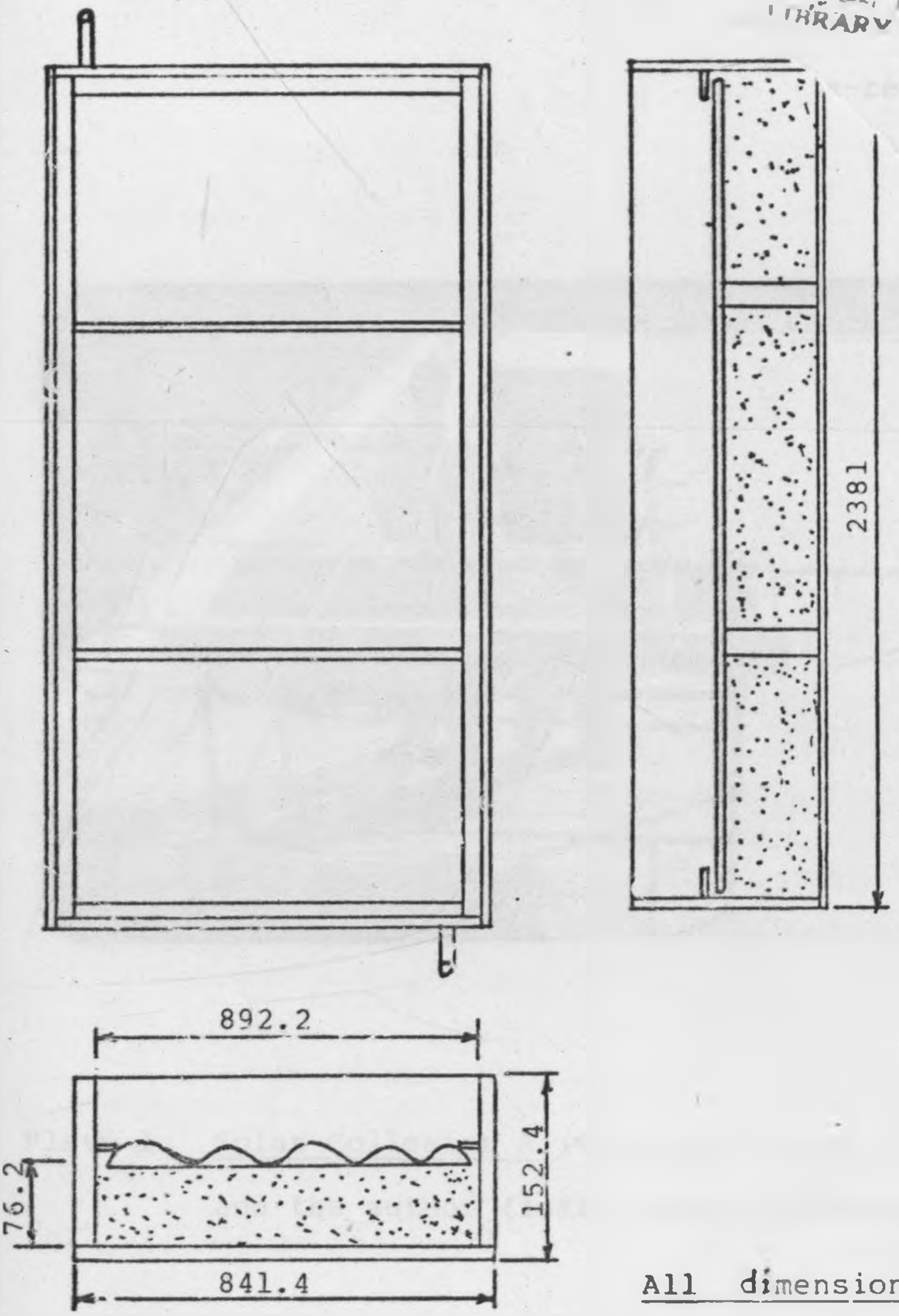
Four flat-plate solar collectors were used in this study and are described in more detail below.

(A) A Flat-Plate Collector Made by the Author in the DIST Workshop.

This collector had a 2.2 m^2 gross area while the effective area measured 1.4 m^2. The absorber was made from a standard sheet of corrugated galvanised steel, 24 gauge, and a flat galvanised steel sheet (24 gauge) as described in a do-it-yourself leaflet of the Brace Research Institute (283). Matt black paint was applied on the exposed corrugated surface. The absorber was enclosed in a wooden casing. Wood shavings were used for insulation. Polyvinyl chloride (PVC) film was used for the transparent cover. A sketch and a photograph of the collector can be seen in Figure 25 and Plate 1, respectively.

(B) Industrial Solar Collector (Beasley Industries Pty Ltd., Australia).

This is a commercial solar collector. The gross area and effective area measure 1.58 m^2 and 1.50 m^2, respectively. The absorber is made of a copper sheet to which is soldered eight 12.7 mm nominal diameter copper tubes. The surface is treated with a selective



All dimensions in mm

Fig. 25. A Sketch of Solar Collector A.

Plate 1. Solar Collector A (with Mr. Kihara (right) and the author (left) in the background).

coating ('black chrome'). The glazing is a special low iron glass sheet treated on the outer surface to minimise the transmission of longwave infra-red radiation. The casing material is 24 gauge galvanised steel sheet, chrometched internally and externally. The rear insulation is 25 mm thick fibre-glass while the side insulation is 10 mm thick fibre-glass. A photograph of the collector is shown in Plate 2.

(C) A Commercial Non-Selective Solar Collector, 'Solapak' (Total Oil Products (E.A.) Ltd.).

The gross and effective areas measure 0.80 and 0.74 m^2, respectively. The absorber material (and construction) is similar to that of the collector B described above. The difference is that a non-selective "special surface finish" is used and the transparent cover is clear window glass (4 mm thick). The rear insulation is fibre-glass wool (25 mm thick) and the side insulation consists of polystyrene (10 mm thick). The casing is the same as in B above. For further details see Plate 2.

(D) A Commercial Non-Selective Solar Collector (ARO A.G., Switzerland).

The gross and effective area are 2.0 and 1.85 m^2, respectively. The absorber is a tube-in-sheet type. The glazing material is a glass sheet. Unfortunately, not much information on this collector is available

Plate 2. Solar Collectors B (right) and C (left).

due to the closure of the firm since the purchase of the collector in 1976. For further details see Plate 3.

3.1.2. 450 l Tank: A glavanised steel tank covered with 25.4 mm thick styropor insulation. The inside surface is painted to prevent corrosion (using an epoxy paint 'Epilac')

3.1.3. Water Heaters: Three 3 kW immersion heaters (one 'Santon', B.S. 3456 and 2 made by Redring Electric Co. Ltd., Peterborough, U.K.) for heating water in the tank mentioned in Section 3.1.2.

3.1.4. Stirrer (Type MR 112A - G13B, J. Willi Sohn + Co. AG, Chur, Switzerland) for stirring water in the tank mentioned in Section 3.1.2.

3.1.5. 120 l Tank: This is an ordinary domestic water heating galvanised steel tank. The tank is covered with 25.4 mm thick styropor insulation.

3.1.6. Pump (Type SB 15, Mono Pumps Ltd., England) for pumping water from the 450 l Tank (Section 3.1.2) through the solar collectors.

3.1.7. Rotameter (G.A. Platon Ltd., Basingstoke, U.K.) for measuring water flow-rate (range:400-4500 cm^3 min^{-1}).

3.1.8. Inverted U-tube Water Manometer (made in DFST Workshop) for measuring pressure drop across a solar

Plate 3. Solar Collector D (with Mr. Kihara in the background).

collector.

3.1.9. Solarimeter (Kipp & Zonen, Delft, Holland) connected to "Miniscript 6D" recorder (Goerz Electro G.m.b.H., Vienna) for measuring solar radiation intensity. The measurement range varies from 0 to 2078 W m^{-2}. Full scale deflection (of the indicator) is caused by 25 mV. A radiation of 83.12 W m^{-2} produces 1.0 mV.

3.1.10. Cup-and-Vane Anemometer connected to the recorder mentioned in Section 3.1.9 for measuring wind speed. The instrument indicates wind speed values in the range 0 to 30 m s^{-1} (Full Scale = 10 Divisions; 1 Division = 3 m s^{-1}).

3.1.11. 'Technotherm' Thermometer (type 5500, Quarz AG, Switzerland) consisting of iron-constantan thermocouples with a digital readout for measurement of water temperature.

3.1.12. Industrial Mercury-in-Glass Thermometers inserted in the tank mentioned in Section 3.1.5 for measurement of water temperature (range: 0-100°C).

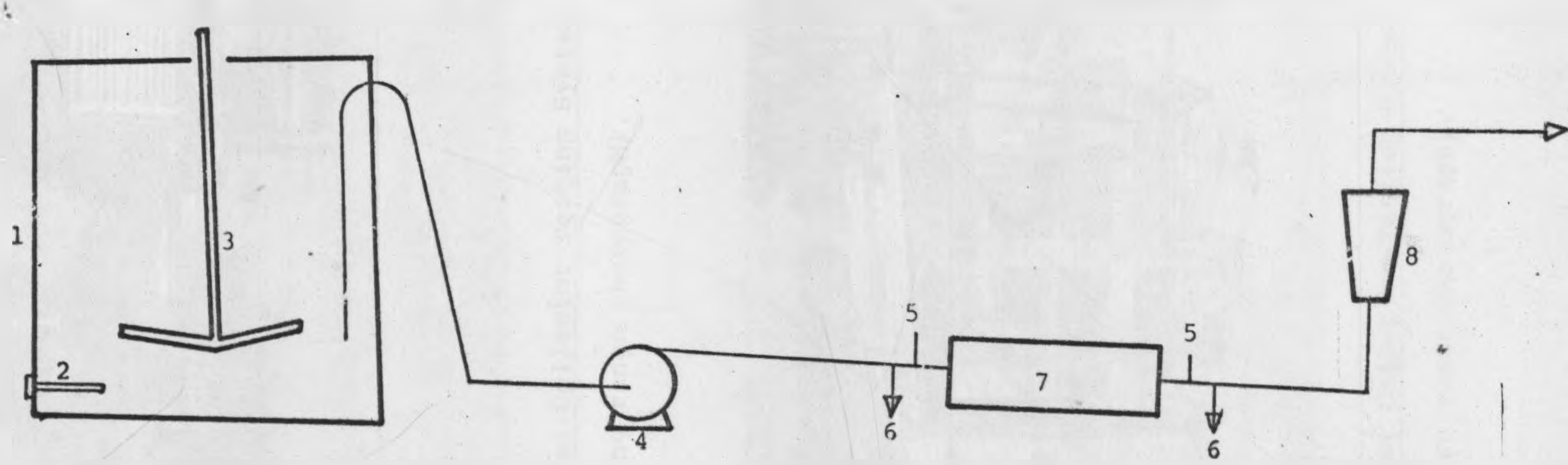
3.1.13. Maximum and Minimum Thermometer (Zeal) for measuring the ambient temperature (range: -35 to 55°C). The thermometer was placed in a shelter having louvred sides (home-made Stephenson's Screen).

3.2. EXPERIMENTAL METHODS

3.2.1. Performance Testing of Solar Collectors

A schematic diagram of the test system is shown in Figure 26. Further details can be seen in Plates 4 and 5. The system is a variant of the test system used by Wang Shing-an (284). The solar collector was tilted 6° from the horizontal plane, facing northwards. The installation was on the DFST Workshop roof-top and measurements were taken only when there was uninterrupted period of sunshine. Measurements were not taken when the insolation was less than 600 W m^{-2} and/or when the wind speed was greater than 6 m s^{-1}. All measurements were taken between 11 a.m. and 3 p.m.

Water was maintained at a desired temperature in the insulated tank (Sections 3.1.2, 3.1.3 & 3.1.4) and pumped through the solar collector (using the pump mentioned in Section 3.1.6) at a constant flow-rate (0.02 kg s^{-1} m^{-2}). The first set of measurements were taken after 30 minutes of operation (at the specified inlet temperature and mass flow-rate). Subsequent measurements were made 15 minutes after changing the inlet water temperature to a new value. Measurements taken included the flow-rate of water (Section 3.1.7), temperature of the inlet water (Section 3.1.11), temperature of the outlet water (Section 3.1.11), ambient temperature (Section 3.1.13), insolation in the plane of the solar collector (Section 3.1.9), pressure drop



1 Insulated Tank
2 3 kW Immersion Heater (x3)
3 Stirrer
4 Pump
5 Temperature Sensors
6 Connections to Manometer
7 Solar Collector
8 Rotameter

Fig. 26. System for Solar Collector Testing

Plate 4. Solar Collector Testing System (long range photograph).

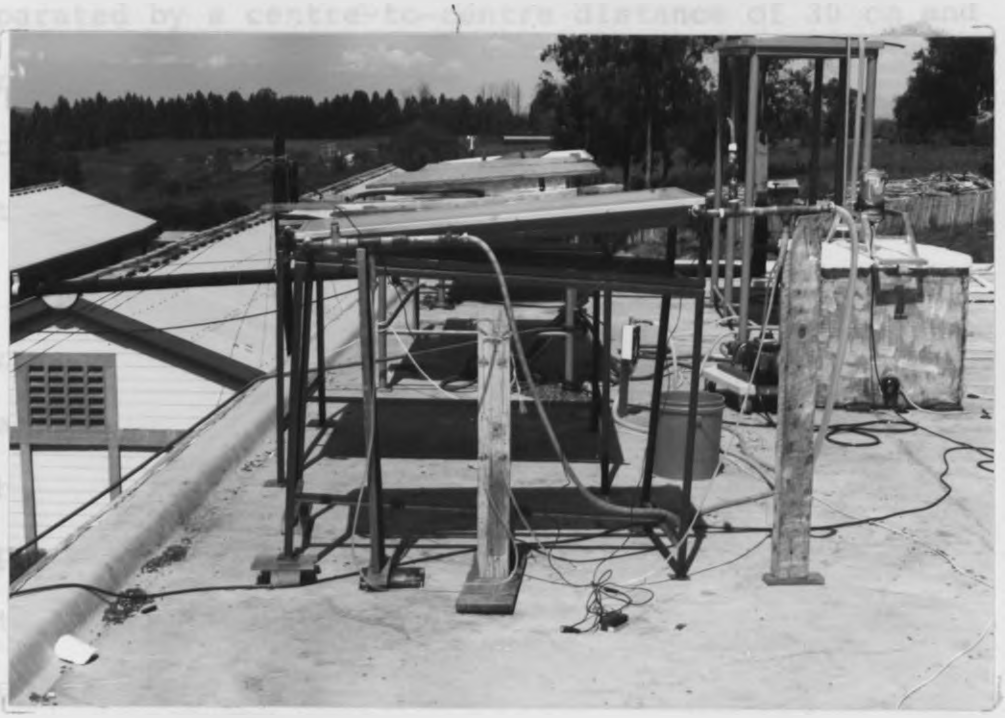


Plate 5. Solar Collector Testing System (close range photograph).

across the collector (Section 3.1.8) and wind speed (Section 3.1.10). The experiment was repeated several times using different values of the inlet water temperature.

3.2.2. Testing of a Thermosyphon Solar Water Heating System.

The system is shown in Figure 27 and Plates 6 and 7. The four solar collectors (Section 3.1.1) were connected to the storage tank (Section 3.1.5) in turn. The solar collectors were tilted as mentioned in Section 3.2.1. Three thermometers (Section 3.1.12) were inserted into the storage tank at different levels in the vertical plane. These three thermometers were separated by a centre-to-centre distance of 30 cm and were 7.5 cm from the top and bottom of the tank, respectively. It was designed so that all three thermometers were always in contact with the water.

The storage tank was filled with water in the morning and the valve in the pipe connecting it to the "header tank" was shut. The water temperature and the ambient temperature (Section 3.1.13) were recorded approximately every hour. The solar radiation intensity was obtained using the solarimeter and recorder (Section 3.1.9).

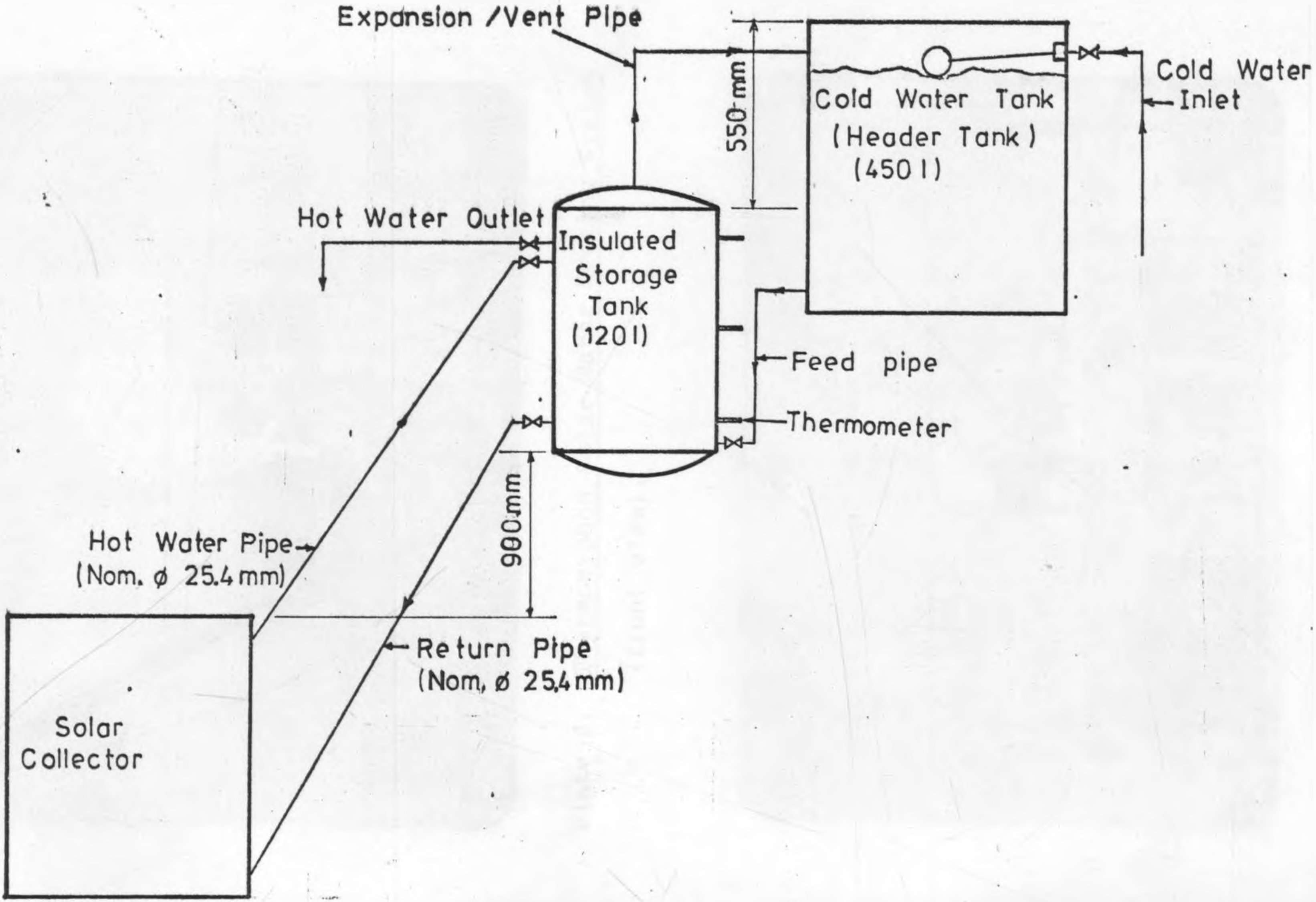


Fig.: 27 Thermosyphon Solar Water Heating System on the DFST Workshop Roof-Top

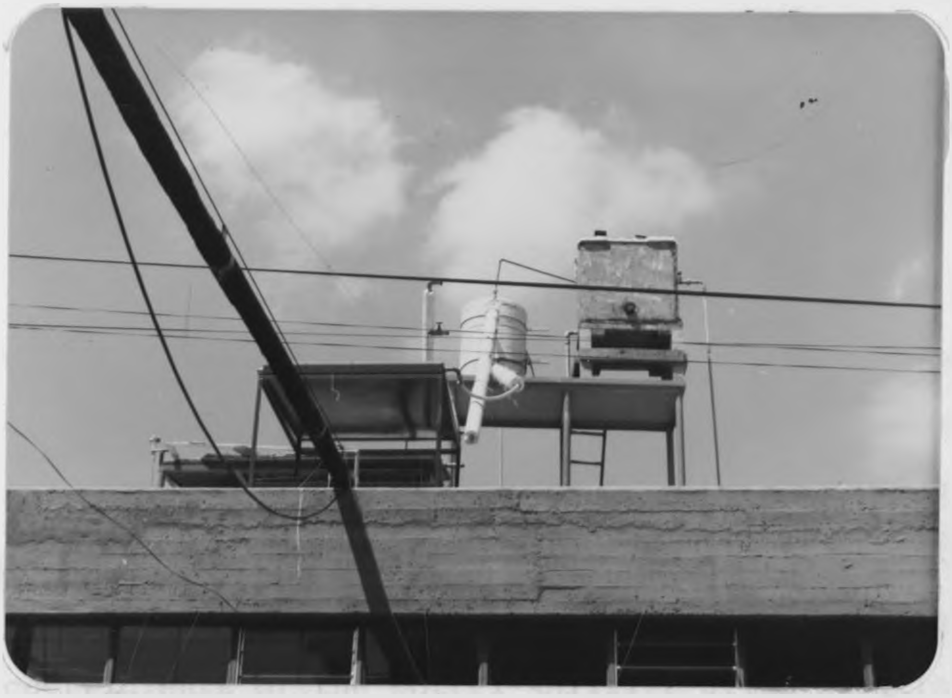


Plate 6. Thermosyphon Solar Water Heating System (front view).

Plate 7. Thermosyphon Solar Water Heating System (side view).

4. RESULTS AND DISCUSSIONS

4.1. Performance Testing of the Solar Collectors

4.1.1. Introduction

It has been shown in Section 2.5 that there is a need for determining the thermal performance of solar collectors. The theoretical basis for a performance test was given in Section 2.5.2. It was shown in Section 2.5.2 that the thermal performance of a flat-plate solar collector can be characterised by the coefficients of the Hottel-Whillier-Bliss equation (Eqn 2.7). Experiments were therefore carried out in order to characterise the thermal performance of the four flat-plate solar collectors A, B, C and D (Section 3.1.1.). The experimental method described in Section 3.2.1. was used.

4.1.2. Results

The experimental data showing the thermal performance of the solar collectors is shown in Tables 13 to 16. The efficiency curves for the solar collectors are shown in Figures 28 to 31. A first-order least-square fit was applied to all the measured data points. The following equations were obtained:

(a) Solar Collector A:

$$\eta = 88.8 - 1314\ (t_i - t_a)/I \qquad \text{..... Eqn 4.1}$$

Correlation coefficient (r) = 0.95

Table 13. Experimental Data Showing the Thermal Performance of Solar Collector A

Experiment No.	Water Flowrate (Kg s^{-1})	Insolation, I (W m^{-2})	Water Inlet Temp., t_i (^oC)	Water Outlet Temp., t_o (^oC)	Ambient Temp., t_a (^oC)	$(t_i-t_a)/I$ (^oC m^2 W^{-1})	Efficiency (%)	Wind Speed (m s^{-1})
1	0.027	955.9	24.2	34.2	22.5	0.00178	84.7	4.5
2	0.027	997.4	34.7	43.0	23.0	0.0117	67.4	4.5
3	0.027	955.9	42.0	49.6	24.0	0.0188	64.4	4.5
4	0.027	748.1	48.4	53.4	24.0	0.0326	54.1	4.2
5	0.027	914.3	68.7	70.7	21.5	0.0516	17.7	3.0
6	0.027	914.3	69.2	71.1	22.0	0.0516	16.8	2.4
7	0.027	945.5	65.5	68.7	22.0	0.046	27.4	3.3
8	0.027	914.3	61.4	66.4	23.5	0.0415	44.3	3.0
9	0.027	914.3	57.0	62.2	24.0	0.0361	46.1	3.6
10	0.027	914.3	52.3	58.6	25.0	0.0299	55.8	1.5
11	0.027	893.5	51.3	56.8	25.0	0.0294	49.9	2.1
12	0.027	914.3	64.4	66.9	27.0	0.0409	21.9	3.0

Solar Collector A

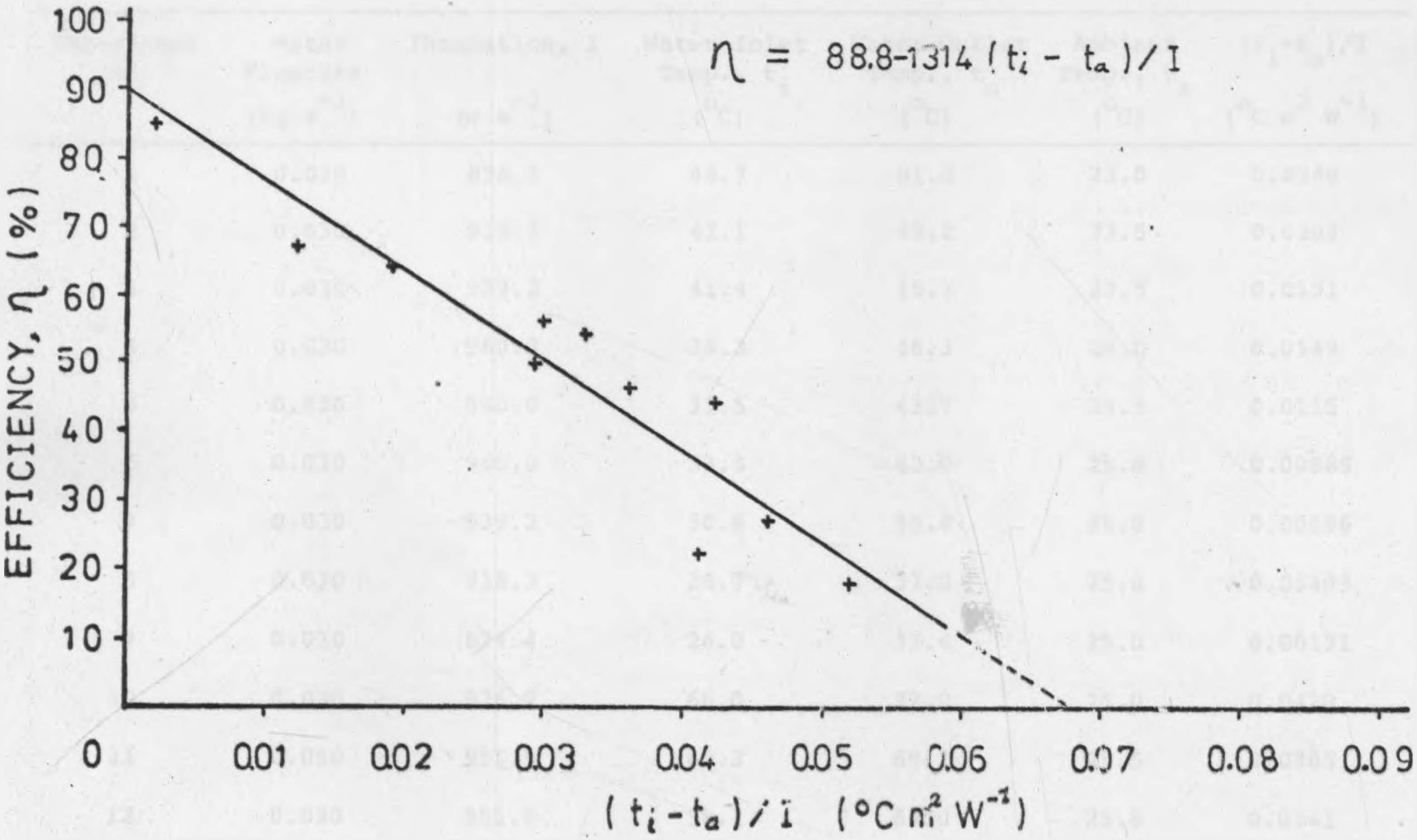


Fig. 28. Collector A Efficiency Curve based on the Water Inlet Temperature and the Effective Collector Area.

Table 14. Experimental Data Showing the Thermal Performance of Solar Collector B

Experiment No.	Water Flowrate ($Kg\ s^{-1}$)	Insolation, I ($W\ m^{-2}$)	Water Inlet Temp., t_i (^oC)	Water Outlet Temp., t_o (^oC)	Ambient Temp., t_a (^oC)	$(t_i-t_a)/I$ ($^oC\ m^2\ W^{-1}$)	Efficiency (%)	Wind Speed ($m\ s^{-1}$)
1	0.030	876.5	44.7	51.2	23.0	0.0248	62.3	4.2
2	0.030	918.3	42.1	49.2	23.5	0.0203	65.0	4.2
3	0.030	939.2	41.4	48.7	23.5	0.0191	65.3	3.9
4	0.030	960.0	38.3	46.3	24.0	0.0149	70.0	4.2
5	0.030	960.0	35.5	43.7	24.5	0.0115	71.7	4.5
6	0.030	960.0	33.5	42.0	25.0	0.00885	74.4	3.9
7	0.030	939.2	30.6	38.8	25.0	0.00596	73.3	4.5
8	0.030	918.3	28.7	37.0	25.0	0.00403	75.9	4.8
9	0.030	824.4	26.0	33.4	25.0	0.00121	75.4	4.5
10	0.030	976.7	66.0	72.0	25.0	0.0420	51.6	3.9
11	0.030	955.9	62.3	69.1	25.5	0.0385	59.7	3.0
12	0.030	955.9	58.1	64.0	25.5	0.0341	51.8	3.3
13	0.030	872.8	51.7	57.4	26.0	0.0294	54.9	3.3
14	0.030	789.6	47.2	52.8	26.0	0.0268	59.6	3.6

Solar Collector B

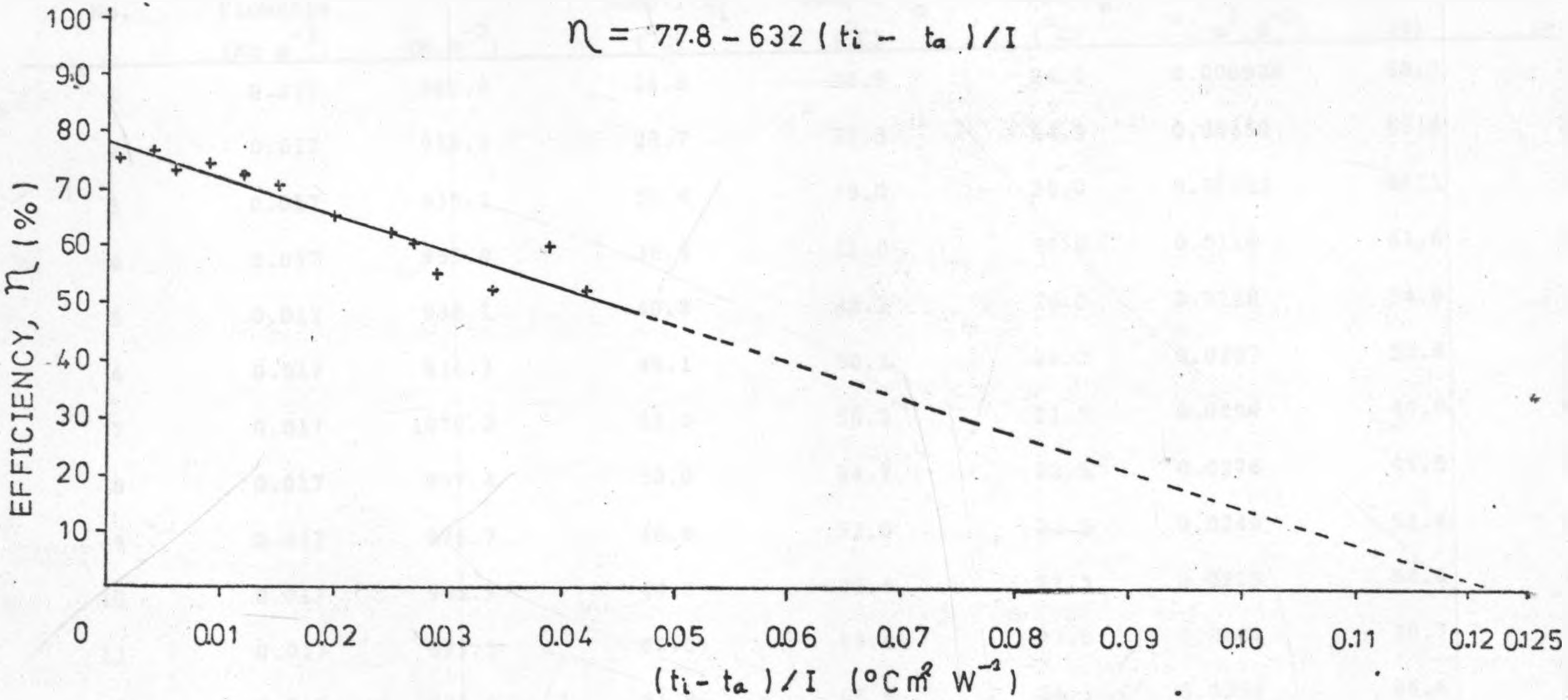


Fig. 29. Collector B Efficiency Curve based on the Water Inlet Temperature and the Effective Collector Area.

Table 15. Experimental Data Showing the Thermal Performance of Solar Collector C

Experiment No.	Water Flowrate ($Kg\ s^{-1}$)	Insolation, I ($W\ m^{-2}$)	Water Inlet Temp., t_i (^oC)	Water Outlet Temp., t_o (^oC)	Ambient Temp., t_a (^oC)	$(t_i - t_a)/I$ ($^oC\ m^2\ W^{-1}$)	Efficiency (%)	Wind Speed ($m\ s^{-1}$)
1	0.017	862.4	24.8	30.9	24.0	0.000928	68.3	2.3
2	0.017	914.3	28.7	35.3	24.5	0.00459	69.6	2.1
3	0.017	935.1	32.6	39.0	25.0	0.00813	66.1	1.9
4	0.017	955.9	36.9	43.0	26.0	0.0114	61.6	3.6
5	0.017	935.1	40.8	46.1	26.0	0.0158	54.6	3.3
6	0.017	914.3	45.1	50.1	26.2	0.0207	52.8	3.6
7	0.017	1070.2	53.0	58.2	21.5	0.0294	46.8	4.5
8	0.017	997.4	50.0	54.7	22.5	0.0276	45.5	4.8
9	0.017	976.7	46.8	52.0	22.5	0.0249	51.4	3.9
10	0.017	955.9	44.0	49.4	22.5	0.0225	54.6	4.2
11	0.017	893.5	66.5	69.4	23.0	0.0487	30.7	4.2
12	0.017	955.9	61.8	65.5	24.5	0.0390	36.6	4.5
13	0.017	955.9	58.5	61.9	25.0	0.0350	33.6	4.5
14	0.017	914.3	55.7	59.4	25.0	0.0336	38.3	4.5

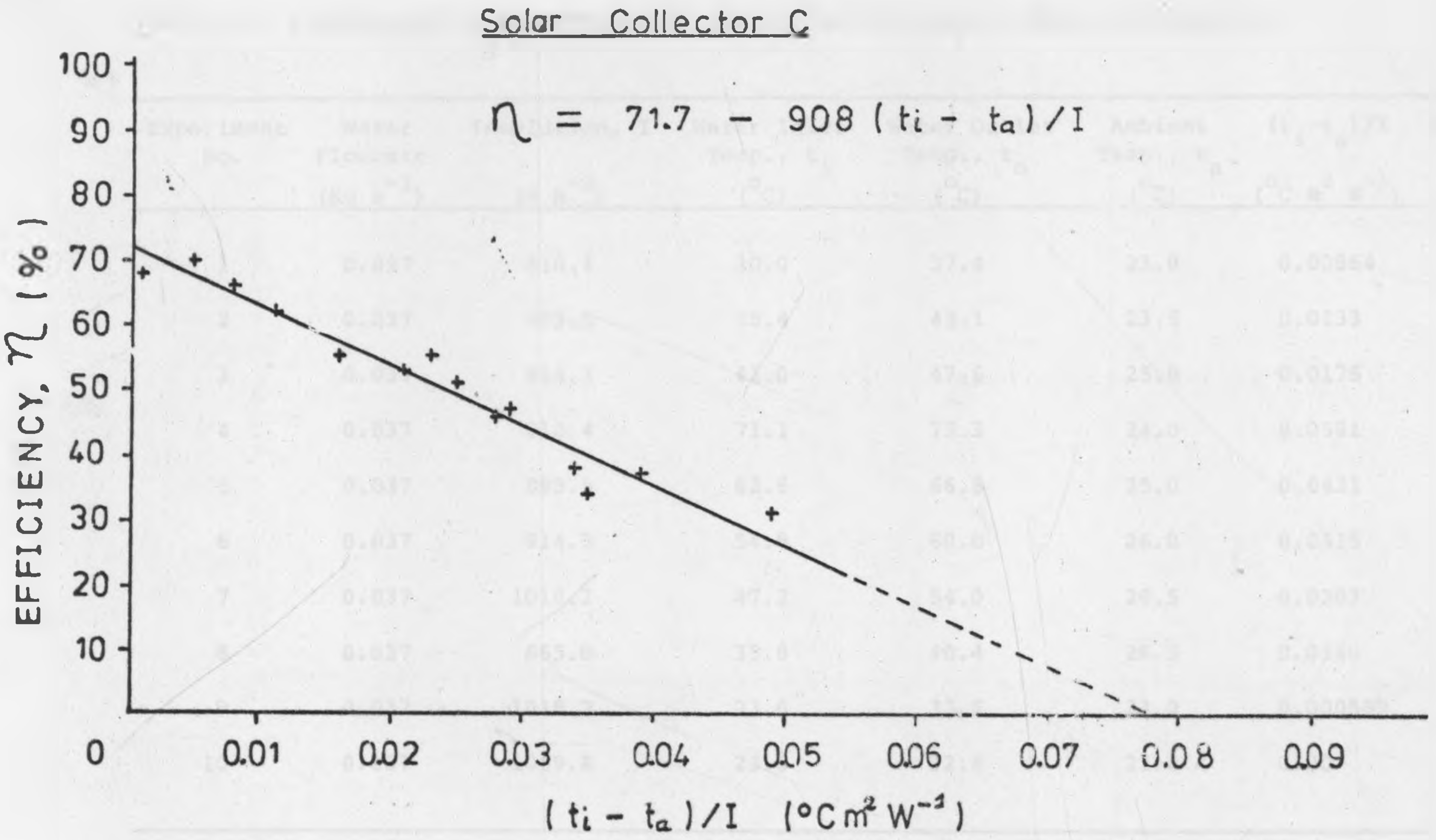


Fig. 30. Collector C Efficiency Curve based on the Water Inlet Temperature and the Effective Collector Area

Table 16. Experimental Data Showing the Thermal Performance of Solar Collector D

Experiment No.	Water Flowrate (Kg s^{-1})	Insolation, I (W m^{-2})	Water Inlet Temp., t_i (^oC)	Water Outlet Temp., t_o (^oC)	Ambient Temp., t_a (^oC)	$(t_i - t_a)/I$ (^oC m^2 W^{-1})	Efficiency (%)	Wind Speed (m s^{-1})
1	0.037	810.4	30.0	37.4	23.0	0.00864	76.8	2.0
2	0.037	893.5	35.4	42.1	23.5	0.0133	63.0	2.3
3	0.037	914.3	41.0	47.6	25.0	0.0175	60.6	1.4
4	0.037	810.4	71.1	73.3	24.0	0.0581	22.8	2.1
5	0.037	893.5	62.6	66.8	25.0	0.0421	39.5	2.2
6	0.037	914.3	54.8	60.0	26.0	0.0315	47.8	2.1
7	0.037	1018.2	47.2	54.0	26.5	0.0203	56.1	2.3
8	0.037	665.0	35.8	40.4	26.5	0.0140	58.1	3.1
9	0.037	1018.2	23.6	33.5	23.0	0.000589	81.6	1.5
10	0.037	1059.8	23.0	32.6	23.0	0.00	76.1	1.2

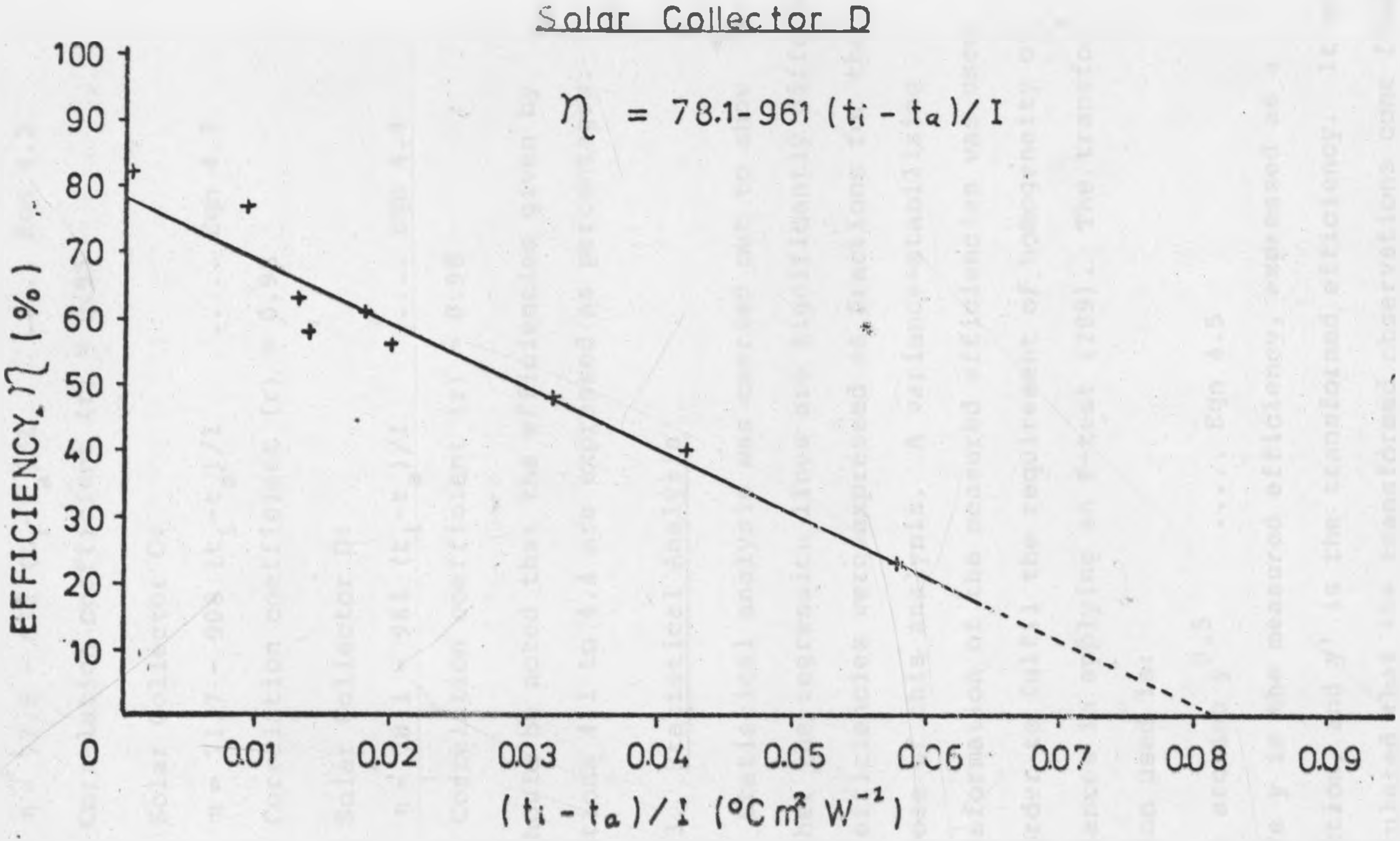


Fig. 31. Collector D Efficiency Curve based on the Water Inlet Temperature and the Effective Collector Area

(b) Solar Collector B:

$\eta = 77.8 - 632\ (t_i - t_a)/I$ ..... Eqn 4.2

Correlation coefficient (r) = 0.95

(c) Solar Collector C:

$\eta = 71.7 - 908\ (t_i - t_a)/I$ ..... Eqn 4.3

Correlation coefficient (r) = 0.98

(d) Solar Collector D:

$\eta = 78.1 - 961\ (t_i - t_a)/I$ ..... Eqn 4.4

Correlation coefficient (r) = 0.98

It should be noted that the efficiencies given by Equations 4.1 to 4.4 are expressed as percentages.

4.1.3. Statistical Analysis

Statistical analysis was carried out to show whether the regression lines are significantly different. The efficiencies were expressed as fractions for the purpose of this analysis. A variance-stabilising transformation of the measured efficiencies was used in order to fulfil the requirement of homogeneity of variances in applying an F-test (289). The transformation used is:

$y' = \text{arcsine}\ y^{0.5}$ ..... Eqn 4.5

where y is the measured efficiency, expressed as a fraction, and y' is the transformed efficiency. It was postulated that the transformed observations come from normal distributions with the same unknown variance. All four solar collectors were first considered.

Testing problem:

H_o : The four regression lines are the same

H_1 : The four regression lines are not the same.

Outcome of F-test: f = 13.24.

The critical value of the f-distribution with 6 and 42 degrees of freedom (0.02 level of significance) is 3.26.

Since f is higher than the critical value it was concluded that the four regression lines are not the same.

F-tests were then carried out to see if any two of the four solar collectors had the same regression line. The six possible combinations are A-D, B-D, C-D, A-B, A-C and B-C. The results of the F-tests are shown in Table 17. The statistical analysis showed that the regression lines for the solar collectors A and D are the same at the 0.02 level of significance. All the other combinations of solar collectors were shown to be different at the 0.02 level of significance.

4.1.4. Discussion

As shown in Section 2.5.2., the thermal performance of a solar collector is characterised by the product of the collector heat removal factor and the effective transmittance-absorptance product ($F_R(\tau\alpha)_e$) as well as the product of the collector heat removal factor and the heat loss coefficient (F_RU_L). It can be seen from Equations 4.1 to 4.4 that the $F_R(\tau\alpha)_e$

Table 17. Comparison of the Efficiency Curves Using F-tests

Solar Collector Combination	f Value	Critical Value of f (at 0.02 level)	Conclusion*
A - D	2.95	6.02	+
B - D	14.66	5.85	-
C - D	7.13	5.85	-
A - B	15.09	5.72	-
A - C	8.67	5.72	-
B - C	67.96	5.61	-

* + The null hypothesis that the two regression lines are the same is accepted at the 0.02 level of significance.

\- The null hypothesis is rejected at the 0.02 level of significance.

values are 0.72, 0.78, 0.78 and 0.89 for the solar collectors C, B, D and A, respectively. The $F_R U_L$ values are 9.08, 6.32, 9.61 and 13.14 W $m^{-2}K^{-1}$ for the solar collectors C, B, D and A, respectively.

Smith and Weiss (285) have discussed the significance of the factors $(\tau\alpha)_e$, F_R and U_L:

(i) The effective transmittance-absorptance product ($(\tau\alpha)_e$) represents the complex interaction of optical properties in the solar radiation wavelengths. It is slightly larger than the direct product of the cover transmittance and absorber absorptance because some of the radiation reflected from the absorber is returned to the absorber due to the cover reflectance (the increase is typically about 5%). The effective transmittance-absorptance product is influenced by the cover transmittance, the number of covers, the absorptance of the absorber plate, and the solar angle of incidence.

(ii) The collector heat removal factor, F_R, is influenced by the heat transfer resistance between the heated absorber surface and the collector fluid. It is affected by the design of the absorber plate and by the properties of the collector fluid. F_R is also affected by the flow-rate of the collector fluid.

(iii) The heat loss coefficient, U_L, is influenced by the number and spacing of covers and by the conditions within the spaces, such as honeycombing and evacuation. It is also influenced by the longwave radiative properties of the absorber and covers and by the wind speed. Top heat loss is reduced by the absorption of shortwave radiation in the collector covers. Glass covers absorb more shortwave radiation than do other transparant materials.

The results given in Section 4.1.2 can be explained as follows:

Solar Collector A had the highest $F_R(\tau\alpha)_e$ value mainly because the PVC film cover had the highest transmittance, with regard to solar radiation. Solar collector B, which had the lowest value of F_RU_L, had a selective absorber surface and the outer surface of the glass cover was treated to minimise the transmission of longwave radiation from the absorber surface. The solar collector A had the highest value of F_RU_L because the PVC film cover had the highest transmittance, with regard to the longwave radiation emitted by the absorber.

In their brochure, the manufacturers of solar collector B have given the results of tests carried out in Highett, Australia on a similar collector. They used a water flow-rate of 0.01 kg s^{-1} m^{-2} and the insolation was 1000 W m^{-2}. They obtained $F_R(\tau\alpha)_e$ and F_RU_L values of 0.779 $\pm$ 0.041 and 5.134 $\pm$ 0.144 W $m^{-2}K^{-1}$, respectively. It can be seen that their value of $F_R(\tau\alpha)_e$ agrees with that obtained by the author. However, their F_RU_L value is less than that obtained by the author by 18.8%. Reasons for this discrepancy are discussed below:

It is quite possible that the two solar collectors used in the tests are not similar in every detail. Even if the solar collectors were exactly similar, one would still expect variations in the results obtained by different people testing in different parts of the world. It is appropriate here to mention the results of a study carried out by Streed et al. (258) in the United States. Efficiency tests on two types of water heating flat-plate collectors were performed at 21 test facilities, distributed across the United States, using a common test procedure. Standard deviations were calculated for $F'(\tau\alpha)_e$ values and found to be $\pm$ 0.05 (or 6.8%) for one collector and $\pm$ 0.036 (or 4.6%) for the second collector. Standard deviations for $F'U_L$ values were found to be $\pm$ 1.01 W $m^{-2}K^{-1}$ (or 15.8%) for one collector and $\pm$ 0.775 W $m^{-2}K^{-1}$ (or 16.8%) for the second collector. Further analysis carried out by Streed et al. (258) indicated that the primary reason for the differences in the experimental values resulted from experimental error or systematic differences from facility to facility rather than from different outdoor test environments.

The experimental values obtained by the author are certainly of the expected order of magnitude. Beard et al. (270) have given efficiency curves for some flat-plate solar collectors with one or two glass covers having $F_R(\tau\alpha)_e$ values varying from 0.68 to 0.74 and F_RU_L values varying from 3.82 to 9.08 W m^{-2} K^{-1}.

The comparative thermal performance of the four solar collectors A, B, C and D can be seen in Figure 32. The theoretical maximum temperature attainable by the collectors A, B, C and D are 85.2, 134.7, 94.2 and 97.4°C, respectively, if the insolation is 900 W m^{-2} and the ambient temperature is 24°C. The solar collector B is thus the most suitable for use in the food processing industry (solar collector A is the least suitable in this regard). It is clear that on the basis of efficiency alone the choice of the most suitable solar collector depends on the operating temperature. This can be illustrated assuming operating conditions of 900 W m^{-2} insolation and an ambient temperature of 24°C. Under these conditions solar collector A is the most efficient collector for inlet temperatures less than 39.3°C while for inlet temperatures above 39.3°C solar collector B is more efficient. Solar collector A becomes less efficient than solar collectors D and C above 52.8°C and 64.1°C, respectively. Solar collector D is more efficient

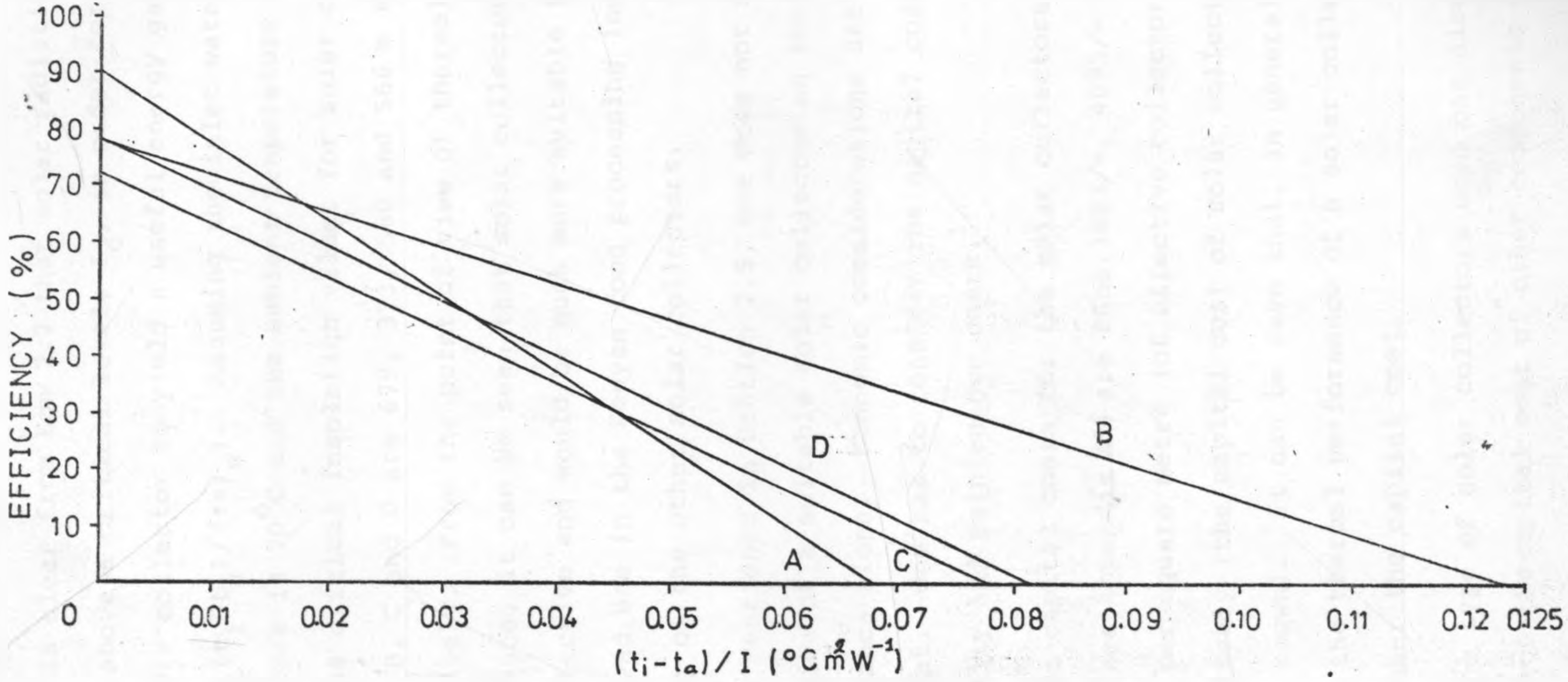


Fig. 32.Comparison of the Thermal Performance of Solar Collectors A, B, C and D.

than solar collector C at any operating temperature.

It is clear from Eqn 2.7 that solar radiation must be above a critical level, I_c, in order for a flat-plate collector to yield a useful energy gain ($I_c = U_L(t_i-t_a)/(\tau\alpha)_e$). Assuming the inlet water temperature is 70°C and the ambient temperature is 24°C, the critical insolation values for solar collectors A, B, C and D are 679, 373, 580 and 566 W m^{-2}, respectively. From the point of view of thermal performance, it can be seen that solar collector B is more effective and would be much more suitable for widespread use in the Kenyan food processing industry than any of the other solar collectors.

As mentioned in Section 2.5, one does not base the choice of a suitable solar collector on thermal performance alone. Economic considerations are also important. One has to consider the capital costs, durability and maintenance costs.

The capital costs for the solar collectors A, B and C (see Appendix X1) are KShs.1083/=, 4095/= and 3148/= per square metre (of effective collector area), respectively (the capital cost of solar collector D is not known). It can be seen that, in general, the better the thermal performance of a solar collector the higher the capital cost.

The type of solar collectors used can also influence the capital cost of other components of a solar water heating system. In a thermosyphon solar water heating system, the pressure drop across the solar collector(s) would influence the size of the connecting pipes and hence the total cost of the system. For a system using a pump, the pressure drop across the solar collector(s) would influence the size of the pump and hence the total cost of the system.

In this study, the measured pressure drop across solar collectors A, B, C and D at 30°C and a flow-rate of 0.02 kg s^{-1} m^{-2} was 441, 68.7, 34.3 and 137 N m^{-2}, respectively. It appears that the pressure drop across all the solar collectors is so low that it would not be a deciding factor in selecting a suitable solar collector. Simon (260), using solar collectors having areas varying from 0.53 m^2 to 2.04 m^2, measured pressure drops ranging from 276 to 6481 N m^{-2} (at a flow-rate of 0.02 kg s^{-1} m^{-2} and ambient temperature). It is clear that there are wide variations in the pressure drop across different types of flat-plate solar collectors.

Durability is a critical factor in the choice of a suitable solar collector for a given duty. A good solar collector should be able to last for over 15 to 20 years with minimal maintenance costs. The life-time of various solar collectors in Kenya is not known with certainty. This knowledge can only come with practical experience gained under local conditions.

There is no doubt, however, that the solar collector A made by the author is the least durable of the four solar collectors studied. The PVC film is not expected to last for a long time, it has to be replaced whenever it wears out. It was used because it was the only suitable plastic film available. Other plastic films which have been considered for covers for solar collectors include a fluorocarbon film, Teflon, a polyvynyl fluoride film, Tedlar, and a polyester film, Mylar type W (286, 287). The projected lifetimes of the three plastic films exposed to Florida (USA) weather conditions have been reported as Teflon, 20 + years; Tedlar, 9 years; Mylar type W, 4 years (286). Another source of weakness for solar collector A is the soldering round the rivets and around the edges which is liable to cause leakage of water.

Solar collector B performed much better than the other solar collectors because of the selective coating on the absorber surface. However, doubts have been expressed as to the long-term stability of selective surfaces (104).

4.2. Testing of the Performance of the Thermosyphon Solar Water Heating System.

4.2.1. Introduction

Thermosyphon solar water heating systems (Section 2.6) are widely used to provide hot water. The results of detailed studies on the performance of these systems in Kenya are largely unavailable. A thermosyphon solar water heating system was installed by the author on the DFST Workshop roof-top (see Figure 27 and Plates 6 and 7) and tested as described in Section 3.2.2.

4.2.2. Results and Discussion

The variation of the temperature of water at the bottom, middle and top of the storage tank of the thermosyphon solar water heating system using the solar collectors A, B, C and D on specified days is shown in Tables 18 to 21. Low temperatures were obtained because of the large size of the storage tank (120 l instead of the recommended 50-63 l per m^2 of collector). Figures 33 to 36 clearly show the thermal performance of the system. From these Figures it was possible to calculate the efficiency of the system using different solar collectors. The efficiency is defined as the percentage of the total solar energy incident on the absorber surface in a specified period which is transferred to the water in the storage tank. It must be emphasised that the efficiency represents the performance of the solar water heating system as a whole is not limited to the solar collector unit. The efficiencies, between 12:00 noon and 3:00 p.m., for the thermosyphon solar water heating system using solar collectors A, B, C and D were 52.6%, 49.9%, 46.6% and 41.0%, respectively. One would expect the efficiency to depend on the operating temperature (in the storage tank), the higher the temperature the lower the efficiency. This is indeed the case in this study. The system attained no more than 37°C when it was tested using solar collector A while a maximum temperature of 57°C was attained when testing with solar collector D. The ambient temperature and wind speed also influence the efficiency of a thermosyphon solar water heating system. The average efficiencies of ten different solar collector designs tested in South Africa were found to lie between 48 and 58% (8).

The rate of increase of temperature (per m^2) between 12:00 noon and 3:00 p.m. was also calculated. The rates of temperature rise for the thermosyphon solar water heating system using solar collectors A, B, C and D were 2.0, 2.4, 2.5 and 2.5$^{\circ}C\ h^{-1}\ m^{-2}$, respectively. The rate of increase of temperature is influenced by both the efficiency of the system and the intensity of solar radiation incident on the collector. The average insolation (between 12:00 noon and 3:00 p.m.) when the thermosyphon solar water heating system was tested using solar collectors A, B, C and

D was 518, 666, 744 and 841 W m^{-2}, respectively.

The manufacturers of solar collector C have indicated in their brochure that on an average day in April the solar collector heats 44.9 litres of water to 60°C at Dagoretti, Nairobi using a thermosyphon system. This is equivalent to a rate of temperature rise of 2.7°C h^{-1} m^{-2} and an efficiency of 49.6% for 120 l of water (using the average climatological data of 19.26 MJ m^{-2} d^{-1} daily insolation, 22°C ambient temperature, 7 hours of sunshine per day). The values obtained by the author are in fairly good agreement with those estimated from the information given by the manufacturers.

Table 18. Variation of the Temperature of Water in the Storage Tank of the Thermosyphon Solar Water Heating System Using Solar Collector A on 14th June 1983.

Standard Local Time (Hours)	Temp. at the Bottom of the Storage Tank, t_1 (^{o}C)	Temp. in the Middle of the Storage Tank, t_2 (^{o}C)	Temp. at the Top of the Storage Tank, t_3 (^{o}C)	Average Water Temp. $((t_1+t_2+t_3)/3)$ (^{o}C)	Ambient Temperature (^{o}C)
10:00	22.0	23.5	25.0	23.5	16.0
11:10	22.0	23.5	25.0	23.5	17.5
12:00	22.5	25.5	28.5	25.5	19.5
14:10	28.0	32.0	34.0	31.3	21.5
15:00	30.0	34.0	37.0	33.7	23.0
16:00	32.0	36.0	38.0	35.3	23.0
16:45	34.0	37.0	38.0	36.3	23.0

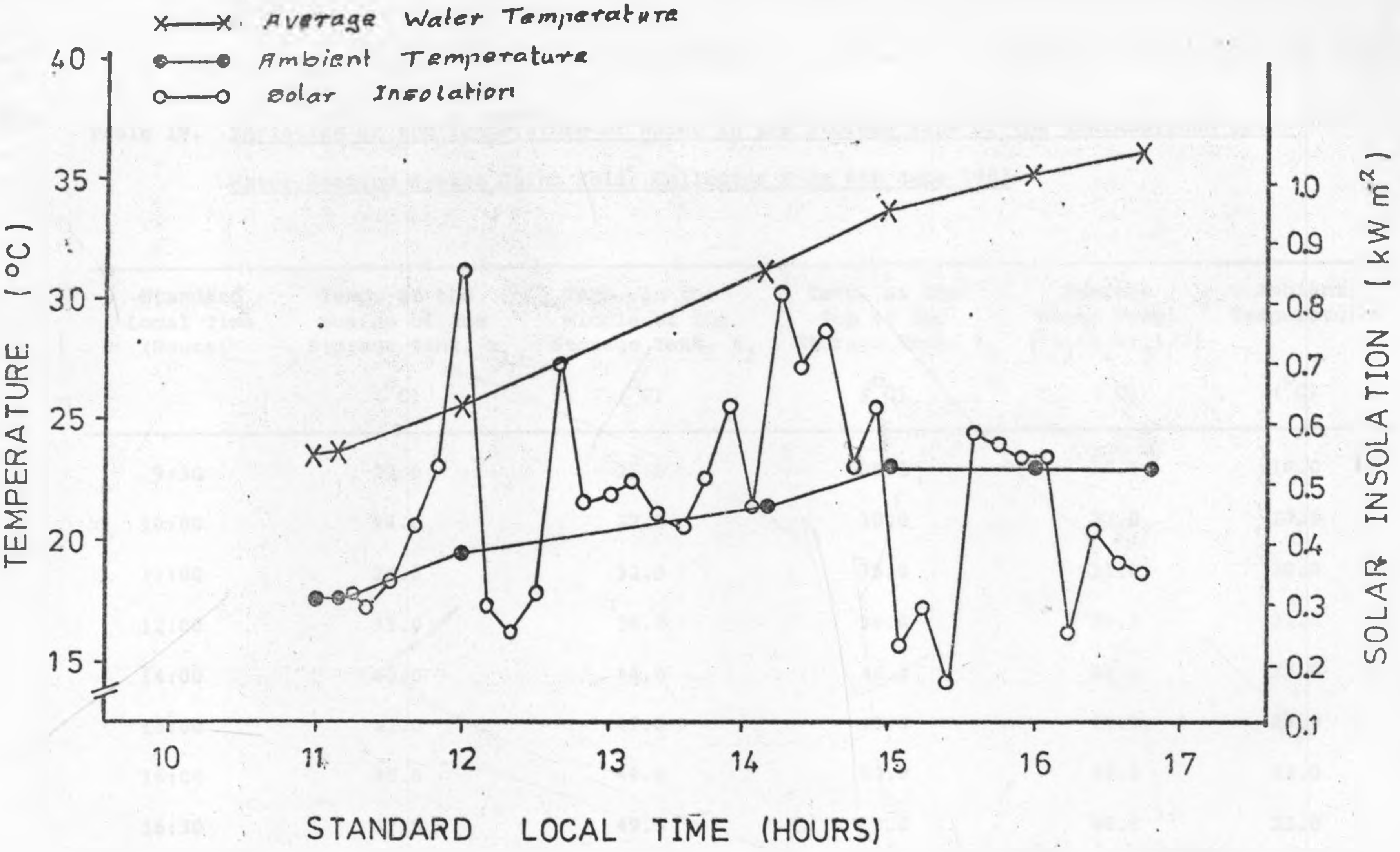


Fig. 33: Performance of the Thermosyphon Solar Water Heating System Using Solar Collector A on 14th June 1983.

Table 19. Variation of the Temperature of Water in the Storage Tank of the Thermosyphon Solar Water Heating System Using Solar Collector B on 8th June 1983.

Standard Local Time (Hours)	Temp. at the Bottom of the Storage Tank, t_1 (°C)	Temp. in the Middle of the Storage Tank, t_2 (°C)	Temp. at the Top of the Storage Tank, t_3 (°C)	Average Water Temp. $((t_1+t_2+t_3)/3)$ (°C)	Ambient Temperature (°C)
9:30	23.0	25.0	28.5	25.5	16.0
10:00	24.0	27.0	30.0	27.0	17.5
11:00	26.0	32.0	35.0	31.0	20.0
12:00	31.0	36.0	39.0	35.3	21.0
14:00	40.0	44.0	46.0	43.3	22.5
15:00	42.0	47.0	49.0	46.0	23.0
16:00	46.0	49.0	50.0	48.3	23.0
16:30	47.0	49.5	50.0	48.8	23.0

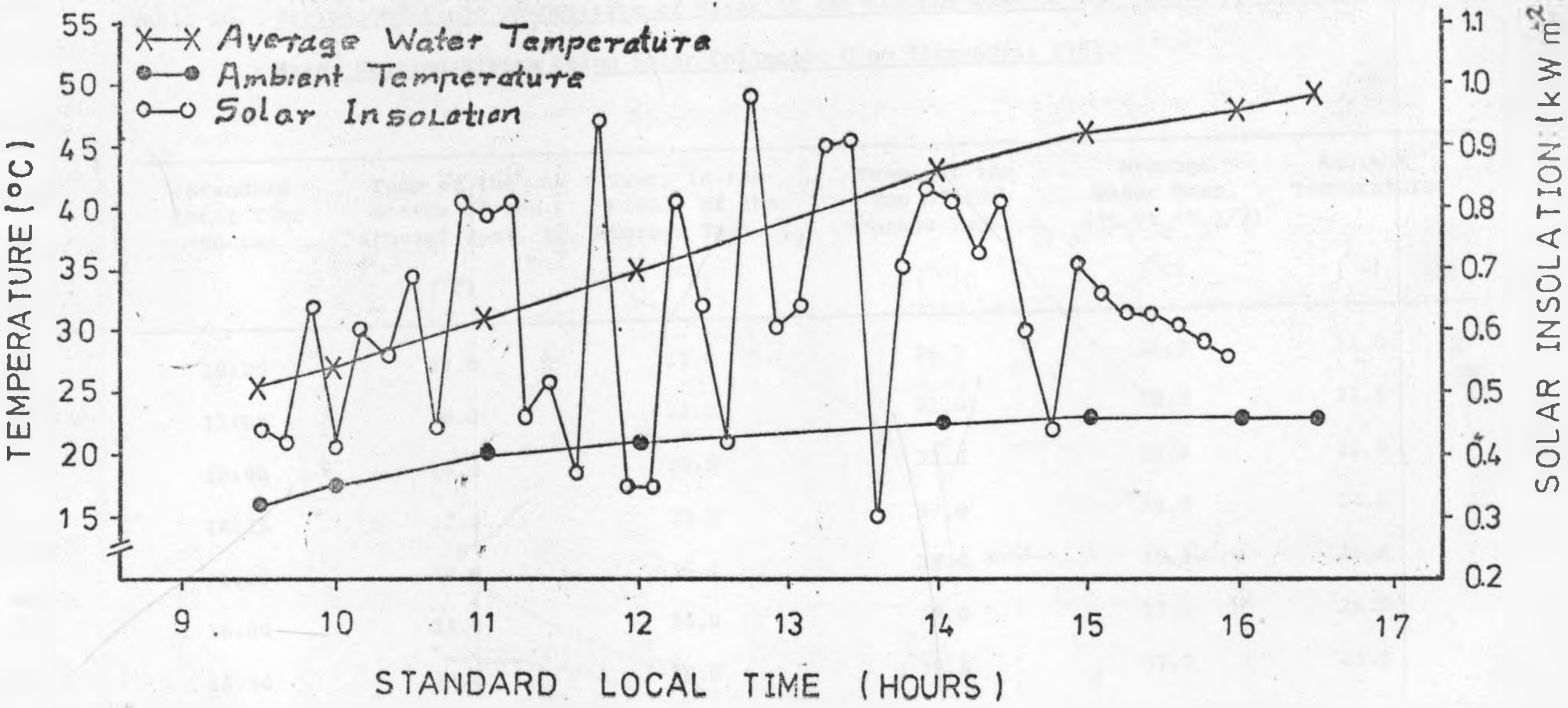


Fig. 34. Performance of the Thermosyphon Solar Water Heating System Using Solar Collector B on 8th June 1983.

Table 20. Variation of the Temperature of Water in the Storage Tank of the Thermosyphon Solar Water Heating System Using Solar Collector C on 15th April 1983.

Standard Local Time (Hours)	Temp at the Bottom of the Storage Tank, t_1 (°C)	Temp. in the Middle of the Storage Tank, t_2 (°C)	Temp. at the Top of the Storage Tank, t_3 (°C)	Average Water Temp. $((t_1+t_2+t_3)/3)$ (°C)	Ambient Temperature (°C)
10:25	22.0	27.0	28.0	25.7	21.0
11:05	26.0	28.0	31.0	28.3	21.5
12:00	26.0	30.5	33.0	29.8	22.5
14:15	32.0	35.5	37.0	34.8	24.0
15:00	32.0	36.0	38.0	35.3	25.0
16:00	34.0	38.0	39.0	37.0	26.0
16:30	34.0	38.0	39.0	37.0	25.0

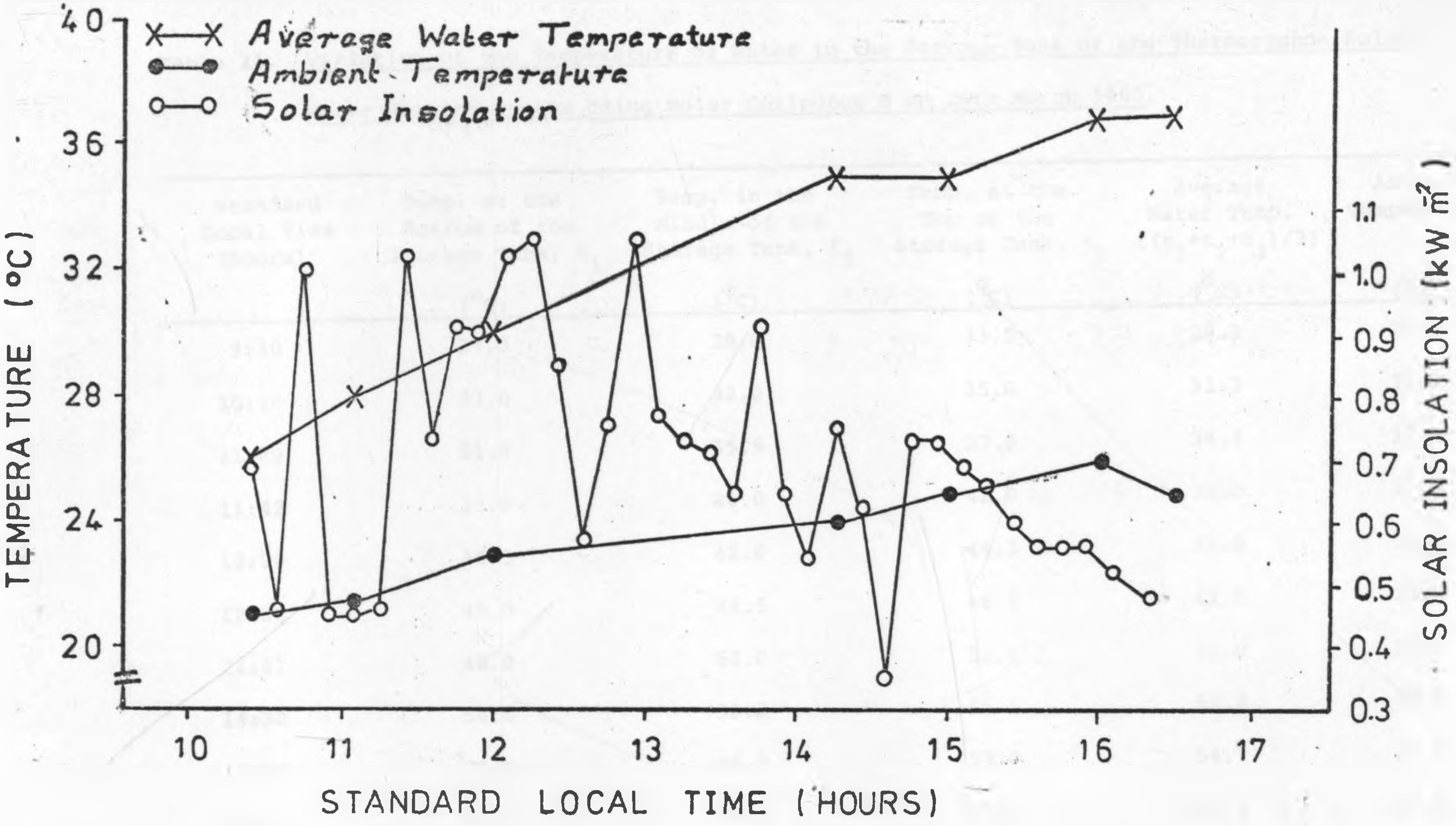


Fig. 35. Performance of the Thermosyphon Solar Water Heating System Using Solar Collector C on 15th April 1983.

Table 21. Variation of the Temperature of Water in the Storage Tank of the Thermosyphon Solar Water Heating System Using Solar Collector D on 26th March 1983.

Standard Local Time (Hours)	Temp. at the Bottom of the Storage Tank, t_1 (°C)	Temp. in the Middle of the Storage Tank, t_2 (°C)	Temp. at the Top of the Storage Tank, t_3 (°C)	Average Water Temp. $((t_1+t_2+t_3)/3)$ (°C)	Ambient Temperature (°C)
9:40	27.0	28.0	33.5	29.5	20.0
10:10	27.0	32.0	35.0	31.3	21.0
11:00	31.0	35.5	37.0	34.5	22.0
11:42	35.0	40.0	42.0	39.0	23.5
12:00	36.5	42.0	44.5	41.0	24.0
12.30	40.0	44.5	46.0	43.5	24.0
14:07	48.0	52.0	53.0	51.0	26.5
14:30	50.0	53.0	55.5	52.8	26.5
15:00	51.0	56.0	57.0	54.7	27.0
15:30	51.0	56.0	57.0	54.7	27.0
16:00	49.0	55.0	56.0	53.3	27.0

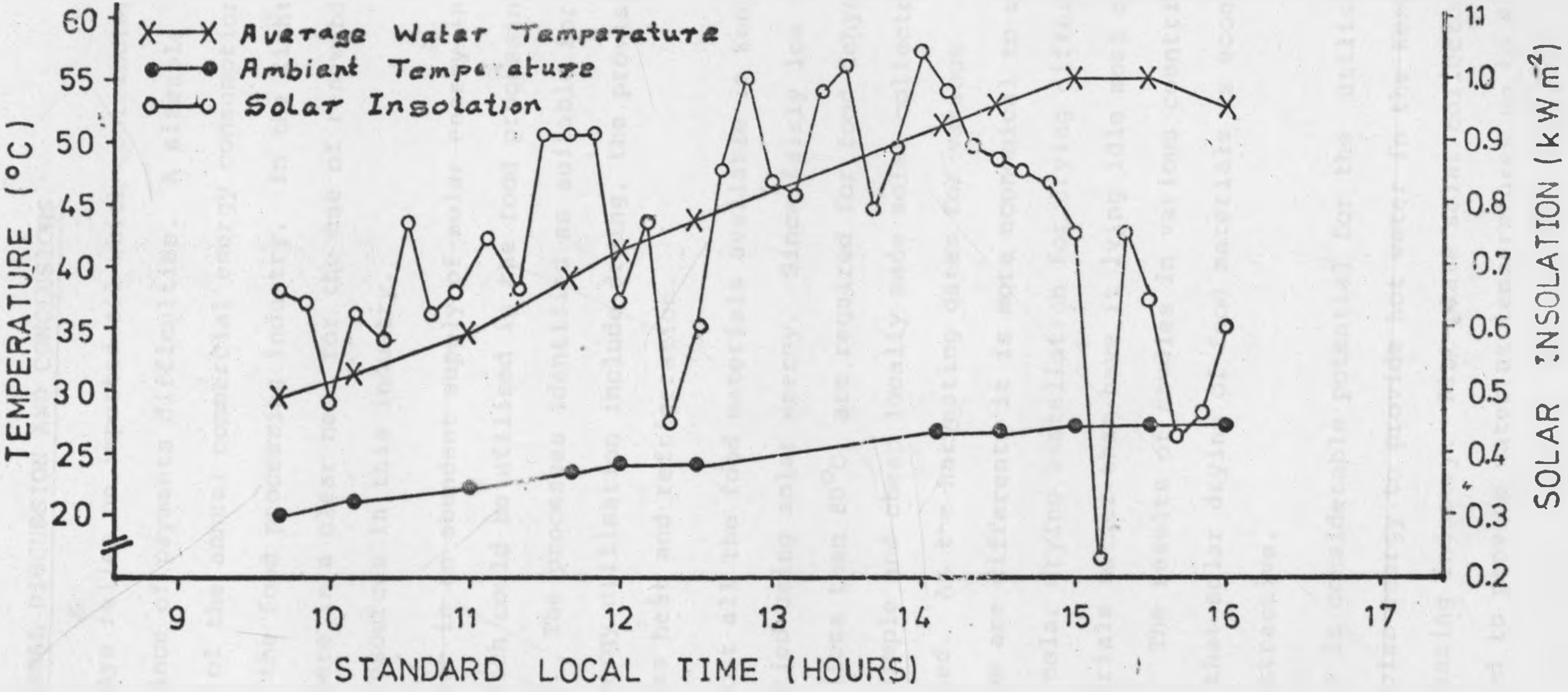


Fig. 36. Performance of the Thermosyphon Solar Water Heating System Using Solar Collector D on 26th March 1983

5. GENERAL DISCUSSION AND CONCLUSIONS

Kenya relies on imported oil which contributes to the balance of payments difficulties. A sizeable portion of the annual commercial energy consumption goes to the food processing industry. In the light of this, there is a clear need for the use of renewable energy resources in this industry.

There is an abundant supply of solar energy in Kenya which could be utilised in the food processing industry. The processes identified as suitable for solar energy utilisation include drying, the provision of process heat and refrigeration.

Almost all the food materials available in Kenya can be dried using solar energy. Since fairly low temperatures (less than 80°C) are required for food dehydration, simple and cheap locally made solar collectors can be used. As the harvesting dates for various food crops are different, it is more economical to use the same solar drying installation for drying different food materials rather than have it lying idle most of the year. The results of studies in various countries indicate that solar drying of food materials is economically attractive.

There is considerable potential for the utilisation of solar energy to provide hot water in the Kenyan food processing industry. Flat-plate solar collectors can be used to provide water at temperatures up to 85°C.

Concentrating solar collectors can be used to provide water at higher temperatures. The main use of hot water in the food processing industry is for cleaning and rinsing which require water at rather low temperatures of between 40 and 80°C. In addition, many food processing operations are carried out at temperatures below 100°C and process heat for these processes can be provided via hot water. Studies carried out in some parts of the USA have indicated that the use of solar energy to provide at least part of the energy required for water heating in the food processing industry is economically feasible. One would therefore expect the use of solar energy to provide process heat in the Kenyan food processing industry to be promising. The use of solar energy is most promising in those plants which operate throughout the year.

An undoubted need exists for the provision of more refrigeration facilities in Kenya. The conventional vapour-compression refrigerators cannot be used in remote rural areas without a supply of electricity or the use of an expensive generator. Even where electricity is available, the running costs are considerable. The conventional absorption-type refrigerators utilising kerosene or fuel-gas could, in principle, be used anywhere in the country but the question of availability of the fuel and its price would greatly hamper their widespread use in rural areas. There is thus a need for the development and use of solar-powered refrigeration systems. Solar-powered refrigeration is technically feasible. However, in places where conventional fuel supplies are readily available, their economic attractiveness is still marginal when compared with more conventional refrigerators. Looked at on a national level, from the point of view of savings in conventional energy supplies and the need for exploiting available natural resources, widespread use of solar-powered refrigerating systems is certainly attractive.

The author has used an objective method to compare the thermal performance of four different types of flat-plate solar collectors (including one made by the author). The attractiveness of the method of testing used lies in the fact that no sophisticated instrumentation and control systems were used. Efficiency curves (based on the Hottel-Whillier-Bliss Equation) for the four solar collectors have been obtained. The efficiency curves for solar collectors are useful both in selecting a suitable solar collector from a given number of different types and in designing and predicting the long-term performance of solar energy systems. It was found that even relatively cheap flat-plate solar collectors made using, as far as possible, locally available materials can perform quite well. The important question of durability of the flat-plate solar collectors will have to await practical experience gained under local conditions. Indications are that flat-plate solar collectors with selective absorber surfaces are most suitable for use in the food processing industry. A detailed feasibility study would, however, have to be carried out in each specific case before arriving at the optimum solar energy system.

Thermosyphon solar water heating systems have the advantage that they are simple and do not rely on electrical power supply for operation (other than via a booster heater). Consequently, they could be used even in remote rural areas. Performance tests carried out on these systems by the author using the four different types of flat-plate solar collectors described in Section 3.1.1. showed that efficiencies of between 41.0 and 52.6% can be achieved when using the thermosyphon solar water heating system constructed in the DFST,Kabete.

A water heating system using a pump is more efficient than a comparable thermosyphon system. Such a system, however, has the disadvantages of increased costs and a reliance on electrical power. However, electrical power could be provided by solar photovoltaic systems in places where there is no electricity supply.

A major drawback to the utilisation of solar energy in the food processing industry is its intermittent nature. Solar energy is not available in sufficient quantity during cloudy spells and at night.

Some form of heat storage is therefore required. Economic considerations restrict the storage capacity. It is therefore essential to make provision for auxiliary heating using other energy sources.

The author is not advocating the use of solar energy to the exclusion of all other energy sources but rather, an integrated energy concept in which renewable and conventional energy supplies are appropriately mixed. It has been seen that there is considerable potential for the utilisation of solar energy in the Kenyan food processing industry. Its widespread use (together with other renewable energy resources) would significantly contribute to reducing the consumption of conventional energy supplies (especially oil) and thereby result in savings for the individual food processing firms and a reduction in the national fuel import bill. On a global scale, the use of solar energy (and other renewable energy resources) would slow down the rate of depletion of fossil fuels and minimise the pollution arising from their use.

6. RECOMMENDATIONS FOR FURTHER WORK

(i) Measurement and estimation of diffuse solar radiation.

(ii) Design and development of simple air heating solar collectors and determination of their efficiency curves.

(iii) Economic evaluation of various food dehydration systems with a view to assessing the economic feasibility of solar dehydration.

(iv) Design, development and testing of simple non-tracking concentrating solar collectors.

(v) A quantitative assessment of energy use in the Kenyan food processing industry with a view to estimating the fraction of the total energy consumption that could be economically provided by solar energy systems.

(vi) Design, development and testing of solar refrigeration units.

(vii) Pilot plant trials using thermosyphon and pumped solar heating system to supply a process heating medium.

7. REFERENCES

1. STARR, C. "Energy and Power". In: "Energy: Readings from Scientific American", W.H. Freeman & Co., San Francisco, 1979.
2. UNITED NATIONS. "World Energy Supplies 1973-1978", Statistical Papers Series J, No.22, U.N., New York, 1979.
3. ANON. The Kenya Times, Nairobi, 22 June 1983, pg. 18.
4. "Energy, Global Prospects 1985-2000", Report of the Workshop on Alternative Energy Strategies, McGraw-Hill, New York, 1977.
5. LINIHAN, J. & FLETCHER, W.W. (Eds). "Energy Resources and the Environment", Blackie & Son Ltd., Glasgow, 1975.
6. FOWLER, J.M. "Energy and the Environment, McGraw-Hill Book Co., New York, 1975.
7. BROWN, T.L. "Energy and the Environment", Charles E. Merril Publ. Co., Columbus, Ohio, 1971.
8. MATHEWS, W.H. "Man's Impact on the Climate", The Massachusetts Institute of Technology, Cambridge, Mass., 1971.
9. GICQUEL, R. "Energy", U.N. Division for Economic and Social Information (DESI)/DPI, 28 January 1981.

10. MISRA, P. "Energy and the Least Developed Countries", U.N., DESI Feature No.119, June 1981.

11. JHA, P.S. "The Other Energy Crisis: A Challenge and an Opportunity", U.N., DESI Feature No.118, June 1981.

12. Press Release, EN/43, 3 August 1981, U.N., Office of Public Information.

13. UNITED NATIONS. "Report of the Technical Panel on Biomass", Doc. No.A/CONF.100/PC/28 (1981).

14. UNITED NATIONS. "Report of the Technical Panel on Oil Shales and Tar Sands", Doc. No.A/CONF.100/PC/26 (1981).

15. UNITED NATIONS. "Report of the Technical Panel on Solar Energy", Document No.A/CONF.100/PC/27 (1981).

16. UNITED NATIONS. "Report of the Technical Panel on Wind Energy", Doc. No.A/CONF.100/PC/24 (1981).

17. UNITED NATIONS. "Report of the Technical Panel on Geothermal Energy", Doc. No.A/CONF.100/PC/23 (1981).

18. UNITED NATIONS. "Report on the Use of Peat for Energy", Doc. No.A/CONF.100/PC/32 (1981).

19. UNITED NATIONS. "Report of the Synthesis Group", Doc. No.A/CONF.100/PC/41 (1981).

20. MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES. "Report of the GOK/UNEP/UNDP Project on Environment and Development", Vol.2 (Draft), Government Press, Nairobi, 1981 (Restricted).

21. SHAKOW, D.; WEINER, D. & O'KEEFE, P. "Energy and Development: The Case of Kenya", Ambio 10 (5), 206-210 (1981).

22. MULI WA KYENDO. Sunday Nation, Nairobi, 2 August 1981.

23. GOVERNMENT OF KENYA. "National Report Submitted by Kenya for the United Nations Conference on New and Renewable Sources of Energy (held in Nairobi, 1981)", U.N. Doc. A/CONF.100/NR/36 (1981).

24. Daily Nation, Nairobi, 26 May 1982, pg.5.

25. O'KEEFE, P. & SHAKOW, D. "Kenya's Ethanol Program: Is it Viable?", Ambio 10 (5), 213-215 (1981).

26. MUCHIRI, G. "Rural Energy Needs and Alternative Sources". In: "Alternative Rural Energy Source", Proceedings of a Biogas Conference held at Egerton College (5-8 September 1978) Egerton College, Njoro, 1980.

27. SINGH, M.S. & MISIKO, P.A.M. "Biogas in Kenya: Present Status and Future Prospect", Egerton College Agric. Bull. 4 (1), 30-34 (1980).

28. LONG, G. "Solar Energy: Its Potential Contribution Within the United Kingdom", HMSO, London, 1976.

29. "Solar Energy in Saudi Arabia: The Soleras Project", Energy Digest 11 (5), 8-15 (1982).

30. CENTRAL BUREAU OF STATISTICS, Ministry of Economic Planning and Development. "Statistical Abstract 1980", Government Press, Nairobi, 1980.

31. CENTRAL BUREAU OF STATISTICS, Ministry of Finance and Planning. "Census of Industrial Production 1972", Government Press, Nairobi, 1972.

32. CENTRAL BUREAU OF STATISTICS, Ministry of Finance and Planning. "Report on Survey of Industrial Production 1973-1976", Government Press, Nairobi, 1980.

33. BARBIERI, R.H. "The Solar Potential for Process Heat: A Commercialisation Perspective", ASME Paper No.79-Sol-24 (1979).

34. CENTRAL BUREAU OF STATISTICS, Ministry of Economic Planning and Development. "Economic Survey 1982", Government Press, Nairobi, 1982.

35. OSORE, E.O. "Farming Systems in Kenya", Part I, Kenya Farmer, June 1980, p.61.

36. ibid., July 1980, p.39.

37. ibid., August 1980, pp.55, 57.

38. ibid., September 1980, p.110.

39. ibid., October 1980, p.60.

40. SALUNKHE, D.K.; PAO, S.K. & DULL, G.G. "Assessment of Nutritive Value, Quality, and Stability of Cruciferous Vegetables During Storage and Subsequent to Processing", CRC-Crit. Rev. Fd Technol. 4 (1), 1-38 (1973).

41. NICKERSON, J.T.R. & RONSIVALLI, L.J. "Elementary Food Science", AVI Publ. Co., Westport, Conn., 1976.

42. CIOBANU, A.; LASCU, G.; BERCESCU, V. & NICULESCU, L. "Cooling Technology in the Food Industry", Abacus Press, Tunbridge Wells, Kent, 1976.

43. DESROSIER, N.W. & TRESSLER, D.K. "Fundamentals of Food Freezing", AVI Publ. Co., Westport, Conn., 1977.

44. FENNEMA, O.R.; POWRIE, W.D. & MARTH, E.H. "Low-temperature Preservation of Foods and Living Matter", Marcel Dekker, Inc., New York, 1973.

45. ASHRAE. "ASHRAE Handbook & Product Directory: 1974 Applications", American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., New York, 1974.

46. "Refrigeration Techniques in Developing Countries", International Institute of Refrigeration, Paris, 1965.

47. VOIROL, F. "The Blanching of Vegetables and Fruits", F. Hoffman-LaRoche & Co., AG, Basel, 1972.

48. FARRAL, A.W. "Engineering for Dairy and Food Products", Chapter 13, John Wiley & Sons, Inc., New York, 1963.

49. RICHARDS, J.W. "Introduction to Industrial Sterilization", Academic Press, London, 1968.

50. MOSSEL, D.A.A. "Water and Micro-organisms in Foods - A Synthesis". In: "Water Relations of Foods" (Ed. by R.B. Duckworth), Academic Press, London, 1975.

51. MELLOR, J.D. "Fundamentals of Freeze-drying", Academic Press, London, 1978.

52. SPICER, A. (Ed.). "Advances in Preconcentration and Dehydration of Foods", Applied Science Publ. Ltd., Barking, Essex, 1974.

53. "Technology of Fruit Juice Concentrates - Chemical Composition of Fruit Juices", International Federation of Fruit Juice Producers, Vienna, 1973.

54. VAN ARSDEL, W.B.; COPLEY, M.J. & MORGAN, A.I. "Food Dehydration", Vol I & II, 2nd ed., AVI Publ. Co., Westport, Conn., 1973.

55. DESROSIER, N.W. "The Technology of Food Preservation", 3rd ed., AVI Publ. Co., Westport, Conn., 1970.

56. PINTAURO, N.D. "Food Additives to Extend Shelf Life", Noyes Data Corp., Park Ridge, New Jersey, 1974.

57. LAWRENCE, A.A. "Food Acid Manufacture", Noyes Data Corp., Park Ridge, New Jersey, 1974.

58. "Directory of Food Processing Industries in Kenya", Kenya Inst. of Fd Sc. and Technol., Nairobi, 1982.

59. "Members List and International Standard Industrial Classification", The Kenya Association of Manufacturers, Nairobi, 1981.

60. CENTRAL BUREAU OF STATISTICS, Ministry of Finance and Planning. "Directory of Industries", Government Press, Nairobi, 1974 & 1977.

61. SAINT-HILAIRE, P. & SHAH, J.N. "Kenya's Food Processing: Cereals, Beverages, Fruits and Vegetables", Paper Submitted for the First National Symposium on Industrial Research and Development (Nairobi, 7-11 December 1981), NSIRD/AGRO/5/01, Ministry of Industry, Nairobi.

62. GIBBONS, E.T. "The Characteristics, Structure and Development of Kenya's Food, Feedstuffs and Beverage Industries". Zeitschrift fuer Auslaendische Landwirtschaft 15, 141-160 (1976).

63. ANON. "Special Report on Kenya's Food Processing Industry", E.A. Report on Trade and Industry, Nairobi, February 1981.

64. "Report on the First National Symposium on Industrial Research and Development (Nairobi, 7-11 December 1981)", Ministry of Industry, Nairobi, Kenya, 1982.

65. KAPLINSKY, R. "A Country Case Study: Food Processing in Kenya". In: "Technology, Employment and Basic Needs in Food Processing in Developing Countries" (Ed. by C.G. Baron), Pergamon Press, Oxford, 1980.

66. NYAMWAYA, S.N. "Rural Small-Scale Edible Oil Industry", Industrial Promotion Dept., Ministry of Industry, Nairobi, Kenya, 1979. (Unpublished Report)

67. DANIELS, F. "Direct Use of the Sun's Energy", Ballantine Books, New York, 1974.

68. EXELL, R.H.B. "Simulation of Solar Radiation in a Tropical Climate with Data for Thailand", AIT Research Report No.115, Asian Institute of Technology, Bangkok, 1980.

69. KONDRATYEV, K. Ya, "Radiation in the Atmosphere", Academic Press, London, 1969.

70. SELLERS, W.D. "Physical Climatology", Ch.6, The University of Chicago Press, Chicago, 1965.

71. RIJKS, D.A. "Measurements and Calculations of Solar and Net Radiation". In: "Agroclimatology of the Highlands of Eastern Africa", Proceedings of the Technical Conference, Nairobi, 1973, WMO Publication No.389 (1974).

72. LONGLEY, R.W. "Elements of Meteorology", p.104, John Wiley & Sons, Inc., New York, 1970.

73. CRITCHFIELD, H.J. "General Climatology", p.22, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1966.

74. OSWAGGO, R.R. "Guide Book for Meteorological Practicals", Faculty of Agriculture, University of Nairobi, 1980 (Unpublished).

75. GRIFFITHS, J.F. "Applied Climatology", Ch.2, Oxford University Press, London, 1966.

76. EXELL, R.H.B. "The Solar Radiation Climate of Thailand", Solar Energy 18, 349-354 (1976).

77. CHUAH, D.G.S. & LEE, S.L. "Solar Radiation Estimates in Malaysia", Solar Energy 26, 33-40 (1981).

78. RIJKS, D.A. & HUXLEY, P.A. "The Empirical Relation Between Solar Radiation and Hours of Bright Sunshine Near Kampala, Uganda", J. Appl. Ecol. 1, 339-45 (1964).

79. WOODHEAD, T.W. "Empirical Relations Between Cloud Amount, Insolation and Sunshine Duration in East Africa", E. Afr. Agric. For. J. 32, 474-477 (1966).

80. SAYIGH, A.A. (Ed.). "Solar Energy Engineering", Academic Press, New York, 1977.

81. STIGTER, C.J. "Solar Radiation as statistically Related to Sunshine Duration: A Comment Using Low-Latitude Data", Agric. Meteorol. 21, 173-178 (1980).

82. MUKOLWE, E. "Regression Analysis of the Mean Monthly Sunshine and Radiation in East Africa", Dept. of Meteorology, University of Nairobi, 1973 (Unpublished Project Work).

83. ÅNGSTRÖM, A.K. "Solar and Atmospheric Radiation Q", J. Roy, Meteorol. Soc. 50, 121 (1924).

84. SCHÜEP, W. IN: "Solar Radiation" (Ed. by Robinson, N.), pp.279-281, Elsevier, Amsterdam, 1966.

85. SCHULZE, R.E. "A Physically Based Method of Estimating Solar Radiation from Suncards", Agric. Meteorol. 16, 85-101 (1976).

86. ONYANGO, F.N. "On the Estimation of Global Solar Insolation", Dept. of Physics, Univ. of Nairobi, 1982 (Unpublished Paper).

87. OKOOLA, R.E.A. "Solar Power Potential in Kenya", Meteorological Dept., Nairobi, Kenya, 1982.

88. OBASI, G.O.P. & RAO, N.N.P. "Solar Energy Resources in Kenya". In: "Energy Resources in East Africa" (Ed. by P.M. Khamala & J.B. Catelino), Kenya National Academy for the Advancement of Arts and Sciences, Nairobi, 1979.

89. MWINGIRA, P.A. "Measurement of Diffuse Solar Radiation at Dagoretti Corner", Meteorological Department, Nairobi, Kenya, 1980.

90. SPENCER, J.W. "A Comparison of Methods for Estimating Hourly Diffuse Solar Radiation from Global Solar Radiation", Solar Energy 29 (1), 19-32 (1982).

91. LIU, B.Y.H. & JORDAN, R.C. "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation", Solar Energy 4 (3), 1-19 (1960).

92. ORGILL, J.F. & HOLLANDS, K.G.T. "Correlation Equation for Hourly Diffuse Radiation on a Horizontal Surface", Solar Energy 19 (4), 357-359. (1977).

93. BRUNO, R. "A Correlation Procedure for Separating Direct and Diffuse Insolation on a Horizontal Surface", Solar Energy 20, (1), 97-100 (1978).

94. LEWIS, G. "Irradiance Estimates for Zambia", Solar Energy 26, 81-85 (1981).

95. STANHILL, G. "Diffuse, Sky and Cloud Radiation in Israel", Solar Energy 10, 96-101 (1966).

96. EGGERS-LURA, A. "Solar Energy in Developing Countries", Pergamon Press, Oxford, 1978.

97. EDWARDS, D.K. "Solar Collector Design", The Franklin Inst. Press, Philadelphia, 1978.

98. KUT, D. & HARE, G. "Applied Solar Energy", The Architectural Press, London, 1979.

99. EGGERS-LURA, A. "Flat-Plate Solar Collectors and Their Application to Dwellings",EEC Study Contract No.207-75-9 ECI DK, Copenhagen, 1976.

100. KREITH, F. & KREIDER, J.F. "Principles of Solar Engineering", Ch.4, Hemisphere Publ. Corp., Washington, 1978.

101. DUFFIE, J.A. & BECKMAN, W.A. "Solar Energy Thermal Processes", John Wiley & Sons, Inc., New York, 1974.

102. BRINKWORTH, B.J. "Solar Energy for Man", Ch.4, John Wiley & Sons, Inc., New York, 1973.

103. SHURCLIFF, W.A. "Transmittance and Reflection Loss of Multi-Plate Planar Window of a Solar-Radiation Collector", Solar Energy <u>16</u>, 149-154 (1974).

104. McCARTNEY, K. & FORD, B. "Practical Solar Heating", Prism Press, Dorset, 1978.

105. INTERTECHNOLOGY CORP. "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat", Vol. II, Final Report, Intertechnology Corp., Warrenton, Virginia, 1977 (NTIS No.COO 28292).

106. HOLLANDS, K.G.T. "Solar Collectors". In: "Sharing the Sun. Solar Technology in the Seventies". (Ed. by Böer, K.W.), Vol.2, The American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1976.

107. WINSTON, R. "Principles of Solar Concentrators of a Novel Design", Solar Energy 16, 89-95 (1974).

108. WYMAN, C.; CASTLE, J. & KREITH, F. "A Review of Collector and Energy Storage Technology for Intermediate Temperature Applications", Solar Energy 24, 517-540 (1980).

109. HOLLANDS, K.G.T. "A Concentrator for Thin-Film Solar Cells", Solar Energy 13 (2), 149-163 (1971).

110. RABL, A. "Comparison of Solar Concentrators", Solar Energy 18 (2), 93-113 (1976).

111. NELSON, D.T.; EVANS, D.L. & BANSAL, R.K. "Linear Fresnel Lens Concentrators", Solar Energy 17 (5), 285-290 (1975).

112. DEAN, T.S. "Thermal Storage", The Franklin Inst. Press, Philadelphia, 1978.

113. INTERTECHNOLOGY CORP. "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat", Vol. III, Final Report, Intertechnology Corp., Warrenton, Virginia, 1977 (NTIS No. COO 28292).

114. TELKES, M. "Solar Energy Storage", ASHRAE Journal, Sept. 1974, pp.38-44.

115. KILKIS, B. "Solar Energy Assisted Crop and Fruit Drying Systems: Theory and Applications". In: "Energy Conservation and Use of Renewable Energies in the Bio-Industries", Pergamon Press, Oxford, 1981.

116. NYDEGGER, F. "Un capteur solaire sous forme de boudin pour la ventilation a'air chaud". Technique Agricole 10, 422-428 (1982).

117. SELCUK, M.K. "Solar Air Heaters and Their Applications". In: "Solar Energy Engineering" (Ed. by A.A.M. Sayigh), Academic Press, New York, 1977.

118. BRACE RESEARCH INSTITUTE. "Survey of Solar Agricultural Driers", Brace Research Institute, Quebec, Canada, 1976.

119. GERMAN APPROPRIATE TECHNOLOGY EXCHANGE (GATE). "Devices for Drying: State of Technology Report on Intermediate Solutions for Rural Application" (Document M:4/1 7/79), GTZ, Eschborn, West Germany, 1979.

120. MINISTRY OF FINANCE AND PLANNING. "Crop Calendar for Kenya: Planting and Harvesting Dates of the Main Crops Grown in Six Provinces", Government Press, Nairobi, 1972.

121. WOOTTON, A.E.: VERKADE, F.A. & MITCHELL, H.W. "The Sun-Drying of Arabica Coffee", Kenya Coffee 33, 261-271 (1968).

122. BORREN, G.W. "New Type of Table for Skin-Drying Coffee", Kenya Coffee 34 (397), 75-76 (1969).

123. KAMAU, I.N. "A Comparison of Sun-Drying of Coffee Under Different Waterproof Covering Materials", Kenya Coffee 45 (536), 325-328 (1980).

124. WANYONYI, J.J.M. (Ed.). "An Outline of Coffee Processing", Ministry of Agriculture, Nairobi, 1972.

125. KAMAU, I.N. "Mechanical Drying of Arabica Coffee in Kenya", Kenya Coffee 45 (537), 343-355 (1980).

126. McCLOY, J.F. "Mechanical Drying of Arabica Coffee", Kenya Coffee 24 (290), 117-133 (1959).

127. McCLOY, J.F. "Mechanical Drying of Arabica Coffee", Kenya Coffee 44 (516), 13-26 (1979).

128. SIVETZ, M. & DESROSIER, N.W. "Coffee Technology", AVI Publ. Co., Westport, Conn., 1979.

129. GIBSON, A. "Mechanical Coffee Driers in Kenya: A Chronological Review" (Memorandum No.1, IBRD-914-KE), International Bank for Reconstruction and Development, Washington, D.C., 1980.

130. KARIGI, P.M. & KIHARA, D.M. "Literature Survey on Drying of Coffee, Tea and Storage Problems in Maize and Wheat", B.Sc. Research Project Report, Dept. of Mechanical Engineering, University of Nairobi, 1979 (Unpublished).

131. MITCHELL, H.W. "A Study Tour of Coffee Producing Countries: Part 1 - Brazil", Kenya Coffee 39 (454 & 455), 24 (1974).

132. EDEN, T. "Tea", 2nd ed., Longmans, London, 1965.

133. HARLER, C.R. "Tea Manufacture", Oxford Univ. Press, London, 1963.

134. WERKHOVEN, J. "Tea Processing", FAO, Rome, 1974.

135. BOKUCHAVA, M.A. & SKOBELEVA, N.I. "The Biochemistry and Technology of Tea Manufacture", CRC-Crit. Rev. Fd Technol. 12 (4), 303-370 (1980).

136. Daily Nation, Nairobi, 20 May 1982.

137. E.A. Report on Trade and Industry, Nairobi Show Supplement 1981.

138. WATERMAN, J.J. "The Production of Dried Fish", FAO Fish Tech. Pap., (16): P.52, FAO, Rome, 1976.

139. KORDYL, E. "Some Protective Measures Against Insect Infestation of Dried Fish in Africa". In: "Proceedings of the Conference on the Handling, Processing and Marketing of Tropical Fish", Tropical Products Institute, London, 1977.

140. LABUZA, T.P. & SLOAN, A.E. "Food for Thought", 2nd ed., AVI Publ. Co., Westport, Conn., 1977.

141. CHAKRABORTY, P.K. "Design of a Commercial Dehydration Plant and Economics of Production". In" Proceedings of the Conference on the Handling, Processing and Marketing of Tropical Fish", Tropical Products Institute, London, 1977.

142. CHAKRABORTY, P.K. "Multi-Deck Tunnel Drier - A New Concept in Hot Air Dehydration of Fishery Products". In: "Proceedings of the Symposium on Fish Processing in Industry in India", Mysore, 1975.

143. BALACHANDRAN, K.K. "An Accelerated Method of Hot Air Drying of Fish", Fish Technol. 6 (2), 124-128 (1969).

144. ODUOR-OTIENO, M.L.; KARISA, P.S.; ODHIAMBO, J.O.O. & RYAN, T.C.I. "A Study of the Supply Functions for Fish in Kenya's Waters of Lake Victoria and on the Kenya Coast", IDS Working Paper No.346, University of Nairobi, 1978.

145. DOE, P.E.; AHMED, M.; MUSLEMUDDIN, M. & SACHITHANATHAN, K. "A Polythene Tent Drier for Improved Sun Drying of Fish", Food Technol. Austr. 29, 437-441 (1977).

146. SZULMAYER, W. "From Sun-Drying to Solar Dehydration: 1. Methods and Equipment", Food Technol. Austr. 23, 440-443 (1971).

147. DOE, P.E."Polythene Tent Solar Driers: A Summary of Projects", Fish Technol. News (3): 5p (1982).

148. CURRAN, C.A. & TRIM, D.S. "Comparative Study of Three Solar Fish Driers". In: "Proceedings of the FAO Expert Consultation on Fish Technology in Africa", Casablanca, Morocco, 7-11 June 1982.

149. NJUGUNA, S.G. "Farming in the Water has a Great Potential", Daily Nation, Nairobi, 29 April 1983, p.11.

150. SALUNKHE, D.K.; DO, J.Y. & BOLIN, H.R. "Developments in Technology and Nutritive Value of Dehydrated Fruits, Vegetables, and their Products". In: "Storage, Processing and Nutritional Quality of Fruits and Vegetables" (Ed. by D.K. Salunkhe), CRC Press, Cleveland, Ohio, 1974.

151. JACKSON, T.H. & MOHAMMED, B.B. "Sun-Drying of Fruits and Vegetables", FAO, Rome, 1969.

152. DUCKWORTH, R.B. "Fruit and Vegetables", p.260, Pergamon Press, Oxford, 1966.

153. MALIK, R.K. & DHINGRA, K.C. "Canning and Preservation of Fruits and Vegetables", Small Industry Research Institute, Delhi, India, 1975-76.

154. FAO. "Food Processing Project: Syrian Arab Republic", FAO, Rome, 1967.

155. GOMEZ, M.I. "The Evaluation of Fruit and Vegetable Resources in the Machakos District, in Relation to Seasonal Deficits and Micronutrient Deficiencies", Technical Report to International Development Research Centre (IDRC) and University of Nairobi, June 1982.

156. KABIRA, J.N.; SAINT-HILAIRE, P. & NOUT, M.J.R. "Problems and Prospects of Ware Potato Storage in Kenya", KIFST Review 1 (3), 19-29 (1983).

157. ANON. "Mathira Farmer Beats Price Cycles", Sunday Nation, Nairobi, 1 May 1983, p.10.

158. "Storage and Handling of Wheat and Maize in Kenya", Report of a Working Party Set Up by the Ministry of Agriculture - Kenya, 1969.

159. BROCKER, D.B.; BAKKER-ARKEMA, F.W. & HALL, C.W. "Drying Cereal Grains", AVI Publ. Co., Westport, Conn., 1974.

160. HUKILL, W.V. "Grain Drying". In: "Storage of Cereal Grains and their Products", American Association of Cereal Chemists, St. Paul, Minnesota, 1974.

161. HALL, D.W. "Handling and Storage of Food Grains in Tropical and Subtropical Areas", FAO, Rome, 1970.

162. "Grain Drying and Storage", Farm-Electric Handbook No.21, The Electricity Council, Farm-Electric Centre, Warwickshire, 1974.

163. CLARK, C.S. & SAHA, H. "Solar Drying of Paddy", Renewable Energy Review J. 4 (1), 60-65 (1982).

164. MATZ, S.A. "Cereal Technology", AVI Publ. Co., Westport, Conn., 1970.

165, NELLIST, M.E. "Developments in Continuous - Flow Driers", The Agricultural Engineer 37 (3), 74-80 (1982).

166. KAMINSKAS, R.A. "Research on the Application of Solar Energy to the Food Drying Industry, Interim Report". TRW Report No.27319-6001-TV-00 (1974). Cited in: Bomben, J.L. "Modification of Food Processing for Reduced Energy Consumption and Effluent Generation", ASAE Paper No.75-6515 (1975).

167. TROEGER, J.M. & BUTLER, J.L. "Peanut Drying with Solar Energy", Trans. ASAE 23 (5), 1250-1260 (1980).

168. HEID, W.G. "The Performance and Economic Feasibility of Solar Grain Drying Systems", Agricultural Economic Report No.396, Economics, Statistics and Cooperatives Service, U.S. Dept. of Agriculture, February 1978.

169. FRASER, B.M. & MUIR, W.E. "Cost Predictions for Drying Grain with Ambient and Solar Heated Air in Canada", Can. Agric. Engng 22 (1), 55-59 (1980).

170. BOSE, S.C. "Solar Energy System for Continuous Processes", The National Industrial Development Corp. Ltd., India, 1980 (Unpublished Report).

171. SINGH, R.K.; LUND, D.B. & BUELOW, F.H. "Application of Solar Energy in Food Processing: II. Food Dehydration", Agricultural Engineering Dept., University of Wisconsin, Madison, 1982 (Unpublished).

172. PROCTOR, D. & MORSE, R.N. "Solar Energy for the Australian Food Processing Industry", Solar Energy 19, 63-72 (1977).

173. LEWIS, C.W. "The Prospects for Solar Energy Use in Industry Within the United Kingdom", Solar Energy 24, 47-53 (1980).

174. BROWN, K.C. & STADJUHAR, S.A. "Matching Solar Systems to Industrial Needs", ASME Paper No.79-Sol-28 (1979).

175. SPONGBERG, R.C. "A U.S. Government Appraisal of the Potential of Solar Energy for Industry". In: "Solar Energy for Industry", UK Section of the International Solar Energy Society (UK-ISES), London, 1978.

176. HARPER, W.J. "Sanitation in Dairy Food Plants". In: "Food Sanitation" (Ed. by R.K. Guthrie) pp.130-160, AVI Publ. Co. Westport, Conn., 1972.

177. HOBBS, B.C. "Food Poisoning and Food Hygiene", Edward Arnold (Publishers) Ltd., London, 1968.

178. GREGORY, V. "Problems with Hygiene", Food Manufacture, December 1982, pp.40-43.

179. BAKKER-ARKEMA, F.W.; RIPPEN, A.L.; MINTZIAS, P.Z.; JAKEWAY, J.S. & BORSUM, J.C. "Feasibility Study of Solar Water Heating in Food Processing Plants in the Midwestern United States - Phase III: Testing of a Pilot Scale System and Planning of a Demonstration Project", Michigan State University, East Lansing, Michigan, 1980 (Unpublished Report).

180. SINGH, R.K.; LUND, D.B.; BUELOW, F.H. & DUFFIE, J.A. "Compatibility of Solar Energy with Fluid Milk Processing Energy Demands", ASAE Paper No. 78-6526 (1978).

181. DAVIS, D.C.; HARREL, R.C.; KRANZLER, G.A.; LEUNG, H.K. & LUEDECKE, L.O. "Solar Pasteurisation of Fruit Juice and Milk", ASAE Paper No.PNW 81-503 (1981).

182. HARREL, R.C.; KRANZLER, G.A. & DAVIS, D.C. "Microprocessor Control of a Solar Fruit Juice Pasteurizer", ASAE Paper No.81-5030 (1981).

183. BACHMANN, M. & LEUENBERGER, N. "Preservation and Commercialisation of Milk by Means of Adapted Technology and Use of Solar Energy", Lebensm.-Wiss. u.-Technol. 12, 124-126 (1979).

184. READ, W.R.W. "Solar Heat Generation for Industrial Process Heating Applications". In: "SUN II: Proceedings of the International Solar Energy Society Silver Jubilee Congress 1979", Vol. 2 (Ed. by K.W. Böer & B.H. Glenn), Pergamon Press, N.Y., 1979.

185. WELLS, K.M. "Energy Management: Cadbury Schweppes - Claremont Experience", The Austr. J. of Dairy Technol. 37 (2), 68-70 (1982).

186. HOLLAND, F.A. "The Potential for Heat Pumps in India", Indian Chem. Eng. 21 (2), 2-8 (1979).

187. SCHULER, H.F.; ROST, D.F. & AMEDURI, G. "Solar Energy System with Heat Pump Augmentation for Industrial Process Heat". In: "SUN II: Proceedings of the International Solar Energy Society Silver Jubilee Congress 1979", Vol.2 (Ed. by K.W. Böer & B.H. Glenn), Pergamon Press, New York, 1979.

188. THOMAS, S.M.; BAKKER-ARKEMA, F.W. & RIPPEN, A.L. "Feasibility of Solar Water Heating in Milk Processing Plants in the Midwestern United States", ASAE Paper No.77-6519 (1977).

189. MINTZIAS, P.Z. "Solar Water Heating for the Food Industry in the United States", pH.D. Thesis, Michigan State University, 1980.

190. SINGH, R.K.; LUND, D.B. & BUELOW, F.H. "Application of Solar Energy in Food Processing: III. Economic Performance Evaluation", Agricultural Engineering Dept., Univ. of Wisconsin, Madison, 1982 (Unpublished Paper).

191. SINGH, R.K.; LUND, D.B. & BUELOW, F.H. "Application of Solar Energy in Food Processing: IV. Effect of Collector Type and Hot Water Storage Volume on Economic Feasibility", Agricultural Engineering Dept., Univ. of Wisconsin, Madison, 1982 (Unpublished Paper).

192. INTERTECHNOLOGY CORP. "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat", Final Report, Vol.I Intertechnology Corporation, Warrenton, Virginia, 1977 (NTIS No.COO/2829-1).

193. "Introduction Paper on Agro and Wood based Industries Sub-Sector", Prepared by the Secretariat for the National Symposium on Industrial Researc and Development (7-11 Dec. 1981), Ministry of Industry, Nairobi, 1981.

194. WESTLEY, S.B.; JOHNSTON, B.F. & DAVID, M. "Summary Report of a Workshop on a Food and Nutrition Strategy for Kenya", Occasional Paper No.14, p.17, Institute of Development Studies, University of Nairobi, 1975.

195. MBOGOH, S.G. & BUTEYO, G.F.W. "Proposals on Milk Marketing Development Projects", A Preliminary Report Presented to the Ministry of Livestock Development, Nairobi, Kenya, 1980 (Draft).

196. RAEMY, O. "Milk Cooling by Use of Charcoal Evaporative Systems in Kenya", Technical Paper No.7, Dept. of Animal Production, University of Nairobi, 1974.

197. MBUGUA, S.K. "A Study of the Keeping Quality of Milk in the Kinangop Plateau and Suggestions for Improvement", M.Sc. Thesis, University of Nairobi, 1976 (Unpublished).

198. The Nairobi Times, Nairobi, 27 July 1982, p.9.

199. SCHULTHESS, W. "Pilot Projects for Dairy Development in Kenya; Proposals for Swiss Bilateral Co-operation", Report Submitted to the Ministry of Livestock Development, Government of Kenya and to the Swiss Federal Government in December 1981 (Unpublished).

200. GITHUKU, J.M. "Improved Milk Storage", The Standard, Nairobi, 3 June 1982.

201. BAUM, E. "Production and Marketing of Vegetables in Wundanyi Division, Taita Hills", Dept. of Agricultural Economics, Univ. of Nairobi, 1974 (Unpublished Report).

202. NYAGAMBI, J.F.M. "Problems Connected with Fish Quality in Kenya". In: "Proc. of the FAO Expert Consultation on Fish Technology in Africa", Casablanca, Morocco, 7-11 June 1982.

203. Kenya Times, Nairobi, 20 April 1983, p.10.

204. BINTA, G.M. "Hygienic Investigation of Fish in Kenya with Special Emphasis on Vibrio Parahaemolyticus", M.Sc. Thesis, Univ. of Nairobi, 1978 (Unpublished).

205. ANON. "Refrigeration, Heating and Ventilation", E.A. Report on Trade and Industry, Nairobi Aug. 1980, pp.45-56.

206. CRAWFORD, A.G. & ELSON, C.R. "Energy Use in the Food Manufacturing Industry", Scientific & Technical Surveys No.128, Leatherhead Food R.A., Leatherhead, 1982.

207. NEWELL, L. "Cooling and Storage of Milk on Farms", J. Soc. Dairy Technol. 33 (4), 136-139 (1980).

208. BARLOW, N.J. "Energy in the Brewery", J. Inst. Brew. 83, p.6 (1977).

209. WILLIAMS, R.H. "Toward a Solar Civilization", p.230, MIT Press, Cambridge, Mass., 1978.

210. LAZAROV, P. & LOTZ, H. "Wirklich gleicher Energieverbrauch bei Absorber- und Kompressor-kuehlschraenken?", Ki: Klima + Kaelteingenieur 5, 301-306 (1977).

211. LORENTZEN, G. "Energy Saving in Refrigeration Systems". In: "Proc. of the International Symposium on Energy and Food Industry", Madrid, 6-8 October 1980.

212. JORDAN, R.C. & IBELE, W.E. "Mechanical Energy from Solar Energy". In: "Proc. of the World Symposium on Applied Solar Energy", Phoenix, Arizona, 1955.

213. JORDAN, R.C. "Conversion of Solar to Mechanical Energy". In: "Introduction to the Utilisation of Solar Energy" (Ed. by A.M. Zarem and D.D. Erway), pp.125-152, McGraw-Hill, New York, 1963.

214. TABOR, H. 'Use of Solar Energy for Mechanical Power and Electricity Production by Means of Piston Engines and Turbines". In: "Proc. United Nations Conference on New Sources of Energy", E-35 Gr-59, Rome, 1961.

215. "ASHRAE Handbook of Fundamentals", Ch.1, ASHRAE, New York, 1972.

216. PRIGMORE, D. & BARBER, R. "Cooling with the Sun's Heat. Design Considerations and Test Data for a Rankine Cycle Prototype", Solar Energy 17, 185-192 (1975).

217. WHO. "Solar Refrigerators for Vaccine Storage and Ice-Making - a Review of Current Development Work Towards Manufacture", WHO DOC.EPI/CCIS/81.5, Geneva, 1981.

218. WHO. "1982/83 Field Trials on Solar Powered Refrigerators for Vaccine Storage", WHO DOC. EPI/CCIS/82.3, Geneva, 1982.

219. KASSATKIN, A.G. "Chemische Verfahrenstechnik", Band II, S.353-355, VEB Verlag Technik, Berlin, 1954.

220. BETT, K.E.; ROWLINSON, J.S. & SAVILLE, G. "Thermodynamics for Chemical Engineers", p.242, The Athlone Press, Univ. of London, London, 1975.

221. WARD, G.T. "Possibilities for the Utilisation of Solar Energy in Underdeveloped Rural Areas", p.57, FAO, Rome, 1961.

222. VELLA, G.J.; HARRIS, L.B. & GOLDSMID, H.J. "A Solar Thermoelectric Refrigerator", Solar Energy 18, 355-359 (1976).

223. KELLY, J. "Explanation of the Mechanism of Thermoelectric Refrigeration", Air-Cond. Heat. Ventl., 56 (3), 89-91 (1959).

224. GLATZ, A.C. "Thermoelectric Energy Conversion". In: "Kirk-Othmer Encyclopedia of Chemical Technology", Vol.20, 2nd ed., John Wiley & Sons, Inc., New York, 1969.

225. KARAKI, S. "Solar Cooling", The Franklin Inst. Press, Philadelphia,1978.

226. FARBER, E.A. "The Direct Use of Solar Energy to Operate Refrigeration and Air-Conditioning Systems", Technical Progress Report No.15, Engineering Progress at the Univ. of Florida, 1965.

227. FAVRE, R. & LEIBUNDGUT, H.J. "Periodische Solar-Absorptionskuehlanlage", KI: Klima + Kaelteingenieur 8, 895-900 (1980).

228. FAVRE, R. & LEIBUNDGUT, H.J. "Verwendung von Sonnenenergie zur Verarbeitung von Lebensmitteln in Entwicklungslaendern", Arbeitsunterlage zum Forschungsproject der ETH-Zuerich, 1980.

229. MANSOORI, G.A. & PATEL, V. "Thermodynamic Basis for the Choice of Working Fluids for Solar Absorption Cooling Systems", Solar Energy 22, 483-491 (1979).

230. NIELSEN, P.B.; STUBKIER, B. & WORSØE-SCHMIDT, P. "A Critical Survey of Intermittent Absorption Systems for Solar Refrigeration", Paper Presented at the 14th International Congress of Refrigeration, Moscow, 1975.

231. CHINNAPPA, J.C.V. "Experimental Study of the Intermittent Vapour Absorption Refrigeration Cycle Employing the Refrigerant - Absorbent Systems of Ammonia-Water and Ammonia - Lithium Nitrate", Solar Energy 5 (1), 1-8 (1961).

232. SWARTMAN, R.K.; HA, V. & SWAMINATHAN, C. "Comparison of Ammonia-Water and Ammonia - Sodium Thiocyanate as the Refrigerant - Absorbent in a Solar Refrigeration System", Solar Energy 17, 123-127 (1975).

233. WILLIAMS, D.A.; CHUNG, R.; LÖF, G.O.G.; FESTER, D.A. & DUFFIE, J.A. "Cooling Systems Based on Solar Regeneration", Refrig. Eng. 66, 33-37, 64-66 (1958).

234. SWARTMAN, R.K. & SWAMINATHAN, C. "Solar Powered Refrigeration", Mech. Eng. 93 (6), 22-24 (1971).

235. SWARTMAN, R.K. & ALWARD, R. "Evaluation of an Experimental Intermittent Absorption Refrigerator Incorporating the Generator with the Flat Plate Collector", Presented to 1968 Annual Meeting, Solar Energy Society, Palo Alto, California.

236. SWARTMAN, R.K. & SWAMINATHAN, C. "Further Studies on Solar Powered Intermittent Absorption Refrigeration", Paper No.6/114, Presented to 1970 International Solar Energy Society Conference, Melbourne, Australia.

237. CHINNAPPA, J.C.V. "Performance of an Intermittent Refrigerator Operated by a Flat Plate Collector, Solar Energy 6 (4), 143-150 (1962).

238. MURADOV, D. & SHADIEV, O. "Testing of a Solar Adsorption Refrigerator", Geliotekhnika 7 (3), 33-35 (1971).

239. EXELL, R.H.B.; KORNSAKOO, S.; JARIMOPAS, B. & SOPONRONNARIT, S. "Experiments on a Prototype Solar Powered Refrigerator for Remote Areas", Paper 0371, International Solar Energy Congress, New Delhi, 1978.

240. EXELL, R.H.B. "Using the Sun to Power a Refrigerator", Appropriate Technol. 5 (3), 4-6 (1978).

241. "National Report Submitted by the Sudan" (U.N. DOC. A/CONF/100/NR/11). U.N. Conf. on New and Renewable Sources of Energy, Nairobi 10-21 Aug. 1981.

242. DÜTTING, S. (Ed.). "Solar Powered Refrigerators", Publication No.M 1/5(11/78). German Appropriate Technology Exchange, Eschborn, 1978.

243. FARBER, E.A. "Design and Performance of a Compact Refrigeration System". Engineering Progress at the University of Florida 24 (2), 17 (1970).

244. SWARTMAN, R.K. "The Status of Solar Refrigeration and Air Conditioning", Technical-Report No.T84, Brace Research Institute, Quebec, 1973.

245. MAKSUDOW, T.M. & WACHIDOW, A.T. "Nutzung der Sonnenenergie fuer die Lagerung von leichtverderblichen Produkten", Die Lebensmittel - Industrie 24 (10) (1977).

246. PILATOWSKY, I.; ROMERO, E. & BEST, G. "Cooling and Conservation of Milk with Solar Refrigeration". In: "Energy Conservation and Use of Renewable Energies in the Bio-Industries" (Ed. by F. Vogt), Pergamon Press, Oxford, 1981.

247. BILGEN, E. "Solar Powered Refrigeration". In: "Solar Energy Conversion" (Ed. by A.E. Dixon and J.D. Leslie), Pergamon Press, Oxford, 1979.

248. TROMBE, F. & FÖEX, M. "Economic Balance Sheet of Ice Manufacture with an Absorption Machine". In: Proc. of the U.N. Conference on New Sources of Energy, Vol. 6, pp.56-59, U.N., Rome, 1961.

249. CHUNG, R. & DUFFIE, J.A. "Cooling with Solar Energy". In: Proc. of the U.N. Conference on New Sources of Energy, Vol. 6, pp.20-27, U.N., Rome, 1961.

250. "Workshop on Solar Energy for the Villages of Tanzania", Held at Dar-es-Salaam, Tanzania on August 11-19, 1977 (NTIS Report No.PB 282 941 (1978), pp.45-46.

251. GRALLERT, H. "Vergleich alternativer solarer Kuehlsysteme unter technischen und oekonomischen Aspekten", Ki: Klima - Kaelte - Heizung 4 (6), 159-162 (1982).

252. ANON. ATH Newsletter 11, p.16, WHO, Geneva, 1982.

253. LISAC, H. "Small-Size Ice Plants for Fishery Industries", FAO Fish Techn. Pap. (131): 6P (1974).

254. LEACH, M. (Ed.). "Freezer Facts", Forbes Publications Ltd., London, 1975.

255. JUSTIN, B. "Some Aspects of Testing the Thermal Performance of Collectors". In: "Testing of Solar Collectors and Systems" (Proceedings of a Conference), UK-ISES, London, 1977.

256. DITTES, W. & GOETTLING, D. "Pruefung der thermischen Leistung von Solarkollektoren - Vorschlaege zur Normierung", KI: Klima +Kaelteingenieur 6, 137-142 (1978).

257. TABOR, H. "Testing of Solar Collectors", Solar Energy 20, 293-303 (1978).

258. STREED, E.R.; HILL, J.E.; THOMAS, W.C.; DAWSON, III, A.G. & WOOD, B.D. "Results and Analysis of a Round Robin Test Program for Liquid-Heating Flat-Plate Solar Collectors", Solar Energy 22, 235-249 (1979).

259. HILL, J.E. & STREED, E.R. "A Method of Testing for Rating Solar Collectors based on Thermal Performance", Solar Energy 18, 421-429 (1976).

260. SIMON, F.F. "Flat-Plate Solar-Collector Performance Evaluation with a Solar Simulator as a Basis for Collector Selection and Performance Prediction", Solar Energy 18, 451-466 (1976).

261. KLEIS, S.J.; CHEN, R.T. & BANNEROT, R.B. "Instantaneous Collector Thermal Efficiencies in Less Time", Solar Energy 24, 111-112 (1980).

262. NBS. "Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices", NBS Technical Note No. 899, National Bureau of Standards, Washington DC, 1976.

263. ASHRAE. "Method of Testing Solar Collectors based on Thermal Performance", Proposed Standard No.93-P, ASHRAE, New York, 1976.

264. "Solar Water Heaters: Methods of Testing to Determine the Thermal Performance of Flat Solar Collectors", Israel Standard S.I. 579 Part 3, March 1979.

265. ISO. "Liquid Circulation Solar Collectors: Determination of Thermal Performance", International Standards Organisation (ISO) Standard NF P 50.501 (Proposed).

266. WHILLIER, A. & RICHARDS, S.J. "A Standard Test for Solar Water Heaters". In: "Proc. of the U.N. Conference on New and Renewable Sources of Energy", Vol. 5, pp.111-113, U.N., Rome, 1961.

267. LEUNG, C.T. "The Utilizability Method of Predicting the Long Term Performance of Flat Plate Solar Collectors", Renewable Energy Rev. J. 4 (2), 20-27 (1982).

268. BECKMAN, W.A.; KLEIN, S.A. & DUFFIE, J.A. "Solar Heating Design", Wiley Interscience, New York, 1977.

269 KLEIN, S.A. "Calculation of Flat Plate Collector Utilizability", Solar Energy 21, 393-402 (1978).

270. BEARD, J.T.; HUCKSTEP, F.L.; MAY, Jr., W.B.; IACHETTA, F.A. & LILLELEHT, L.U. "Performance and Analysis of "Solaris" Water-Trickle Solar Collector". In: "Sharing the Sun: Solar Technology in the Seventies", Vol.2: "Solar Collectors" (Ed. by K.W. Böer), pp.46-63, American Section of the International Solar Energy Society, Cape Canaveral, Florida, 1976.

271. BLISS, R.W. "The Derivation of Several'Plate-Efficiency Factors' Useful in the Design of Flat-Plate Solar Heat Collectors", Solar Energy 3 (4), 55-64 (1958).

272. KALT, A. "Baustein Sonnenkollektor", Verlag C.F. Mueller, Karlsruhe, 1977.

273. TULLY, G. "Solar Heating Systems", McGraw-Hill Book Co., New York, 1981.

274. NIGG, J. "Sonnenkollektoren im Selbstbau", Juerg Nigg Verlag, Zuerich, 1981.

275. LORENZ-LADENER, C. "Solaranlagen im Selbstbau", Gesamthochschule, Kassel, 1979.

276. DUFFIE, J.A. & BECKMAN, W.A. "Solar Engineering of Thermal Processes", John Wiley & Sons, New York, 1980.

277. GUPTA, C.L. & GARG, H.P. "System Design in Solar Water Heaters with Natural Circulation", Solar Energy 12, 163-182 (1968).

278. HEYWOOD, H. "Solar Energy for Water-and Space-Heating", J. Inst. Fuel 27, 334 (1954).

279. SHITZER, A.; KALMANOVIZ, D.; ZVIRIN, Y. & GROSSMAN, G. "Experiments with a Flat Plate Solar Water Heating System in Thermosyphonic Flow", Solar Energy 22, 27-35 (1979).

280. MORRISON, G.L. & RANATUNGA, D.B.J. "Thermosyphon Circulation in Solar Collectors", Solar Energy 24, 191-198 (1980).

281. CLOSE, D.J. "The Performance of Solar Water Heaters with Natural Circulation", Solar Energy 6 (1), 33-40 (1962).

282. MORRISON, G.L. & RANATUNGA, D.B.J. "Transient Response of Thermosyphon Solar Collectors", Solar Energy 24, 55-61 (1980).

283. SINSON, D.A. "How to Build a Solar Water Heater", (Do-It-Yourself Leaftlet No.L-4), Revised edition, Brace Research Institute, Quebec, Canada, Jan. 1979.

284. WANG SHING-AN. "An Experimental Study of Corrugated Steel Sheet Solar Water Heater", Solar Energy 23, 333-341 (1979).

285. SMITH, C.C. & WEISS, T.A. "Design Application of the Hottel-Whillier-Bliss Equation", Solar Energy 19, 109-113 (1977).

286. DUFFIE, J.A. "New Materials in Solar Energy Utilisation", Solar Energy 6 (3), 114-118 (1962).

287. BLAGA, A. "Use of Plastics in Solar Energy Applications", Solar Energy 21, 331-338 (1978).

288. MALIK, M.A.S. "Solar Water Heating in South Africa", Solar Energy 12, 395-397 (1969).

289. LITTLE, T.M. & HILLS, F.J. "Agricultural Experimentation: Design and Analysis", John Wiley and Sons, New York, 1978.

290. "Climatological Statistics for East Africa; Part 1: Kenya", E.A. Meteorological Department, Nairobi, 1975.

291. NOUT, M.J.R. "Aspects of the Manufacture and Consumption of Kenyan Traditional Fermented Beverages", Ph.D. Thesis, University of Agricultural Sciences, Wageningen, 1981.

292. LUNDGREN, B. (Ed.). "Land Use in Kenya and Tanzania", Royal College of Forestry, Stockholm, 1975.

X. APPENDIX

LIST OF CONTENTS FOR APPENDIX

X1. THE CAPITAL COSTS OF SOLAR COLLECTORS A, B & C

X1.1. Solar Collector A (1.4 m^2 effective area)

The capital cost was calculated by adding material and labour costs as follows:

Material	Galvanised steel - corrugated sheet	KShs. 112/50
	Galvanised steel - flat sheet	KShs. 250/--
	Galvanised steel rivets	KShs. 7/50
	Washers	KShs. 20/--
	Soldering sticks	KShs. 310/--
	Matt black paint	KShs. 75/--
	Soldering flux	KShs. 33/--
	Wooden casing	KShs. 138/40
	PVC film	KShs. 150/--
	White gloss paint	KShs. 120/--
Labour		KShs. 300/--
Total cost		KShs.1516/40

X1.2. Solar Collector B (1.5 m^2)

It should be noted that this type of collector has never been sold in the Kenyan market. The absorber plate and the glass cover were imported directly from Australia for the purpose of this project. The solar collector was assembled in Nairobi by Total Oil Products (E.A.) Ltd. (Solar Division). They have estimated the capital cost of the solar collector (excluding fittings) in Kenya as follows:

Sale price	KShs.5250/--
17% Sales tax	KShs. 892/50
Total cost	KShs.6142/50

XI.3. Solar Collector C (0.74 m^2)

This collector was bought from Total Oil Products (E.A.) Ltd. (Solar Division). The capital cost was as follows:

Sale price	KShs.1991/--
17% Sales tax	KShs. 338/50
Total cost	KShs.2329/50