NOVEL AND IMPROVED COOKSTOVE TECHNOLOGY
FOR USE IN THE SUDAN: THE APPLICATION
OF HOME ECONOMICS TO THE QUESTION OF
APPROPRIATE TECHNOLOGIES

Lesley Vivienne Brattle B.Sc.

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Department of Home Economics
University of Surrey
Guildford
Surrey
England
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SUMMARY

The research concentrated on two areas of interest: the feasibility of solar cooking in the Sudan and the improved fuel consumption of the traditional charcoal stove. The spread of desertification in Northern Sudan has justified the development of alternative cookstoves designed to alleviate the demand for woodfuel for cooking.

The development of 'appropriate technologies' in the Western world has met with disappointing levels of acceptance in the field. Therefore the research took an interdisciplinary approach to the problem of consumer choice and acceptance. Considerable attention was given to the psychology and sociological perspectives of the culture.

The experimental work took the form of seeking fairly simple modifications to the Sudanese charcoal stove. The effects of various design features were examined to improve combustion and burning efficiency. The aim was to complete the cooking process on a reduced quantity of fuel. Eventually three alternative charcoal stoves were developed. After considering the solar cookers available for testing in the Sudan, a quasi-parabola was conceived. Templates were taken to the Sudan so that it could be constructed by a local carpenter.

Standard survey techniques were adapted to test the three charcoal stoves and the three solar stoves among small samples of Sudanese women. The consumer trials took the form of semi-structured interviews, the emphasis being on the individual rather than the aggregate. Analysis was of a descriptive nature, with each woman being given ample opportunity to develop her views. The objective was to gain insights into the perceptions and attitudes of the women testing the appliances.

The feedback from the consumer trials demonstrated that women regarded convenience as important as economic savings. With regard to the charcoal stoves, perceptions of economy
were strongly influenced by the ease of combustion and the speed of the cooking process. Some efforts were made to quantify fuel use. The speed of cooking was also an important attribute for a solar cooker. Overall, solar cooking was thought to be a useful convenience for light foods.

Interpretation of the findings from the consumer surveys required considerable knowledge of the culture and the women taking part. Certain cultural norms and female subordination were seen to affect women's values and attitudes to household technology.
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CHAPTER 1
INTRODUCTION, AIMS AND METHODOLOGY

1.1 Introduction

Although the term 'appropriate technology' has become widely associated with the Third World and development problems, it was first conceived by Schumacher. It is described as being something between traditional technology, which is primitive, inefficient and wasteful of skills and resources, and Western technology, which is capital intensive, labour saving and sophisticated, and depends on a high degree of training and skill. Perhaps a better description is that given by Balcomb (1); "simple, low-cost, relating to tradition and existing practices where possible but improved according to scientific principles. Devices should be made from locally available materials and be built or maintained by craftsmen within easy reach. Appropriate technologies are compatible with conditions existing in the area of intended use".

It has been the experience in recent years that appropriate technology devised in highly industrialized countries has had a disappointingly low level of acceptance at the village level. This is probably attributable to a limited approach to the problem. The separation within academic disciplines of the 'social and anthropological' from the scientific and engineering aspects of appropriate technology is unlikely to initiate change or adoption. The success of rural technology calls for practical interdisciplinary research and development necessitating a detailed knowledge of local conditions with continual consumer feedback.

Traditionally, home economics has drawn together the technical and social aspects of design and development translating consumer needs and choices into viable products. The application of these principles to the consumer in the developing countries is novel and yet it is central to the philosophy of appropriate technology.
It therefore seems timely that the development of appropriate technologies involve more consultation and participation from local inhabitants, and that the human/technological interface be the subject of serious study. It is the socio-cultural and psychological factors that impinge on consumer choice; the values, attitudes and perceptions of the user that determine the acceptance and adoption of technical innovations among rural inhabitants.

In particular, it is the women in the developing countries who are very often responsible for maintaining living standards within the home. Home economics is therefore likely to have a potential contribution in the area of homestead technology. Familiarity with the cultural environment and the sociology of the home and family is important so that opportunities are recognized and the needs of the housewife translated into viable devices. An appreciation of the values and attitudes of women will aid technological choice and design criteria, which ultimately contribute to the acceptance of technical innovations in the household economy. It is fitting that home economics explore the suitability of typical survey research methods to the psychological appropriateness and requirements of rural household technology.

1.2 Area of Research

An extremely important and topical problem for research is the economical use of domestic energy. It is well known that in many parts of the world, there is a shortage of fuelwood, on which the rural poor are dependent for their very basic needs. According to the Food and Agricultural Organization of the United Nations; "100 million people are now unable to obtain sufficient wood to meet their needs; a further one billion are affected by shortages" (2). Brandt (3) reports that nine-tenths of the population in the poverty belts rely on wood as their chief source of fuel, and although in the cooler areas, some is used for heating, by far the most important energy need is for cooking. Makhijani (4) estimates that cooking fuel represents approximately 50% of fuel use
in many rural areas and up to 80 or 90% of energy needs in warmer areas. In fact, from the point of view of the average villager in the developing world, the firewood crisis can simply be termed the cooking fuel crisis.

As fuel collecting becomes more time consuming, often for women and children, less time is available for other productive activities. Although wood used to be available free of charge, the current population growth has increased demand to the point that even the semi-urban poor are finding themselves purchasing fuel at rapidly increasing rates. Labourers in Niamey are reportedly spending one quarter of their incomes on wood (5). Poor wage-earners are spending greater proportions of their income on fuel in many areas of the undeveloped world and this is an important factor in influencing the standard of living.

The shortage of woodfuel in Third World countries and the highly culture-specific nature of cooking, with all the social considerations attached to the preparation of meals lent itself to the application of home economics in the economic use of domestic fuel. Incorporating knowledge from design and engineering with the application of social research methods would have the advantage of identifying fuel economies and stove attributes which are most likely to be acceptable to the Third World consumer. The research and development of novel or alternative fuel saving cookstoves made an ideal subject area for a pilot study using consumer research methods, and this was seen to be an important step in our understanding of appropriate technologies.

In effect, the research was to concentrate on two approaches to fuel saving. The first approach was to look at the energy saving potential of traditional woodfuel stoves. Improved stove and woodburning efficiency is generally agreed to be one of the cheapest and most effective ways of cutting energy demand. Potentially if every household could reduce its energy consumption by a small amount, then the sum total reduction could be substantial. Some work has been undertaken on the improvement of burning efficiency and heat conservation
with clay stoves. However, much depends on the area concerned as to what shape or form local stoves take, and appropriateness needs to be interpreted within the framework of local cooking and eating habits and the other social norms that influence the cooking task.

The second approach was to consider the use of solar energy for cooking. Since many fuel scarce countries are situated in the tropics, arid and semi-arid areas, the potential value of solar energy devices has recently received attention. Several types of solar cookers have evolved but perhaps the most common is that based on the idea of a simple parabolic reflector which brings the sun's energy to focus on a small area. Other proposed designs are a solar oven in the form of an insulated box with reflectors on the sides to increase the collection area and focus the solar energy into the oven. Yet another design takes the form of a high temperature flat plate collector which produces steam commonly referred to as a solar steam cooker.

Solar cookers have been very much at the developmental stage, built and tested mostly by individual enthusiasts. Feedback has been scanty and often inconsistent; there was some doubt as to the technical performance of the various designs and differing reports as to the social acceptability to village families. It therefore seemed timely to carry out some detailed in-depth consumer studies to determine preferences on the different designs and to clarify the feasibility of solar cooking. Since this would necessitate an interdisciplinary approach with input from both the social and physical sciences, home economics was seen to have much to contribute in the study of stove technology and the potential use of alternative fuels among energy poor communities.

The next step was to decide on the location for the study, and there were several important reasons for choosing the Sudan. The Sahel region, located approximately between 10 and 25 degrees latitude north, embraces some of the poorest countries in the world, having little conventional energy.
Approximately 60% of energy consumption is as fuelwood for cooking rising to 94% in some parts of the Upper Volta and Sudan (5).

The ecological environment is one of the most adverse in the world. The high levels of annual and daily insolation represents a very important energy potential, ideal for solar cooker feasibility studies. If this most abundant and non-wasteful source of energy is not a viable proposition in the Sahel, it is unlikely to be successful anywhere. In Sudan in particular, little had been done to utilize solar energy, and since introductions to local communities were forthcoming, the research was undertaken among Sudanese communities. It was also appropriate that Sudanese women did their main cooking during the day when the sun was hottest.

Unlike other areas of the developing world, where traditional stoves are usually made of clay, East African inhabitants tend to use tin stoves i.e. made from oil or kerosine tins. Little or no development had been undertaken to improve their burning efficiency, and the potential improvement of these tin stoves was considered an important area of research. In provinces such as Khartoum, which are some distance from wooded areas, charcoal is usually burnt since this is easier to transport.

An integrated approach to new and improved cookstove technology could provide comparative information from consumer surveys.

1.3 Aims and Broad Methodology

The aims and methodology employed fell into three stages: the first stage was to undertake considerable background research into the local conditions in Sudan, and the state of the art of improved woodfuel and solar stoves.

A preliminary fieldtrip enabled observations to made on the social milieu, where first hand information was obtained
through informal talks and discussions with local inhabitants. Observations were made on family modes and living patterns including local cooking and eating habits and other cultural norms that impinge on the preparation of meals. The fieldtrip also enabled detailed knowledge of the environment and familiarity with local skills and materials.

Supporting these observations and discussions among local inhabitants, desk research, both in the U.K. and the Sudan yielded further information on the extent and implications of desertification and domestic energy perspectives.

A worldwide literature survey was undertaken to determine the results of other researchers in the field of solar cookers and improved cookstoves. Some field experiences were also noted.

The background research therefore, had the aim of defining the social and technical framework from which a programme of development and testing of improved charcoal stoves and a solar cooker could be undertaken.

The second stage of the research was to carry out extensive development and testing in a U.K. laboratory to check for noticeably large economies in fuel consumption by altering various design parameters of the typical Sudanese charcoal stove such as draft, flue size, grill height etc; hence improving burning efficiency and reducing excess heat. As well as searching for several simple modifications to the traditional tin stoves, it was also intended to incorporate bricks in a stove design as an alternative to tin.

The wife of a Sudanese student was involved in checking the cooking procedure and typical use of a charcoal stove.

Parallel to the charcoal stove development, a suitable solar cooker design was sought. A series of simple tests were used to determine the necessary collection area; and the construction
of paper models, the most appropriate reflector arrangement. The aim was to have a simple design that could be easily constructed by a local carpenter from available materials, and which could be incorporated in a programme of physical testing in the Sudan alongside several pre-fabricated solar cookers.

The final stage of the programme was to undertake semi-quantitative consumer surveys on both the modified charcoal stoves and the solar cookers among two local samples of Sudanese women.

The aim of this consumer research was to determine consumer appeal and preferences of the different units and to examine their appropriateness within the local community. The units were introduced to the samples in an experimental design where each family used each stove for several days. Follow-up in-depth interviews checked the usage of the stoves and analysed the attitudes and perceptions of the women to the new technology. Findings from the interviews with each family were recorded on a questionnaire via a translator.

This completed the overall purpose of the research; to develop and test among local consumers some modified charcoal stoves to see if fuel consumption could be reduced, both by technically improving efficiency and by encouraging more resourceful use of charcoal. Secondly, the research was to check the potential and feasibility of solar cooking as an alternative fuel. In addition, since this research was an exploratory study in the application of survey techniques to the Third World consumer, a final aim was to determine the consumer research methods necessary for further large scale testing of household technology.
SECTION ONE

THE BACKGROUND RESEARCH
CHAPTER 2
SUDAN - THE PHYSICAL ENVIRONMENT

2.1 Desertification

The intensification or extension of desert conditions is worldwide and is caused by human rather than climatic factors. The increased human and animal population is over-exploiting the land; overcultivation, overgrazing, overcutting of vegetation for fuel are the main causes. The south-west of the African continent is affected from the Atlantic coast of the Sahara right across north Africa and the Sahel, and through the Middle East to north-west India.

Harrison (6) reports that the "world is losing precious agricultural land - an area bigger than Great Britain is disappearing every year". The effects of cutting vegetation for fuel has contributed significantly to this grave situation. Digernes (7) explains that in semi-arid areas, trees and bushes "bring up nutrients from below that are released to the soil from decaying leaves and reduce the rate of evaporation from the ground after rain. Furthermore, the extensive root systems of most perennials bind the top soil preventing it from blowing away during dry seasons and droughts". Increased demand for fuelwood on fragile ecosystems, in adverse climatic conditions, has resulted in the soil being exhausted, eroded and blown away. The number of people in the semi-arid region of the Sahel is doubling every 25 to 30 years, and worldwide concern for desertification became particularly prominent in 1973 after people in the Sahel had suffered five long years of drought.

Figure A1 shows the vegetation of the Sudan and the significant boundary between desert and semi-desert in the north and grasslands and savannahs in the south. The Sahelian desert belt gives place gradually to one where vegetation, though sparse consists mainly of acacias; thorny bushes, although during the rainy season green grasses appear for
Figure A1  Vegetation of the Sudan

In the savannahs of central Sudan, there is more permanent grass, and south of this zone the vegetation becomes richer with a scattering of trees. Forests are numerous in the south except for the Sudd swamp which expands during the rainy season.

However, a recent United Nations conference on the environment (8) reported that in Sudan, the southern edge of the Sahara had moved south some 100 kilometres between 1958 and 1975. "Roughly 650,000 sq.km. of good land has been transformed during the last 50 years on the southern end of the Sahara alone". Patches of desert appear around population centres or watering holes and then spread and eventually merge into the desert itself.

With increasing populations in the Sahelian zone, intensive cultivation and excessive use have depleted the fertility of the lands nearest the settlements. When the land is less productive, agricultural yields decline and there is less grazing for livestock. The result is that people must work harder to farm larger areas for the same production. Since no suitable land is left at the original site, they must travel longer distances to widely scattered fields.

Deforestation is widespread and causes difficulties for local inhabitants. Hancock reproted from a recent United Nations conference on energy (2); "more than 90% of wood cut in Africa - five million acres a year - is burnt as fuel". In Sudan 98% of the wood cut is used for domestic purposes and the shortage has particular significance for women, who are forced to walk farther and farther away to obtain enough fuel for their daily needs as forests near villages disappear. It is reported that in some areas, they may travel as much as 15 kilometres in a single day (9). Men are usually only engaged in the commercial production of wood and charcoal, although women are the prime consumers.
The problem is not only confined to the Sahelian zone. In Gambia, Makhijani (4) reports the observations made by Openshaw that where at one time only dead or dying trees were removed for woodfuel, now living trees are being cut at increasing distances from the villages. People complained that wood was more and more difficult to find. The scarcity of woodfuel in some areas of the world has meant that local inhabitants have had to move or turn to substitutes. The World Bank (10) reports that between a half to one billion people use agricultural and animal waste to fuel their fires. In parts of India dried manure is the second most important source of fuel for cooking and heating after wood (11). Once collecting wood takes too long to be worth the trouble, farmers turn to cattle dung. Now this source of fuel represents three-quarters of the Indian domestic fuel consumption (6), robbing the land of valuable nutrients. In some parts of Africa too, crop residues and stubble is now uprooted and used for fuel.

In Sudan, not only must people travel further to productive land and to collect woodfuel, but there is increased loss of water through both evaporation and run-off such that people must work harder to find sufficient water for even their basic needs. Apparently, it is not uncommon for women to spend up to one third of their day drawing and carrying water in areas most affected by desertification (9). A shortage of water can have serious implications in the field of hygiene, while the transportation and storage of water can introduce health hazzards.

In summary, the social and economic consequences of desertification are substantial and deforestation for woodfuel is one of the main contributing causes. The shortage of fuelwood for cooking is greatest in the central and northern areas of the Sudan. Consequently, any reduction in the demand for fuelwood would be most beneficial in these areas.

2.2 The Climate in Khartoum Province

Fieldwork was carried out mostly in Khartoum Province, where
in addition, the research programme was facilitated by a better communication network than exists in other parts of the country. The following is a detailed description of the climate and seasons in this area.

Table 1 contains mean values from measurements taken between the years 1941 and 1970 for the Khartoum area by the 'Sudan Meteorological Department'. However, an investigation undertaken by Heliotechnic Associates International (12) referred to solar radiation figures taken by the University of Khartoum, (Department of Mechanical Engineering), as being more realistic of actual incident radiation due to modified recording equipment. The figures for the year 1975 are reported to be representative of measurements taken over four years and are presented alongside the eight year average figures provided by the meteorological department, and which are consistently lower.

In this semi-desert province, there are essentially three seasons, with long months of extreme heat broken by a short period of occasional rain followed by cooler weather. The cooler weather or winter lasts from October to March when daily temperatures range from a minimum of 16°C to a maximum of 39°C.

From March to the end of June, is the hottest time of the year and the daily maximum temperature is about 41°C. Minimum daily temperatures are around 24°C. Towards the end of the summer season when vegetation is scarce, haboobs or sandstorms are common. The depletion of vegetation and topsoil is likely to make these sandstorms a more frequent occurrence.

Two wind forces dominate the climate, the dry northerlies and the moist southerlies. The latter advance north reaching their furthest point in August, which is the wettest month of the year. During the rainy season, generally July to August, about 75% of the annual 167 mm. of rainfall falls in short but heavy showers. These months are also associated with high relative humidities, about 40% in August compared to 13% in April, the lowest relative humidity. During the rainy
<table>
<thead>
<tr>
<th>Month</th>
<th>Atmospheric Pressure (30 yrs) (mm)</th>
<th>Dry Bulb Mean °C (30 yrs)</th>
<th>Daily Max °C (30 yrs)</th>
<th>Daily Min °C (30 yrs)</th>
<th>Radiation Total Cal/cm²/day (30 yrs)</th>
<th>Bright Sunshine Duration Hrs (30 yrs)</th>
<th>Relative Humidity % (30 yrs)</th>
<th>Rainfall (mm) (30 yrs) Max in one day</th>
<th>Wind Drn. Speed (10 yrs)</th>
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</thead>
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<td>30.4</td>
<td>31.7</td>
<td>16.0</td>
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<td>10.5</td>
<td>93</td>
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<tr>
<td>Feb</td>
<td>965.3</td>
<td>31.8</td>
<td>33.2</td>
<td>16.7</td>
<td>641</td>
<td>16.7</td>
<td>93</td>
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<tr>
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<td>963.5</td>
<td>35.6</td>
<td>37.0</td>
<td>19.9</td>
<td>717</td>
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<td>87</td>
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<td>962.1</td>
<td>38.7</td>
<td>40.1</td>
<td>23.0</td>
<td>784</td>
<td>10.7</td>
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<td>40.5</td>
<td>41.9</td>
<td>26.3</td>
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<td>962.4</td>
<td>39.9</td>
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<td>743</td>
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<td>963.3</td>
<td>36.4</td>
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<td>698</td>
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<td>Aug</td>
<td>963.8</td>
<td>34.6</td>
<td>36.2</td>
<td>24.8</td>
<td>660</td>
<td>8.7</td>
<td>69</td>
<td>40</td>
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<td>Sept</td>
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<td>Dec</td>
<td>965.9</td>
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<td>32.3</td>
<td>16.9</td>
<td>600</td>
<td>10.5</td>
<td>94</td>
<td>22</td>
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</tr>
<tr>
<td>Year</td>
<td>963.7</td>
<td>35.7</td>
<td>37.1</td>
<td>22.4</td>
<td>681</td>
<td>10.0</td>
<td>83</td>
<td>22</td>
<td>167</td>
</tr>
</tbody>
</table>

Table 1: General Climatic Data for the Khatoum Area (lat. 15°36'N., long. 32°33'E. Alt. 380m.)
season the maximum daily temperature is about $37^\circ C$ and the minimum about $25^\circ C$. 
CHAPTER 3
SUDAN - DOMESTIC ENERGY PERSPECTIVES

In 1972, the energy consumption in Sudan on input basis averaged about 0.15 equivalent oil tons per capita, which is about one tenth of the per capita world average.

Petroleum, firewood and charcoal make up some 95% of the energy sources in Sudan. Transportation uses about 50% of the petroleum in the country; tractors, pumping and construction plant taking another 19%, and marginal proportions going to industrial direct heat; light ca 10%, and electricity generation ca 8% (13). Oil imports account for a large proportion of government expenditure, and the discovery of crude oil in south west Sudan should provide some benefits, although it is unlikely to transform rural life in the near future.

In 1981, total consumption of woodfuel was said to be 13 million tons per year (14); (1 ton≈1000 kgms). About two thirds of this was used directly as firewood and the remaining third converted to charcoal. However, most woodfuel is used in the domestic sector as shown in table 2. It has been suggested that growth of domestic use could only approach about 50% of the forestry regeneration capability by the end of the century.

Table 2

<table>
<thead>
<tr>
<th>Fuelwood Uses</th>
<th>%</th>
<th>Charcoal Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakeries</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Burning Bricks</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Steam production,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>curing tobacco,</td>
<td></td>
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</tr>
<tr>
<td>carbide production</td>
<td>1.5</td>
<td>Domestic 90.2</td>
</tr>
<tr>
<td>Domestic Use</td>
<td>78.5</td>
<td>Services 8.3</td>
</tr>
<tr>
<td>100.0</td>
<td>1.5</td>
<td>Industry 1.5</td>
</tr>
<tr>
<td>100.0</td>
<td></td>
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</tr>
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</table>
3.1 Domestic Fuel Sources

A survey undertaken in the Sahelian zone by F.R.I.D.A. (5) between 1979 and 1980, draws the conclusion that poor sections of the population depended exclusively on various combinations of biomass fuels, whereas families in the high socio-economic bracket tend to use single fuels rather than combinations of them. Medium income households were found to use combinations including butagaz plus firewood and charcoal.

Butagaz seems to be of more importance as a commercial fuel for cooking than kerosine. The survey showed that renewable fuels ie. firewood, charcoal, dung or millet stalks accounted for approximately 90% of the total. Moreover, firewood was mentioned everywhere.

Charcoal was found to be very important in some capitals including Khartoum which are served from long distances, whereas Niamey and Ouagadougou depend much more heavily on firewood than charcoal. For the rural communities and centres less than 50,000, firewood largely prevails over charcoal.

In Sudan itself, Abayazaid (13), reports that direct heat from fuelwood is by far the most important source of domestic energy, accounting for 94% and the rest coming from the urban use of commercial fuels. Table 3 shows the domestic energy prospects based on 1974 consumption trends.

However, despite the greater population growth in the urban areas, Muhktar's survey (14) carried out in 1978 established that there was relatively little increase in the use of these fuels due to the high increase in their cost and the appliances through which they are used. Digernes also reports that since 1978, kerosine had not been available and some villages had abandoned their kerosine stoves.
Table 3  

Population and Domestic Energy Prospects

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1. Population - growth @ 2.9% pa. (millions people)</td>
<td>20.2</td>
<td>23.4</td>
<td>31.6</td>
<td>42.2</td>
</tr>
<tr>
<td>2. Firewood and Charcoal Consumption (million kgms/year)</td>
<td>6500</td>
<td>7440</td>
<td>9740</td>
<td>12400</td>
</tr>
<tr>
<td>3. Total Kerosine usage: mainly urban (growth @ 10%), (million kgms/year)</td>
<td>93</td>
<td>151</td>
<td>398</td>
<td>1050</td>
</tr>
<tr>
<td>4. Butagaz: (growth @ 10%), (million kgms/year)</td>
<td>3.3</td>
<td>5.2</td>
<td>13.3</td>
<td>36</td>
</tr>
</tbody>
</table>

Notes: 1. These figures assume a 2.5% population growth in rural areas and a 6% growth in urban areas.

2. The estimated per capita use of fuelwood in 1974 was 320 kgms. This is a weighted average of fuelwood per capita in rural and urban areas multiplied by the proportion of population in these areas ie.

\[ \text{Fuelwood weighted average} = \frac{350 \times 0.85 + 135 \times 0.15}{1} \]

3. 1974 per capita consumption = 4.3 kgm/year.

4. 1974 per capita consumption = 0.15 kgm/year.

Electricity is only available in urban areas, mostly in Blue Nile and Khartoum Provinces. It is accessible to about 8% of Sudan's population. However, the most important use of domestic electricity is for lighting and even then most households only have one or two lights. Very few people can afford to cook by electricity or use other electric appliances.

3.2 Fuelwood Availability in the Sudan

It has been estimated that natural forests in the Sudan cover 23.3% of the total area of the country. Productive forests cover 18% of the country, the remaining forested areas being protective forests on dry and semi-arid areas. There are few places in the north where tree stocks have not been drastically depleted: for every 100 feddans of timber cut, only 70 are replaced (9).
At present, resources are scarce to lacking in the most demanding areas and abundant in areas with lowest consumption.

Table 4 Fuelwood Resources in Four Main Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. North and east</td>
<td>5.04</td>
</tr>
<tr>
<td>B. Centre</td>
<td>22.38</td>
</tr>
<tr>
<td>C. West</td>
<td>29.29</td>
</tr>
<tr>
<td>D. South</td>
<td>43.29</td>
</tr>
<tr>
<td></td>
<td>100.00</td>
</tr>
</tbody>
</table>

Considering the population inhabiting each area and the consumption per capita, region A is seriously short of resources reflected in the high prices there and the presence of desertification. Area B is fairly self-sufficient, but with high population growth rates and expansion in agricultural clearances, and the growing dependence of region A, shortages of firewood are inevitable. If there were sufficient transport facilities, region C could meet the demands of regions A and B, although it is not an optimal solution since this region might also become barren. In region D, there is no firewood problem.

3.3 Firewood Collection and Charcoal Production

The F.R.I.D.A. survey in the Sahelian zone as a whole showed that direct collection by family members predominated in the rural areas. Among communities of less than 10,000 people well over 50% of rural families were reported to collect all, or part of their fuel. For communities up to 3000 inhabitants, walking is the usual way of reaching collection areas usually within a radius of 10 to 15 kilometres. Overall, the fuel collection effort remains the responsibility of women, although men occasionally help out if convenient to their occupation.
Donkeys and carts are used for larger infrequent collections and with the increased use of transport, more men become involved with collections. As urban areas grow, merchants play an increasing role. Trading concentrates in the medium to large urban centres although families in very small villages also purchase fuel when sources of firewood are distant.

In Digernes study in Bara, some 250 kilometres south of the desert boundary, she found that women mostly had to buy wood from villagers coming in from the surrounding savannah, since distances to wooded areas were too long for them to walk. Approximately 2 to 10 kilometres away would take a donkey journey ½ to 1½ hours.

The firewood in Sudan is mostly used for baking the local bread 'kisera', and in preparation of 'asida' - a porridge made from sorghum, which is the staple diet of the poorer families.

Both for wood and charcoal, Acacia Senegal is the main tree species. Being hard it gives excellent coal when young to middle aged. Only old and dead trees should be used for fuelwood, but as all old trees are consumed, living trees are damaged so that they die, are left for a month to dry before being cut and chopped.

Charcoal is produced commercially in earth kilns by charcoal merchants. Piles of wood pieces are covered by grass and a layer of sand mixed with water: holes are made to allow for ventilation and the wood is carbonized as the temperature reaches 250°C. It is not an efficient process - much of the wood is only half carbonized.

Using these crude means of carbonization, conversion efficiencies given by various observers are said to be in the range of 15 to 30%.
Figure A2 The Charcoal 'Souq'
Men are the main suppliers of charcoal, transporting it in sacks by cart or lorry to a central place, (Figure A2). One weight unit of charcoal contains approximately twice the calorific content of wood, and Digernes states that "charcoal is more economical than firewood as regards heat utilization". F.R.I.D.A. states that when the cost per calory is compared, charcoal is two to three times more expensive than a caloric of firewood. However, since charcoal stoves can be three times more efficient than open fires, the cost of useful heat could well be lower for charcoal consumers than those using firewood.

3.4 Domestic Fuel Costs

A number of surveys have been carried out which compare the costs of domestic fuels in the Sudan. Those undertaken by Sudanese authorities are a little out of date but are compared with prices charged during the fieldtrip. However, the cost of some fuels depend to a large extent on where they are purchased and there is likely to be some sampling fluctuation in the findings from the surveys. In addition, prices vary with the seasons.

In the F.R.I.D.A. survey of the Sahelian zone; findings showed that retail prices for wood grow dramatically as one moves from rural areas and small villages to the larger cities and capitals, confirming the speculative nature of the retail business in the urban centres. They noted that since charcoal is produced mainly for the large urban areas, no significant decrease in price was detected for rural consumers.

Table 5 gives the average retail price for the different domestic fuels in the three towns; Khartoum, Omdurman and Khartoum North for 1970, 1975 and 1976 (15).

In this urban centre at least, it is apparent that the price of firewood and charcoal has increased by approximately 600% in six years; that is approximately six times the increase in the cost of the other fuels.
Table 5  
**Annual, Average Retail Prices for Khartoum, Omdurman and Khartoum North (price in piasters)**

<table>
<thead>
<tr>
<th>Unit</th>
<th>1970</th>
<th>1975</th>
<th>1976</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood &amp; Charcoal Khanter*</td>
<td>24</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td>Kerosine 4.5 litres</td>
<td>11</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>Butagaz 12.5 kgm cylinder</td>
<td>179</td>
<td>191</td>
<td>229</td>
</tr>
<tr>
<td>Electricity kwh</td>
<td>2.6</td>
<td>3.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**NOTE:** Seasonal variations have been excluded.

* A Khanter is a 4 litre oil tin.

The following table taken from Abayazaid's report on fuel and energy in the Sudan, compares fuel costs in 1964 with those in 1974. The units of measurement are different from the earlier table and since 1973/74 and 1978 were years of high inflation, this may explain the difference in cost increases between the two tables. Nevertheless, between these years the cost of firewood increased more than that of other fuels, with the exception of kerosine.

Table 6  
**Comparing Domestic Energy Costs**  
(price in piasters)

<table>
<thead>
<tr>
<th></th>
<th>1964</th>
<th>1974</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood (dry) pt/cu.m.</td>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td>Charcoal pt/45 kgm sack</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Butagaz pt/12.5 kgm bottle</td>
<td>153</td>
<td>153</td>
</tr>
<tr>
<td>Kerosine pt/4.5 litres</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Electricity pt/kwh</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure A3 shows stacked firewood in a village close to the Kenana sugar project. Families are semi-nomadic and some firewood is collected free of charge from the surrounding scrub with the use of a camel or donkey. Such journeys were reported to be twice a week. However, the commercial cost of woodfuel in the village was extremely expensive especially
Figure A3   Stacked Firewood in Kenana Village
since the average income was only SL 18 per month during the preliminary fieldtrip of 1978.

In Kenana, woodfuel could be purchased as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 large log (approximately 1 metre long and 10 cm. dia ≈ 4 to 5 kgms)</td>
<td>20 piasters</td>
</tr>
<tr>
<td>6 thin twigs (approximately 1 metre long and 3 cm. dia ≈ 1 to 2 kgms)</td>
<td>10 piasters</td>
</tr>
<tr>
<td>Small clump of charcoal (about 100 gms or enough to cover dinner plate)</td>
<td>5 piasters</td>
</tr>
</tbody>
</table>

At least three large logs would be required for cooking a meal and the small quantities of charcoal sold would barely be sufficient for one small fire.

The F.R.I.D.A. survey noted that the price of firewood in Khartoum was 252pt/cu.m. (≈ 550 kgms) in 1980; a price which is identical to that in the Bara survey a year earlier.

Between the fieldtrips of 1978 and 1981, a large sack of charcoal purchased from the suburbs of Khartoum rose from 300 piasters to 500 piasters, although during the rainy season when roads are impassable and supplies from the south of the country limited, a large sack was reported to cost 900 piasters. Since the preliminary fieldtrip was during the rainy season, the reported cost of a sack of charcoal, 300 piasters may have been inflated, such that there may have been an increase of more than 100% during these years.

During 1978, a bottle of butagaz cost 245 piasters, an increase of 10% since 1976. A bottle of gas was reported to last a family of six about one month, but prohibitive to the widespread use of butagaz, a cooker cost between SL 200 and SL 300 at that time.

3.5 Annual per Capita Woodfuel Consumption

The levels of fuel consumption has received considerable
attention and a number of figures have been forthcoming from several surveys. However, there tends to be wide variations; some of which may be accountable by regional differences in needs, customs and methods of collecting the data. Also, figures have been calculated in different units. Some crude measurements taken in Khartoum confirmed figures from Digernes study in Bara that the weight/volume ratio of dry wood in Sudan is approximately 0.55 gms/cm³. It therefore seems reasonable to use this figure as a conversion factor.

F.R.I.D.A. report an average firewood consumption for the Sahelian zone of 0.93 cu. m. (512 kgms) /capita/year; although from a very small sample taken in Khartoum in 1980, annual per capita consumption was estimated to be 1.29 cu. m. (709 kgms).

Among the social groups, including the more affluent of the Bara study in 1979, an average of 1.32 cu. m. (724 kgms) was consumed annually per person.

It is likely that less firewood is consumed by families in Khartoum than in the provinces due to greater dependence on charcoal and alternative fuels. The two samples of women who participated in the testing of the charcoal and solar cookstoves were asked about their firewood consumption. They tended to answer in terms of the number of sticks they purchased each day for baking the bread, but some rough estimates show that about 1.06 cu. m. (583 kgms) was consumed annually per person.

With regard to charcoal consumption, in 1977, Muhktar reported that average annual per capita consumption of charcoal ranged from 90 kgms in the North and East to 1.8 kgms in the South, where there is no shortage of firewood; the national average being 38 kgms.

Digernes gives a figure of over 400 kgms of charcoal being the annual per capita consumption in Bara, which seems to
be very high; whereas throughout the Sahel, F.R.I.D.A. produced a figure of 129 kgms and 95 kgms taken from a small sample in Khartoum.

Again, women from the consumer surveys were asked about the quantity of charcoal used, (Appendix I). This averaged 100 kgms per capita per year, which is within the range of Muhktar's figures and those produced by F.R.I.D.A..

These annual per capita consumption figures are about three times higher than those produced by Abayazaid (table 3), from annual total consumption of fuelwood divided by the total population. However, the results of the three surveys are consistent and reliable for the North and Khartoum Province.

Families consistently used more firewood than charcoal. Considering that charcoal is the predominant fuel with twice the calorific value of firewood, there tends to be support for the idea that more economical use is made of charcoal than firewood.

3.5 Monthly Household Expenditure on Fuel

The proportion of income spent on fuel has received attention from several surveys including some early work undertaken by Sudanese Ministries.

The Ministry of Health carried out some surveys in suburbs of Khartoum during the early 1970's (16). They found that over 300 piasters was being spent on domestic fuel (inclusive of electricity) each month, and was said to represent between 10 and 20% of monthly income.

A survey undertaken by the Ministry in El Hassanab village some 48 kilometres south of Khartoum breaks down monthly fuel expenditure as follows:
Kerosine | 56 piasters  
Charcoal | 155 piasters  
Firewood | 58 piasters  
**Total** | **269**

Average income was reported to be SL 22 in 1971 such that monthly fuel expenses accounted for between 10 and 15% of income.

Electricity was found to account for half the expenditure on domestic fuel in a later survey (16), which seems high considering that it is generally only used for lighting.

During the preliminary fieldtrip of 1978, personal communication with families living in Blue Nile and Khartoum Provinces, established that a reasonable amount to spend on fuel, mostly firewood and charcoal, was about SL 13 per month; about 10% of average income, although one family spent twice this amount.

Digernes reported that in her Bara survey, monthly household expenditure on firewood was 186 piasters and on charcoal 358 piasters. According to her estimates, average monthly income should have been in the region of SL 17, such that the proportion spent on fuel ranged from between 32 and 43%. This seems very high and there may be some inaccuracy in the answers from the women.

From the two consumer surveys undertaken in 1981, it was found from the interview administered questionnaires that an average of 375 piasters were spent on firewood each month and 872 piasters spent on charcoal, although not all the families used firewood. This represented 10% of income, although one family was estimated to spend 17% of its income on woodfuel.

A survey undertaken in the sub-Sahara as a whole (18), found that expenditure on fuelwood was generally between 10 and 20% of household income.
F.R.I.D.A. reported that in both rural and urban areas, expenditure on fuel and light increased as income rose, though less rapidly than the rise in income.

In summary, this chapter has shown that most woodfuel is used for domestic purposes. Particularly in the north of Sudan and Khartoum Province which are served from long distances, charcoal is the predominant fuel, although wood is very often used for baking 'kisera'. Fuel costs have risen in recent years and families were seen to spend between 10 and 20% of their income on fuel. There is some suggestion that more economical use is made in burning charcoal than firewood.
Attitudes, values and behaviour are shaped in the family environment, which is part of the larger society where social and cultural norms permeate every aspect of life. Since this work was undertaken in suburban villages near Khartoum, this section sets the cultural framework of the social milieu outside the home, which is predominately male orientated, and within which the household and female environment exists. Sociological perspectives can identify some of the less tangible determinants of successful technology.

4.1 Population and Tribes

Sudan is the largest country in Africa with a population of 15.6 million people (19). It has a rough cultural split between the Moslem north and the non-Moslem south, the former containing about 75% of the population (20). The tribes of Sudan are numerous, both among the Arabic speaking north and The African south.

The majority of the population living in Khartoum Province are of Arab tribes, except for the Nubians from the north and the westerners from Nigeria and former French colonies. The juxtaposition of many tribes in these areas contrasts with the more homogeneous southern areas.

Sudan is a country of 'young people': nearly 75% of the population being under 30 years old and only about 1% are more than 70 years old. Approximately half a million people live in the capital; some 15% live in urban centres in all, and the rest are sparsely distributed throughout the rural areas.
4.1 Occupation and Work

It is the author's opinion that the two most dominant forces in shaping life in central and northern Sudan are the agricultural based economic livelihood of the people and the culture which is rooted in Islam. The occupation and work of the people shape their daily lives whilst the cultural values shape the social structure of the community.

The daily work patterns may vary slightly between rural and suburban communities. In the rural areas, most men are farmers. They keep animals; sheep, cattle and maybe some goats for meat and produce. Depending on how settled the community is, sorghum, potatoes, onions and other crops are grown.

In the Gezira area, the land is irrigated by hundreds of small canals. Farmers rent from the Central Gezira Board and grow cash crops such as cotton, wheat, sorghum and groundnuts. Tenants receive a share of the profits from the sale of these crops and are also free to grow vegetables and other crops for their own consumption. They also keep what animals they need for milk and meat.

Where farming is the livelihood of a community, the day usually starts between 5.00am and 6.00am or maybe even earlier. Breakfast is taken around 9.00am and in the early afternoon, the men return for dinner and possibly take a short nap. Work then continues depending on the agriculture and occupation until sunset just after 6.00pm. Another small meal may be taken but the day usually ends quite early and families are asleep shortly after 9.00pm. Women may help on the land with subsistence agriculture or animal husbandry. However, it is usual for them to perform tasks within the proximity of the home.

During Ramadan, the month of fasting, no food or drink is taken during sunlight hours. People eat the main meal of
the day at 6.00pm and take another at around 11.00pm. Consequently they retire much later and the hours of work are frequently shortened.

Every village or group of villages has it 'souq' or market place where many work as merchants or craftsmen. The size of the 'souq' and variety of goods and skills available depends on the distance from an urban centre. In suburban areas, there are many more skilled craftsmen and shopkeepers; carpenters, tailors etc.. However, local skills and industries are mostly maintained by men. In most rural villages, there would be a carpenter or two, a blacksmith, a stove maker and a shoe repairer. Carpenters make tables, chairs and beds of wood and fibre from the date palm or animal skin, and blacksmiths make axes, knives etc; often from the scrap metal of old cars, (Figure B1). Sometimes, goods are displayed outside the mud hut rather than in the central 'souq'.

In the 'souq', one can typically find grocers selling a variety of goods such as coffee, tea, beans, spices, dried onions, sugar, sweet drinks, cigarettes, salt, charcoal, batteries and cooking oil. There may also be a limited supply of tinned food and the odd piece of clothing. There is also likely to be a butcher and some fresh vegetable vendors.

In suburban areas, most merchants will take breakfast, usually a sandwich outside the home. Work stops at 2.00pm for lunch; shops and offices shut at this time and agricultural workers return home for a break. Shops often reopen at 5.00pm or 6.00pm for a few hours.

4.3 Male Social Groups

Outside the home, in the predominantly male world, all social groups are mono-sexual. No friendship groups have members of both sexes.
Figure B1  The Village Blacksmith
The 'souq' is the centre of trade and hence the focal point of a community where men work or meet socially. In a social anthropological study of life in a suburban village, Barclay (21) has provided some details as to the type of men's groups that one could expect to find.

Neighbourhood groups are characterized by having a regular, informally established public meeting place, and usually consist of men of one age group. Young men between the ages of fifteen and thirty may gather somewhere where there is a radio, possibly in a shop or near the home of someone who possesses one. Older men might meet at some other meeting point, possibly near the home of the village mayor, where they might pray together and otherwise spend their evenings in discussion.

Barclay also observed that other informal groups may be composed of closely related kinsmen, in which key members may be neighbours, while others may live in different parts of the village. Kinship groups may be rather mixed in terms of age, ranging from younger men to elderly patriarchs.

Among young boys and adolescents, cliques result from school attendance. Cliques of young men often indulge in card games, occasionally playing for money. They may spend an evening drinking native beer or liquor, 'aragee'. Aside from playing cards or listening to the radio, the main activity of such gatherings is conversation. Topics vary according to the age of the participants. Younger men devote their conversation to football, politics and such questions as to the best radio singer. Older men discuss village and national politics, religion, local gossip, prices and other current affairs. In such gatherings, the men usually squat on the ground in a small circle or seat themselves on 'angarebs'; the Sudanese beds.

It has already been mentioned that transistor radios can be the centre of attraction during a social gathering. Apart
from the traditional Sudanese music, which is very popular, national and international affairs are transmitted and news then travels by word of mouth throughout the villages. In effect, it provides broader horizons to the young men and keeps them informed, enabling a greater political awareness.

Such meetings for exchanging news and information are part of daily life. Discussions of topical issues raise the political and social consciousness of the male sector, and debates are usually of intrinsic value, whereas to the European, such discussions are very often of instrumental value rather than an end in themselves. Meetings and social gatherings are usually accompanied by vast quantities of highly sweetened tea.

4.4 Some Prevailing Cultural Norms

The limitation of the women's world restricts the types of groups in which they may participate, and they are excluded from the centre of economic and political activity. Aspects of religion, education or local politics remain the realm of the men, who with greater opportunity for discourse and information exchange tend to determine or reinforce the socio-cultural values and norms of the society. Women have limited access to contribute to the decisions and activities that shape their milieu.

This social segregation of men and women is typical in Moslem society although female subordination is common throughout the Third World. The cultural values and norms of Sudanese society have been shaped by its history which is rooted in the Islamic tradition.

In this male dominated world outside the home, society is very homogeneous, and male cliques are very close knit; the bonds of friendship or kinship being paramount. The uniformity of the community propagates certain attitudes and behaviours about which one can make some general observations.
The fatalistic attitude among the men in particular is less attributable to what Galbraith calls the 'accommodation to poverty' (22), but is more likely to be related to the religion. There is the idea that life is pre-determined and man must not interfere with the will of Allah (God). This underlying assumption within society is implied by the many expressions of fatalism in the language. The view that all events are out of one's hands, inevitable and uncontrollable manifests a somewhat submissive attitude to either positive or negative circumstances and a degree of complacency. These underlying attitudes internalized through history and reinforced by a somewhat closed society tend to nullify any forces of change, advancement or development. Passive acceptance of circumstances tends to be a negative trait within the culture, hindering creative and positive improvement.

The primacy of family obligation and hospitality is another social norm which is born of economic and environmental hardship as well as certain attitudes. Cultural obligations are supportive for the well being of the group but can work to bind the enterprising individual who wants to be relieved of family duties to improve his lot and be autonomous. That a person should consider education or occupation of more importance than supporting or helping the extended family is totally unacceptable. Hospitality to family, friends and other guests is traditional and social obligations to visit others or receive them, can be oppressive to the stranger, but again are internalized and accepted as part of one's life. To break from tradition for other priorities is almost heretical. Consequently, a large part of life is based on visits and visitors with little or no instrumental value. There is consequently a lack of privacy for study, for example, the emphasis being on the family and group rather than the individual. The family or social group takes priority over the individual and his or her needs; another factor contributing to the homogeneous social system. Opportunity for individual expression and self development therefore has to be specifically sought out.
In contrast to the Western world, where individualism is valued and encouraged, and where individual thought, self expression and self advancement within the community is valued, independence, autonomy and the development of individual potential is not sought among this close knit society, where the norms and values of the milieu are paramount and conformity is therefore spontaneous unquestioned and unchallenged. Consequently, there is very little in the way of change within this mono-culture. Financial support for relatives is taken for granted and although this has many benefits, it can be a hindrance to those aspiring to improve their living standards.

In short, the Islamic culture with its prevailing attitudes of fatalism and obligation tend to strengthen a homogeneous close knit society, which has the advantages of a social state, but which tends to discourage individual thought, self determination, autonomy and enterprise. Group identity and group norms take precedence over individual goals. Expectations of friends, relatives and the community result in many obligations which become part of the Sudanese way of life, but which do not necessarily contribute constructively to the development of the individual.

With increasing education and opportunity to broaden horizons, some attitudes are open to change especially within the male sector. However, this must inevitably be a slow process. Too fast development and simple emulation of Western norms can have the reverse effect of making people resort even more strongly to their traditional roots and culture. The rising power of the Moslem Brothers shows a trend to strengthen the traditional system rather than accept changes, evolve or modify positively. Reaction to change has resulted in a clinging to tradition and preservation of identity within that culture.
In Islamic Sudanese society, a woman's life is restricted to the home environment. Her work and social activities are among members of her own sex. This chapter outlines the role of women within the home. The self image of women and their attitudes to life are important in studying the reaction to new household technology.

5.1 Marriage

Women have no choice but to marry. Indeed should a girl reach her mid twenties and remain unmarried, she would not be considered socially acceptable. However, marriage is a costly affair. The men are expected to provide their wife with seven items of shoes, dresses and underwear etc. Weddings are associated with large ceremonies often with two hundred guests or more. Musicians are invited to perform and there is much dancing and feasting. The bride is expected to be a little upset at leaving her family.

Due to the high cost of marriage, the Islamic custom of plural marriage is dying out. Attitudes are changing, and for a man to have more than one wife is very often shunned these days.

However, typical among Islamic countries is the prevailing attitude that women are of a lower status, the property of men, and to be 'kept at home'. Although the institution of marriage provides material support for the woman, she is expected to fulfill the role of domestic and mother. By adolescence, this role is well internalized. The limited role of women makes them submissive in the presence of their menfolk although they can be quite gregarious amongst themselves.

The subordination of women within society is not unique to Islamic Sudan. However, subordination tends to be reinforced
by sexual segregation, which alienates women from the man's world and sharing in the decisions or contributing in any way to life outside the home. Even within the home, among traditional families, women may eat and sleep in separate living quarters. Sexual relations may take place in secrecy.

The relationship between men and women then are simply a matter of emulating well defined roles rather than sharing companionship based on communication. The social and physical restrictions on women give them very little opportunity for individual expression or development.

Another custom contributing to the subordination of women and enhanced by sexual segregation is the practice of female infibulation. Described in detail in a later section, over 80% of women are genitally mutilated (23). There are many health hazards associated with this operation, but the physical impairment in sexual relations must inevitably affect women's perceptions of themselves and their sexual identity.

It is uncertain whether men demand their prospective wives to be infibulated or not, but the practice is perpetuated by women, possibly because they think it pleases the men. Although female circumcision and infibulation has been practiced for over ten centuries, there are certain attitudes within Sudanese society that support the continuation of the practices. Genital mutilation is of ritualistic importance and is accompanied with certain celebrations. Mothers are the guardians of their daughters morals, and unless a girl can prove herself to be a virgin on her matrimonial night, she will be instantly divorced by her husband. It is also thought that a non-infibulated girl is 'unclean', and sometimes the operation is associated with hygiene.

The social pressures on women to have their daughters and granddaughters infibulated are very strong. It has been
suggested that they perpetuate the custom with zeal due to memories of their own suffering and out of spite. However, where mutilation is the rule, and where the force of the community identity is so strong, women may feel alienated if they do not submit their children to such an operation.

Infibulation must be a traumatic experience for a young girl. Women suffer from sexual intercourse and childbirth, but the exact psychological effects are unknown.

5.2 The Woman's Occupation

Ideally the woman's occupation is to maintain the home. That a woman stays in the house and takes proper care of everything in it, is the first criterion of the 'good woman'. When women do work on agricultural projects for an income, it is usually seasonal and poorly paid, such as cotton picking or fruit growing. Sometimes basket weaving is undertaken and women earn a little income from the sale of prayer mats or baskets, while others manufacture native beer or liquor.

However, among the poorer rural sectors many women contribute by producing food for family consumption. An article on 'Women and the Environment' (9) notes that "much of the processing of food is regarded as women's work"; winnowing, washing, pounding flour, making yoghurt as well as drying fruits and vegetables. In addition, women are active in food production, raising domestic animals and cultivating subsistence crops. Women therefore provide economic benefits to the family through their own labour.

In suburban areas, women may also rear chickens or goats for sale. Others may undertake dressmaking for friends and neighbours or make the skullcaps worn by men and other items of clothing. However, men do not necessarily regard this as an occupation.
Figure B2  Typical Housing in Suburban Khartoum
Whether a woman is economically productive or contributing to the family indirectly, it is considered preferable that she is essentially a homemaker and most of her activities are limited to this sphere.

Certain rural education centres are designed to help women help themselves by teaching them home management and means of earning income by making crafts. Classes cover home economics, carpet making, craftwork, animal husbandry and childhealth. However, unaccustomed to doing anything more than their duties in the home, the centres do not appeal to many rural women. In suburban areas where women tend to adopt the custom of seclusion, it is likely that those attending are the more enterprising women.

5.3 Family Decision Making

In all families, the men are the providers, and certain principles characteristic of life in both the nuclear and extended families are borne out. Barclay (21) made some observations on decision making and the division of labour within the home.

The senior male is the head of the household and theoretically the final judge on all matters pertaining to it. He allots money for household expenses. Finances may be managed leniently, with the wife receiving a certain allowance. He may also provide spending money for her as well as small sums for the children.

If a man works near a suburban centre or occasionally has cause to go there, he will do the necessary marketing and the wife should make do with what is brought home. She may have the opportunity to make small additional purchases at the village shops. Similarly, a man may select clothes for the family or he may buy cloth which the wife takes to a local seamstress to be made up into clothes. Generally speaking, the ready-made clothes are not widely available and tend to be very expensive. Sometimes men allow their women to shop in urban centres for their own clothing and kitchen
needs, although the head of the household usually buys livestock and furniture.

The role of husband and wife may vary somewhat if living with parents and relatives, and older women such as mothers and grandmothers exercise some authority over the wife. If the husband is relatively young and older male relatives live in the compound, these play an important role in decision making. However, the general principle that everything done outside the home is the province of the male is also applicable when it comes to shopping and the female has relatively few decisions to make when it comes to marketing.

5.4 The Division of Labour

Women bear the burden of practically all the domestic work and a large share of the effort for subsistence agriculture. However, the women who do work in the fields in the rural areas are very often the older women who have passed into grandmother status. However, women may be found gathering brush and firewood, although the majority of these are unmarried preadolescence girls and old women. Only the very poor young married women would ever be seen collecting wood according to Barclay. The poorer the family the more often its female members, especially those with no childrearing duties, work outside the home. With increased wealth, more women may be expected to stay at home whereas the greater the poverty the less the seclusion.

Generally speaking, female occupants are expected to provide meals for husband, family and often guests. They are responsible for keeping the house clean, washing the clothes, taking care of the animals in the compound, keeping the earthen jars full of clean water and generally waiting on the men.
Another principle concerning the division of labour is that the oldest persons are regarded senior in status; they do the least work and exercise the greatest amount of supervision. Outside the domestic environment, this principle also applies to family occupations such as farming and family-run shops.

According to Barclay, girls ranging in age from six to seven up to eleven stand at the bottom of the 'pecking order'. They are assigned the duties of keeping the house clean, taking care of the younger children, going to the shop or to other houses on errands. Girls slightly older may be assigned cooking duties and a supervisory role over younger siblings. They may also be expected to take care of the goats and chickens in the compound. Senior females tend to function as general supervisors.

In rural areas and within traditional suburban families, men and women eat separately. Women and children do not eat until the men have finished their food. They then eat the leftovers or cook again. If guests come for dinner then they must be fed, the duty of hospitality being paramount. The arrival of unexpected guests often means that the wife and older girls sacrifice their part of the meal.

For the women, it is shameful to display eagerness for food and they feel uncomfortable and embarrassed to set their portion aside before the men are fed. Women maintain an attitude of aloof indifference to eating.

Older boys who eat with the men are expected to eat 'kisera' and meat juice but not the actual meat.

It is not always the case that meals are prepared for a single household only. The baking of 'kisera' and the preparation of various items may be accomplished in a relatives home, often that of the wife's mother. A woman
may spend more of her time in her mother's house, where she prepares food for the day while her husband is away. She returns home with the main part of the meal, when he is expected back. Such a practice permits most of the food for several families to be prepared on fewer stoves and consequently uses less fuel.

Even if there is no joint cooking, visits to relatives' houses are very frequent and meals are often taken together, so that the preparation of meals is very often for family and guests.

5.5 Women's Social Groups

The limitation of the female world restricts the types of groups in which they may participate. Women's cliques are based on age, neighbourhood and kinship, with young girls participating in friendship groups established in the schools.

Barclay observed that neighbourhood women as well as kinswomen associate for informal purposes and divide according to age and marital status. There are groups of pre-adolescent girls and groups of unmarried girls primarily between thirteen and eighteen years old, although older unmarried girls may be found in such groups.

Television is becoming increasingly popular in suburban areas. It is an information medium but is also used for showing religious ceremonies, cultural programmes, dancing, Egyptian films and plays, and the occasional foreign film with subtitles. Young adolescent girls may gather around a home with a television to watch a play or film in the evening. The friend or neighbours' house with a television becomes the focal point for a social gathering. Egyptian plays are very popular with young girls, since they often depict social or family problems apparent in their own lives; for example, parental arranged marriages of which they disapprove. While these problems are now being openly discussed in Egypt, they are only just being questioned by Sudanese youth. Generally speaking, films and plays shown on television are extremely melodramatic and often quite sad – a mood which is also
expressed in Sudanese music.

Another type of female clique includes married women who are not yet grandmothers. Those under twenty retain their associations with unmarried girlfriends and may be viewed as in a transitional stage. Older married women without children are somewhat comparable in status to those of the unmarried of twenty-five in that both are atypical in this culture.

Finally, there is the group of women who have been grandmothers. These women usually remain apart from other groups.

Discussions among married women revolve around several major themes; raising children, pleasing the men and marriage. Younger girls also talk much about marriage, and to become a wife is their main ambition. In public women cover themselves with their tobes and are quiet and reserved.

With so much time spent in socializing, news soon travels. However, in the event of a death or a happy event, women spread news by other means. In the former case, the crying and mourning of the womenfolk informs a village that there has been a death in the family, and neighbours gather to join in the mourning. In the event of a wedding or some other welcome event, the Sudanese women make a high pitched warbling noise with their mouths.

5.6 The Female Lifecycle

Basically the lifecycle can be divided into four stages; child, adolescence, married and post childbearing.

Children enjoy considerable freedom - boys and girls are free to wander and roam as they please. There is little private property and virtually no traffic to impose restrictions on them. From a very early age, children become accustomed to
to the care and company of older sisters. They therefore become well adapted to interpersonal relationships and in this homogeneous society, young children form close and binding friendships from the neighbourhood at an early age, growing up in a well defined social order.

One person commented that children lacked the discipline necessary for achievement through formal education. However, they soon learn the social skills of the community and emulate the older children in running errands and helping in the daily chores. By school age, young girls can be expected to care for the younger members of the family by spending time playing and amusing them generally so as to relieve the elder women for cooking duties.

With the introduction of legislation in 1946 against female infibulation, women rushed to have their daughters mutilated before the legal process could take effect. Now infibulation is taking place at an increasingly younger age. Most girls are mutilated before the age of ten. Performed by older women in the village, infibulation is one of the most severe types of female genital mutilation (23). The clitoris, labia minora and at least the anterior two-thirds and often the whole of the medial part of the labia majora are cut. The two sides of the vulva are then pinned together with thorns. The operation is done with razor blades or pieces of glass. Anaesthetics are rarely used and the girl has to be held down by several women. The girls legs are then bound together from hip to ankle and she is allowed to rest for some forty days.

The operation may be associated with special food and celebrations although this is dying out. At one time, it may have signified a girls initiation into adulthood, but the reasons for the persistence of the custom are complicated and varied.

By the time a girl reaches adolescence, preoccupation with marriage and the acquisition of clothes, tobess and jewelry
is paramount to her female identity. At this age young women will cover their heads with the tobe when in public or when visiting friends. Having become accustomed to home-keeping and childrearing, the institution of marriage is regarded as an arrival point, through which a young girl achieves her ambition and identity as a domestic and child-bearer.

Births and marriages are big landmarks in the Sudanese lifecycle. Sudanese girls marry young and move directly from their father's provision to that of their husband's. Education for girls takes a lower priority than that for the boys and there is generally little opportunity to learn or develop skills outside the home environment. Once married, women start bearing their own children and consequently life continues much as before in their husband's house. Fulfillment as a mother is central to a woman's role and identity, and most would have at least five children and probably more. At this time there is great socializing with relatives. Meal preparation may be shared and female relatives are actively involved with the young children so that they may spend a great deal of time in one another's houses.

From the consumer surveys, women had low expectations of their lives; they wanted their boys to be educated and their girls to marry, but were contented and satisfied with their own roles. Only some of the men, when asked about their own lives, said that they would like to have more money. However, life is extremely simple and one could expect the lifestyle of the women to remain the same for generations in the suburban areas.

Once women reach grandmother stage, they may remain active in baking the 'kisera' or they may start to retire from family duties. Once relieved of childrearing responsibilities, more attention can be given to other matters; for example, economic and religious affairs. The present author observed that older women seemed to be more outward in their attitudes considering affairs beyond the realm of the home and family.
It was particularly noticeable that the elder women had more opinions to offer about the new and improved cookstoves. Generally speaking, once women reach the grandmother stage, they assume a passive authority over the family affairs, and are respected for their knowledge and opinions.
6.1 Diet and Eating Habits

In the F.R.I.D.A. survey of the Sahel, it is reported that all countries use staples in the form of flour; millet, corn, yam, sorghum etc. Flours had their own names in different regions and when mixed with boiling water form a sticky paste. In Sudan, sorghum flour is made into 'asida' by boiling it with water until it resembles a thick porridge or the whole grains are boiled until soft. This staple food is very easy to prepare on an open fire and is usually eaten with a meat sauce.

The other staple food made from sorghum flour is 'kisera', a flat pancake type bread. It is generally eaten with all meals, although risen wheat bread, made commercially at bakeries is becoming more popular particularly in urban and suburban areas. All food is eaten with the hands, the 'kisera' being used to dunk in the sauce or pick up pieces of meat and vegetable.

F.R.I.D.A. noted that throughout the Sahel, staples were eaten everywhere whatever the social level of the family and that wealth could be gauged by what sauce or stew was eaten with it. In Sudan, the meat used to make the sauce or 'mulah', stew is usually mutton or beef. With so many animals in the Sudan, meat is very popular. Mutton is preferred and chicken is also popular, although both these meats are relatively expensive commercially. Poorer families eat beef or resort to goats meat, dried meat or cheaper offals. Liver is very popular, but expensive and is considered a delicacy. Although dried meat is commonly eaten, it is not in preference to fresh meat if it is available. Oil from sesame seeds and groundnuts is usually used for cooking, and some fish from the Nile is eaten. Fish is usually shallow fried whole. Eggs are expensive commercially and are more usually eaten by families keeping their own chickens.
Apart from sorghum products and meat, in the Sudan families in suburban areas may eat a little macaroni or rice - sometimes sweetened with sugar as a sweet or breakfast dish. Although citrus fruits are grown in Central Sudan, they are expensive and poor families may purchase custard powder, which when made up with sugar and water provides an alternative sweet. However, in Northern Sudan, melon, bananas and dates are eaten when in season. A limited quantity of vegetables are consumed in Khartoum Province: potato, sweet corn, aubergines, cucumber, tomato and onion. A salad made of tomato and cucumber with groundnut paste is a common dish. Few leafy vegetables are eaten, and are usually cooked to a pulp in the traditional stew.

Coffee and tea are usually taken as a separate activity the meal and are part of a social ritual. In Sudan, a teapot may be placed on hot ashes after the main cooking is done or a small charcoal stove is used for making tea and coffee.

Eating habits may vary a little between the many tribes of Sudan. For example, among the cattle camps of the Dinka tribe in the south, milk is the main food and meat is only eaten occasionally. Ogilvy (24) notes that unlike northern Sudan, children are given first priority when milk is in short supply.

Generally speaking, diet tended to be very monotonous among the poorer sections, and F.R.I.D.A. noted that throughout the Sahel "uniform eating habits are as much a result of poverty as a cultural constraint".

Rural migration to the suburban areas often results in a poorer diet. Although most suburban families observed during the study kept some pigeons, chickens and maybe a goat for produce, immigrant families find it expensive to buy the food that they traditionally obtained from their animals and subsistence crops. A survey of one migrant community, El Cartoon (16), (so named because homes are made out of cardboard boxes), found that most families spent
about 50% of their income on food, some groups being low on protein intake and deficient in Vitamin A, Vitamin C and riboflavin.

In three other suburban areas of Khartoum, the survey found that carbohydrate supplied 61% of the total calorie intake. An average of 155 gms of sugar was consumed daily according to the survey, and since a small glass of Sudanese tea is sweetened with about five teaspoonfuls, (approximately 30 gms) of sugar, this high figure is not unreasonable. Fat intake was found to contribute a further 25% of total energy supply. Animal protein was found to contribute 37% of the total protein supply.

6.2 Number of Meals and Cooking Times

The number of meals taken each day depends to a large extent on the occupation of the head of the household and the family income. Very poor families may only take one large meal a day, although two to three are usual. The Sahelian survey noted that two to three meals a day are usual, and that for families cooking three times a day, breakfast was prepared very early, lunch around noon and dinner at 6.00pm. Another frequent pattern was reported displacing these times to mid-morning, 3.00pm. and a later dinner respectively.

Among the women of the consumer surveys, the former meal pattern was observed. However, it is common to cook sufficient food in the morning for both lunch and dinner. In Khartoum, it has been reported that 80% of the woodfuel used for cooking is consumed in the middle of the day. Fuel conservation is done by limiting the number of meals cooked per day, switching to foods requiring less preparation time or that can be eaten cold, and by not boiling drinking water (9). Mrs. G.M. Culwick did a survey of social factors affecting diet in the Gezira as long ago as 1949 (25), and found that there was no special cooking for young children due to the shortage of fuel. Women's reaction to extra cooking was "too busy - no time". To a European observer,
this comment may sound strange in view of the general low level of activity. However, one has to reckon with a different set of values with regard the utilization of time. Behind factors such as the severe climate and poor diet which contribute to a slower way of life is an established attitude of mind not easy to alter.

Appendix I gives the questionnaire that was used in the consumer surveys. When asked "How many times a day do you cook?", seven out of nine families replied twice a day, generally for breakfast and dinner. One family bought 'ful' (beans) from a local canteen for breakfast and another always reheated food from the previous day. Several families bought 'ful' for a third meal in the evening, but for the most part supper consisted of food left from dinner and was either eaten cold or reheated. Several women mentioned that they reheated supper during the winter months, although food is rarely eaten hot.

Breakfast was prepared anytime between 7.00am and 9.30am. Soup, 'asida', salad and 'ful' were the most frequently mentioned foods eaten for breakfast, although eggs, fish and chicken were also mentioned. The time spent in the preparation of breakfast varied between three-quarters of an hour to one and a half hours, presumably depending on the type of food being cooked. 'Ful', for example, would typically be left to soak overnight and then cooked for an hour or more for breakfast the next day. All families said that they only used one cooking pan and one charcoal stove in the preparation of breakfast.

Although dinner was generally prepared between 10.00am and 12 noon, several women mentioned reheating the dinner at around 3.00pm when the menfolk returned. Typically, the cooking would start with vegetables; potato, bamia, carrot, to which meat would be added. It is interesting to note that two families gave the quantity of meat they cooked for
dinner; one quarter of a kilogram of meat per day between a
family of ten and one kilogram a day between a family of
eighteen.

Cooking times ranged from one to three hours although between
one and one and a half hours was common. Typically, two
pans of food would be prepared for dinner, and this often
necessitated the use of two charcoal stoves.

During Ramadan, the month of fasting, food preparation for
the evening 'breakfast' often starts early in the afternoon
between 2.00pm and 3.00pm. It may then be reheated for the
evening meal. After one month of fasting during the daylight
hours, there follows three days of feasting, for which
special biscuits are baked on a metal plate.

6.3 Methods and Quantities in Cooking

In Sudan, preparation of the traditional 'mulah' involves
several stages. Vegetable such as potato may be pre-boiled
and then added to the meat which is previously shallow fried.
Seasonings and other vegetables such as tomatoes may be
added at various later stages. Sudanese meat and vegetable
stews are made with a large amount of fat or oil as this is
seen to be an indication of wealth.

Meat that is purchased from a suburban market can be quite
tough, presumably because the animals have walked some
distance before slaughter and lack of storage facilities
means that the carcass is not hung for any length of time,
and the prolonged cooking times are necessary to soften the
meat. The overcooking of the vegetables is a matter of
personal taste. Vegetables are usually served in the form
of a semi-pulp which makes them go further as well as being
easier to dunk the 'kisera' in. Sometimes, some meat such
as liver is shallow fried, but this only seems to be for
special occasions.
Apart from stew, the preparation of 'asida' has already been mentioned, and the local bread 'kisera' is made by mixing the sorghum flour with water and spreading it sparsely on a hot griddle - a small metal plate supported on bricks over a wood fire (Figure B3).

All cooking operations such as making 'kisera' or tending the stew, are done in the squatting position or seated on a low stool or even bed.

In terms of the quantities of food prepared, the women from the consumer surveys were asked about the amount of food they cooked each day. Two samples were used for testing the charcoal and solar stoves respectively. Those undertaking the solar stove testing tended to have fewer members in the household and generally speaking their diet and eating habits were more uniform than those of the women undertaking the charcoal stove testing. This can be explained by the fact that the former families were new migrant families, whilst the latter families were older, more established families with more interest in agriculture. They certainly had more variety in their diet and tended to cook greater quantities of food for larger households.

However, all the families reported using one pan to prepare breakfast, and by taking measurements of the pan and asking women to estimate how full it usually is, rough approximations were made of the quantities cooked.

Among the women testing the solar stoves, an average of 1½ litres of foodstuff was prepared for breakfast and somewhat more 2½ litres among the families testing the charcoal stoves.

For dinner, one or two pans were used; it was often reported that if only one vegetable was prepared, one large quantity was sufficient, or if two vegetables were to be cooked; they would use two pans but only half full. Again, crude estimates were made of the quantities involved. For both samples, the average pan would contain about 3½ litres of foodstuff, although the range was quite wide. It must be said that there is
Figure B3  Baking 'Kisera' on Firewood
some doubt as to the reliability of some of the larger figures as it is likely that women have overestimated. Total quantities of food cooked for dinner ranged from 2½ litres upwards, although in most cases these quantities also included supper and in one instance, breakfast the following day.

The number of people in the household ranged from five to eighteen persons. However, it is considered that the quantities are somewhat on the high side; certainly the dishes served for the meal did not seem to correspond to the large quantities calculated from the cookpans. Reduction due to vaporization, overestimates by the women themselves and the necessity for ready measurements offer some explanation. There is also the possibility that more than one pan was used in the preparation of the final dish.

Nevertheless, it can be assumed that a cookpan needs to have the capacity for between 1½ and 3 litres; and that up to three pans of foodstuff may be cooked during the morning in the preparation for dinner and the early evening meal.

The total quantity of food cooked during the morning averaged 5 to 6½ litres for the two samples. Assuming a reduction rate of about 30% and some inaccuracies, the final quantity of food cooked is likely to be in the range of 3 to 4 kilograms for an average of eight to ten people.

6.4 The Cooking Place and Hardware

It is generally true to say that cooking is undertaken in the coolest place. In suburban areas, there may be a small separate building as a kitchen called a 'matbukh', (Figure C1). This very small room would have holes in the walls as windows and there might be a crude fireplace on the floor where the 'kisera' is baked. At most times the cooking place is simply a supported structure of straw or sacking to provide shade. Consequently, smoke fumes are easily dispersed and cooking is more often than not performed outdoors for this
Figure C1  The Sudanese Kitchen
reason. Very poor families living in one room with no outer shelter from the sun, will usually cook in the shadow from the wall. Only when it rains or during a sandstorm is cooking undertaken inside. Eating and other social activities are nearly always in a separate area.

A detailed description of the typical cookstove made out of a 4 litre oil tin is given in the next chapter. The consumer surveys showed that between one and three charcoal stoves are used for the morning food preparation. Each stove usually only supports one pan, although cooked food and perhaps a teapot are often placed on one stove to keep warm. Any remaining fuel is often dampened with water, although some women extinguished the fire by covering it with ash or an inverted pan.

In Central Sudan, both in the suburban and rural areas, cooking vessels; that is, the pots and pans, are made of aluminium and imported from China or other Eastern countries. China plates and dishes are also imported and many plate are made of aluminium.

In Western Sudan, where pottery is made, earthenware cooking pots are used. It is probably due to the poor infrastructure that local goods do not reach other parts of the country.
CHAPTER 7
THE STATE OF THE ART OF WOODFUEL STOVES FOR THE THIRD WORLD

Generally speaking the literature available on woodfuel stoves for the Third World is more country specific - different countries or areas employ variations of cooking methods or stove designs. This chapter is not intended to present all the possible stove designs that are used or that have been developed but simply demonstrates the range of units. Particular bias is given to those units which are simple modifications of existing stoves or which may have implications for stove design in the Sudan.

7.1 Predominantly Woodburning Stoves

Throughout Africa and other parts of the developing world, the most common means of cooking is on an open fire. The most basic stove is simply three stones arranged on the ground in a triangle. Use of this cooking method does however vary from region to region. F.R.I.D.A. noted that in some areas it was frequent to expand the three stone fire into a five stone base for two pots.

Figure C2 shows this basic means of cooking common throughout the rural regions of Sudan.

Figure C2  A Three Stone Fire
As might be expected, large amounts of heat are lost both from the fire and the pan, especially if there is a wind blowing. F.R.I.D.A. noted that some attempts to improve efficiency of firewood use consist of adding a wind protection.

However, to some extent, an experienced operator can control the rate of burning by pushing the sticks closer between the stones or pulling them apart for a slower rate of burning. A V.I.T.A./I.T.D.G. design guide (26) reports; "after a short period of time the stones become hot to 300 to 500°C. These hot stones absorb heat and also transfer some of it back to the fire, the pot, and the incoming air. This air has to pass through the hot gaseous products of combustion. Thus the air is preheated and can therefore react more easily with the wood gases at the glowing ends of the sticks. So in the middle of the fire there is a very hot region with continual movement of hot gases out and the intake of colder air. Now the energy needed to sustain the combustion of a piece of wood comes from both radiation from the flame and from the glowing tips of the other pieces of wood. As the pieces of wood are moved apart, the energy absorbed by any one piece decreases. Thus the rate of productivity of gases, tar and charcoal decreases and therefore the total rate of heat releases by the wood also decreases".

One modification of this traditional woodburning method is a stove made of clay and dung which has the shape of a large bowl, on which the cooking pot is placed (Figure C3). Wood is placed through the gaps so that the fire burns at the bottom of the bowl. The V.I.T.A./I.T.D.G. design guide reports that "only part of the incoming air is actually drawn down to where the wood is burning".

In South-east Asia and the Indian sub-continent, the use of woodburning stoves made from clay is widespread. They consist of a hollow rectangular box with an opening underneath for the fire and two holes on the top for the cooking pots. These stoves are generally known as 'chulas' and
there are many different versions of them. In some cases these stoves are no better than a three stone open fire. Singer (27) reported them to be only 6 to 7% efficient. Apparently, the cooking pots absorb only a small percentage of the radiant heat from the fire and cold incoming air tends to flow over the top of the wood, tending to lower the flame temperature, and preventing the ignition of the volatile wood gases.

Some work has been undertaken on improving these clay 'chulas' and there are several variations; the 'Herl' smokeless chula, built in India is 'L' shaped with a flue. It is not a portable design and it has been reported that all the cooking pots need to be used to make it operate efficiently.

A similar stove that relies on the same basic design is made of a solid block of clay. Called the 'Lorena Stove', a tunnel carries hot gases beneath and past the pots. The addition of a chimney and front damper controls the availability of oxygen. The Lorena Stove has found wide acceptability and is said to use less wood than the Herl chula.
Clay is generally not available in northern and central Sudan, but there is the potential use of sheet metal for stove making, and a sheet metal stove has been designed by Dr. De Lepeliere. One particular advantage is that the combustion chamber has been shaped to accommodate long pieces of wood, (Figure D1).

![Diagram of De Lepeliere's Metal Woodburning Stove]

**Figure D1  De Lepeliere's Metal Woodburning Stove**

Air enters the combustion chamber under the stove and both pots receive radiant heat from the flame and some heat by convection from the hot flue gases.

Another metal stove designed by J.C. Overhaarte of the Techische Hogeschool, Eindhoven in the Netherlands, is called the Family Cooker (28). This stove has the advantage of being portable, but is only operational with small pieces of wood rather than larger lengths, (Figure D2).
Primary air enters through four cylinders into the middle of the combustion chamber, and as before, hot gases flow underneath the pot and around the firebox transmitting some of their heat to both the primary air inlets and to a second pot that is placed on the base of the stove. It is reported not to last more than twelve months in humid conditions.

Some performance tests have been undertaken on this cooker using charcoal. It was reported to hold only 150 gms of charcoal which burnt out in 30 minutes, and more fuel needed to be added at intervals. Efficiency was reported to vary from 21 to 34% for different design and operating conditions. It was estimated that heat loss from the pan was 10% of the total heat input of which 50% was by convection in laboratory conditions. This suggests the preference for a sunken pan as in De Lepeliere's design. Insulating the combustion chamber reduces losses by 14% but only shows as a 3% increase in the efficiency of the unit. This might imply that a
stove made out of clay need not necessarily result in higher efficiencies. Flue box losses accounted for approximately one sixth of the total heat input. The second pan near the flue has an increased efficiency of 2½%. Finally, the carbon dioxide on the top of the fuel bed was again about one sixth of the fuel used up in the experiment, and it was tentatively suggested that the introduction of secondary air on top of the fuel bed could lead to more complete combustion in the rather compact combustion chamber.

For use in the Sudan this stove would need to accommodate larger pieces of wood. Clay stoves are said to perform better only when long durations of cooking are involved.

7.2 Charcoal Stoves

The typical charcoal stoves used in the Sudan are made from square or rectangular tins with a hole cut in one side and a metal grate attached, a few inches below the top, on which the fuel is burnt, (Figure D3). The fire is not always

![Figure D3 Typical Sudanese Charcoal Stoves](image-url)
confined to the cooking pot, (depending on how tightly it fits on top of the stove), and inevitably heat losses to the surrounding area and from the fire container itself are wasteful. Some preliminary cooking trials held in outdoor conditions showed that the efficiency of these units ranged from between 18 and 29%.

Some clay stoves used for charcoal burning in some parts of the world were tested by Singer (27). He undertook tests on several portable designs made of fireclay or refractory ware. One such model, found nearly everywhere in Indonesia, is shown in figure E1. Eleven holes of 1.4 cm diameter in the bottom provide for air circulation and the shape ensures that the charcoal placed in it is very tightly packed. However, the walls are apparently too thin and need to be at least two centimetres thick.

![Cross-section of a Typical Indonesian Stove](image)

Figure E1 Cross-section of a Typical Indonesian Stove

The other models tested by Singer were square and had certain design features such as a damper on the side. Overall, efficiency figures for these stoves averaged about 30%.
A traditional charcoal stove commonly used in Thailand was compared by Oppenshaw (26) to the traditional metal charcoal burner used in Tanzania, and found that it reduced the amount of charcoal used to boil water by about a half.

The Thai stove, (Figure E2) essentially consists of three layers: an outer metal cover to give durability, a middle layer filled with ash with a simple cement seal to contain the ash, and an inner layer made of burnt clay about 3 cm thick at the top, tapering to about 1 cm at the base.

The airspace in the grate is about 25% of the total area of the base as compared to about 10% in the metal stove.

The rim of the stove has three raised platforms which support the pots and pans, and the air intake at the base may be restricted by a brick. It was noticed that unlike the metal stove, the charcoal never had to be moved around to obtain a complete burn.
Charcoal stoves made from metal such as discarded oil drums and a metal bucket have been experimented with. The Georgia Institute of Technology adapted the design principles of a traditional Japanese earthenware cooker to a double-walled stove made of an outer paint tin with an inner ceramic liner (18). Two vent holes, one cut in the base and the other in the lid, permit the control of the draft. The ceramic fire container minimizes heat conduction to the outer tin. The ceramic firebox and grate can be made locally in simple disc and cylinder shapes.

The Brace Research Institute (29) attempted an experimental design made of an inexpensive mass produced galvanized bucket,
which was modified by providing an expanded metal grate about 15 cms from the top. This grate supported the charcoal, above which was placed the cooking vessel. The stove can also be used for firewood, and although there has been no field testing, a 50% saving of wood has been estimated.
CHAPTER 8
THE STATE OF THE ART OF SOLAR COOKSTOVES

A detailed survey of solar cooker units developed throughout the world showed that there was in fact a range of designs. This section outlines that range and presents any fieldtesting results. There is however, some variation in the results given by different researchers. Different modifications of some designs and varied operating conditions offer some explanation.

8.1 Principally Hot Box Cookers and Ovens

The hot box cooker is one of the simplest designs to make. Solar radiation enters a well insulated box through glass panes and is absorbed by the dull black inside surfaces (30). The addition of an elementary concentrating system by two reflecting surfaces increases the efficiency of the cooker, (Figure F1). However, in these designs cooking must be done with very little water since the box has to be put aslant to the sun (31).

Figure F1 Hot Box Cooker with Internal Reflectors
G.A.T.E. prepared a survey and analysis of previous experiences with solar cookers in developing countries, the main part of the information being gathered during a tour of ten countries in Africa and Asia (32). Some performance data is given for a similar hot box cooker with a solar collection area of 0.25 m\(^2\) and the capacity to hold four small pots. Testing took place in New Delhi, where the maximum power of the cooker was found to vary between 50 watts in winter and 100 watts in summer. Temperatures above 100°C were reached only during April and May in India. During other months, maximum temperatures were as low as 85 to 95°C - sufficient only to cook rice.

Hoda reported some tests on this cooker (33) and found that with scorching to strong sun, food could be cooked within two hours, but with mild sun, food took three to four hours to cook. The weak sun radiation was also able to cook soft material like rice unless intercepted by cloud patches. If the temperature dropped to below 90°C however, it is difficult to cook rice.

Once the cooker is put in the sun, no permanent control is needed. However, during this period, the lid should not be opened to prevent undesired heat losses. Stirring or tasting the food is impossible and the cooker is not suitable for baking, roasting or frying.

A version more suitable for cooking with a large pan of food is the triangular box, where the longest side consists of two thin glass plates placed at an angle to the horizontal so that it is perpendicular to the sun's rays, (Figure F2). An insulated lid carries a reflector, adjustable to the altitude of the sun, and can be closed to keep the food hot after sunset.

A similar cooker was tested in India by G.A.T.E.. The cooker had a collection area of 0.4 m\(^2\) and had to be positioned
Figure F2  Triangular Solar Cooker

towards the sun every 30 minutes. The mirror had to be adjusted to give optimum reflection. However, it cooked two meals a day. With an efficiency of 50%, the cooker was found to deliver 170 watts at 830 w/m² global insolation. Maximum attainable temperatures were 140°C and 170°C in winter and summer respectively. Cooking time for one kilogram of food together with water varied from 1½ hours for rice to 3 hours for meat and pulses. The time required to boil 1 litre of water was about 90 minutes. All boiled and simmered dishes can be prepared in this cooker, for example, spaghetti, lentils, rice and millet.

A solar oven initially developed by Telkes as long ago as the 1950's is similar to the hot box, but radiation entering
the oven is augmented by four flat reflectors (34). Since the cooker needs to be orientated towards the sun, the design incorporates a moveable food platform which can be kept in the horizontal position. The functioning of the oven depends to a large extent on the use of heat storage materials to release heat during cooking or after sunset.

![Diagram of Telke's Solar Oven](image)

Figure F3  Telke's Solar Oven

Other versions of this solar oven operate without the use of heat storage materials. G.A.T.E. reports some performance observations from a solar oven tested in India. This solar oven had a capacity of two 1 litre pans and an efficiency of 45%. It delivered 170 watts at 850 w/m² global insolation.

The maximum temperature was reported to reach 300°C in summer and 250°C in winter; thus roasting and baking were possible with this cooker. The cooking time for 1 kilogram of food with water was said to vary between 45 minutes for rice and 75 minutes for pulses. The cooker needed to be positioned every half hour.
A solar oven with external reflectors tested by Hoda in India was less powerful. In spite of strong sun, Hoda noted that the temperature started falling from 1.30 pm onwards and that by 3.00 pm, it had dropped to 100°C. Maximum temperature, however, was only 120°C at 1.00 pm.

8.2 Paraboloid Direct-Focusing Cookers

Of these cookers the best known is that developed at the University of Wisconsin (35). Sun's rays are reflected to a focal point where the cooking pot is supported, (Figure G1). The main modifications to this design are different means of constructing the parabola and different reflecting surfaces. A few collapsible focusing cookers have been developed but generally speaking tend to be less efficient and less durable.

![Diagram of Wisconsin Direct Focusing Solar Cooker]

Figure G1 Wisconsin Direct Focusing Solar Cooker

A preliminary evaluative study of seven cookers was made in Florida (26). A total of fifteen characteristics or evaluation points were listed and assigned somewhat arbitrary weighting factors, which provided a means of discerning the
better systems. The highest scores went to Telke's oven—it scored highest in the performance and use categories, although its score in the economic categories was the lowest of the seven cookers. The Wisconsin cooker also scored well in this study—particularly on performance, having a high delivery rate. However, it was rated down on durability due to the gradual reduction in the reflectivity of the aluminiumized Mylar film, which usually only lasts about two years. It is also very fragile and liable to damage.

This design is one of the few to have received any fieldtesting. The Wisconsin cooker was tested in Mexico and a similar design in India, but there has been no official report of the results in either case.

The parabolic cookers fabricated in Mexico utilized small squares of mirror as a reflector surface in place of Mylar film. About 200 of these cookers were built in three Mexican villages. It was reported that maintenance of the cookers became a problem. Although the mirrors themselves lasted well, they had not remained attached to the parabolic shell after about three years. A village artisan was taught how to make the glue to paste back the mirrors, but he indicated that it was easier to go back to burning wood. His comments suggest that wood was not particularly scarce at that time and there was little incentive to repair the cookers.

More recently, some 250 parabolic dish aluminium concentrators were introduced to three villages in the Upper Volta. Frames and supports for these dishes were fabricated on site and Mylar film applied to the surface of the dish.

Concerning the performance of these cookers, G.A.T.E. reported that the cookers had a diameter of 1.4 m and a focal length of 65 cm. Apparently, due to the unstable vessel support, the capacity was only about 3 litres. The temperature reached 180°C and it is reported that baking and roasting are possible. The effective cooking power was said to be
about 340 watts. The cooker needed to be adjusted every 15 minutes.

Results from the field study (37) showed that none of the cookers were used for cooking all the daily dishes because the cooking was slow. 21% of the women did not appreciate the advantages; another 16% mentioned no inconvenience with the cooker and the majority, 63% felt that minor problems could be alleviated.

The advantages mentioned by the women were; "no need for wood", 53%, "no smoke", 30%, better cooking 4%, and easy to cook with.

Some difficulties were reported with the solar cooker; adapting the local pot to the cooking vessel, operating alone, assembling and disassembling, and the reflections from the parabolic dish. A major disadvantage reported was the impossibility to cook the staple food 'tô'.

Although 40% of the women were reported to use the cooker regularly, some of the reasons given for not using the cookers included, "lack of sun", "the pots were not suitable", and "the quantity of food was too large for the solar unit".

In summary, there were a variety of opinions offered. The majority of women thought the cookers were useful but they were mostly used for cooking small dishes - mostly sauces. Some mention was given to the fact that the cookers needed to be cleaned often and in all cases the cookers were dismantled when not in use.

Another direct focusing cooker was built by Tabor (38). This cooker is unique in that its design is based on optical theory, the reflector being twelve glass mirrors mounted in paraboloidal array, (Figure G2). The geometrical arrangement of the mirrors keep the reflected beams more to the bottom of the pan and its low pivot point makes the cooker more stable and easy to use because the reflector is closer to the ground at low sun angles. The cost of this cooker will
depend on the price of the mirrors within the country, and it should be relatively easy to fabricate on site.

A model in Mali was reported by G.A.T.E. to have a collection area of 0.8 m$^2$ and a focal length of 85 cm. If the mirrors are well adjusted, temperatures of 300°C and an effective cooking power of 185 watts are reported. Apparently, the cooking stand was too high for easy access but positioning was not difficult. Cooking performance was found to be affected by wind as with other direct focusing cookers.

A fresnel direct focusing cooker was developed by V.I.T.A. in the early 1960's (39). It is remarkably easy to construct out of a series of masonite rings and extra rings can be added to increase the cooker's power output.

The incident sunrays are imperfectly concentrated at a 75 cm distant focus. The solar collection area is 1.1 m$^2$. This cooker was tested by G.A.T.E. in Kenya, and was reported to
Figure G3  Fresnel Solar Cooker

deliver only 200 watts corresponding to an efficiency of 22% due to imperfect concentration. The capacity was said to be 2 litres of food. It was not possible to cook larger amounts due to the instability of the system. The long focal length of 75 cm required frequent positioning every 10 to 15 minutes. This cooker also suffers from deterioration of the reflective material.

Some fieldtesting of this cooker was undertaken in Morocco and its cooking performance was reported to be good. Apparently, a local ministry funded the construction of about 50 cookers, but they were given to friends who did not really have any need for them, so that use of the cookers eventually dwindled.
The sun basket is a most recent design in the development of solar cookers (40). Made almost entirely of local materials, the sun basket is essentially a parabolic mirror, the cooking pot being suspended inside the basket at the focal point, (Figure H1). An equally cheap and simple tracking device has been developed, which both facilitates the cooking work and increases the efficiency of the unit. It operates on the principle of a weight floating on a gradually descending water level, which pulls a string and in turn repositions the basket.

G.A.T.E. reports on one such model; the focal length of the basket being 10 cm, its diameter 93 cm and solar collection area of 0.68 m². Only small portions of food, up to 2 kilograms can be cooked in a blackened pot. On a sunny day (direct insolation 750 w/m²), the effective cooking power is said to be 250 watts corresponding to an efficiency of 50%. The maximum temperature, according to G.A.T.E. was 170°C, sufficient for baking cakes or biscuits. However, to stir the food the pot has to be completely removed, but the main disadvantage is that the paper maché shell has to be protected from rain.

![Figure H1 The Sun Basket](image-url)
8.3 Combination Cookers

The combination cooker is an attempt to combine the best features of the direct focusing cooker with those of the oven type cooker. The idea was first considered by Prata (41). His design consists of an oven with a small window, (low thermal loss), onto which rays are reflected from a fairly large reflector area, so that the net energy delivery rate to the cooking pan is relatively high. The double-walled cylinder has a large cooking capacity, and since the oven is stationary and the oven floor horizontal, it is somewhat easier to construct than the solar oven, and would have greater versatility due to the heat being supplied from below. However, the reflector quality needs to be very good to obtain a narrow focal line coinciding with the slit in the oven, and presumably it is a little more complicated to adjust the reflectors.

Figure H2 Prata's Combination Cooker
A modification of this design utilizes both direct and reflected rays through two glass windows, one being aslant to the sun and the other being at the base of the oven receiving reflected rays from a rough cylindro-parabolic mirror (31). No physical testing has been reported, but it would appear to be a little difficult to build, (Figure H3).

![Diagram of Bernard's Combination Cooker]

Yet another modification of the combination cooker was developed in Florida (36) in 1977. This design incorporates Tabor's optical arrangement - a parabolic section reflector pivoted about a point vertically below the oven box. With this arrangement, the reflector can stay roughly below the receiver (cooking surface) and most of the reflected rays will hit the receiver at something approaching normal incidence even at low sun angles, (Figure I1). The low
Figure I1 Florida Combination Cooker

reflector arrangement does not extend as high in the air at any sun angle; it enhances stability and minimizes wind loading making it easier to use.

At present, no fieldtesting of any kind has been undertaken on any of these combination cookers.

8.4 The Solar Steam Cooker

The solar steam cooker was developed as a means of providing indoor cooking and without the need to adjust the collector during cooking. Originally developed by the Brace Research Institute in Canada (42), a flat plate collector is used to raise steam to an insulated cooking vessel. (Figure I2).
G.A.T.E. reports on a solar steam cooker built in India; it had an absorbing area of 0.75 m² and was made of sheet aluminium with a copper plate welded on it. The pipe was 3.5 m long and wound threefold. The upper outlet of the pipe was connected to the bottom of the steam cooker, and the blackened absorber plate placed in a wooden tray, with a double glass cover and 10 cm thick fibreglass insulation.

It is reported that the water in the half filled copper pipe reaches boiling temperature after about 20 minutes exposure to the sun. The steam condenses at the two vessels in the steam cooker, heating them up. From then on it takes 65 minutes to bring 2 litres of water in the vessels to the boil. The effective cooking power was reported to be 150 watts, the overall efficiency being 20%. Roasting and baking are not possible, and adjusting towards the sun is only necessary twice a day. Each day the water in the collector has to be refilled. Only the upper vessel in the steam cooker is accessible for stirring.
Slow boiling of cereals, rice and potatoes has been achieved, the steam cooker taking $2\frac{1}{2}$ hours for complete boiling. Other reports of these cookers are not too favourable.

Some 20 of these cookers were installed in a school in Haiti some years ago, but the experiment ended in total failure. Foods cooked in these units were reported to be soggy and unappetizing.

A larger version of this steam cooker has been built in Iran (43). Having a collection area of $3.6 \text{ m}^2$, two absorber plates made of galvanized sheet iron with twelve 2 cm steel pipes welded at 12.5 cm intervals. The pipes are connected with each other at the top by another 2.5 cm pipe, the upper one being connected with the steam cooker, which consists of a double-walled well insulated box holding two cooking vessels.

In Iran, steam is produced from about 10.00 am until late in the afternoon. Five litres of water in two pots are brought to the boil within one hour, corresponding to an effective cooking power of 470 watt and an efficiency of 14%.

There have been some attempts to quantify the various attributes of different solar cookers, such as cooking power, maximum temperature, cooking capacity etc. However, as this chapter has shown, there are several variations of the same unit. Different researchers have reported different performance results and unless all the cookers were tested under the same solar conditions at the same time, a realistic meaningful comparison cannot be made. However, some conclusions can be drawn. The simple hot box cookers and solar ovens obtained fairly low temperatures on the whole. These cookers are best suited to the long slow cooking of rice and pulses, although during cooler months, they take quite a long time to cook. However, these cookers are simple to build and operate, requiring less frequent adjusting than the direct focusing cookers. There are several designs of direct focusing cookers utilizing different materials. Some seemed
to have a problem of stability and could only hold small quantities of food but under favourable operating conditions, they cook faster than the hot boxes. The combination cookers are rather more complicated and no performance data is reported. Similarly, the solar steam cooker still seems to be at the experimental stage. Very little fieldtesting has been reported. Reaction from the Upper Volta to the direct focusing cooker was mixed. It seemed to have most benefit for cooking light foods.
SECTION TWO: RESEARCH AND DEVELOPMENT OF NEW/IMPROVED COOKSTOVES
CHAPTER 9
SOME PRELIMINARY EFFICIENCY TRIALS ON A GAS COOKER

9.1 Introduction

Before embarking on a series of experiments to improve fuel consumption and use of the traditional Sudanese stove, a series of experiments of a preliminary nature were carried out on a standard household gas cooker. Cooking by gas afforded the operator greater control over the rate of heat input and a gas flow meter enabled the energy input to be measured quite accurately.

These experiments served the purpose of gaining familiarity with the concept of 'efficiency' and the testing procedure necessary for the improvement of the Sudanese charcoal stove. They were designed to determine the efficiency of cooking on gas with varying rates of heat input and to check the benefits of simmering with a lid on the saucepan.

9.2 Method

1½ litres of water was brought to the boil and 'cooked' for some time to simulate the simmering stage of cooking a stew. A standard aluminium saucepan was used for these experiments. The rates of gas input were varied according to the markings on the dial. The water was brought to 100°C at 'full gas', 'three-quarters gas', and 'half gas', after which the gas rate was reduced to maintain simmering (as judged by the visual appearance of small bubbles rising to the surface). Using a gas flow meter, the volume of gas used was noted every 30 seconds during the cooking operation and a thermocouple recorded the temperature of the water. Two tests were carried out for each dial marking and the average computed.

Methane gas has a calorific value of 8.16 k.cals/dm³ and recordings of the volumes of gas used to boil and simmer
were computed using this value to give the actual energy used.

Example: Initial temperature of the water = 26.5°C
Gas required to boil = 30.33 dm³

Theoretical energy; to raise 1.5 litres (100-26.5°C)= 73.5°C x 1.5 = 110.25 k.cals.
Actual energy = 30.33 dm³ gas used at 8.16 k.cals/dm³ = 247.5 k.cals.

Efficiency to boil = \frac{110.25}{247.5} = 44.5%

If it took 247.5 k.cals to boil 1.5 litres in 306 secs or 5.1 mins, actual energy input \frac{247.5}{5.1} = 48.5 k.cals/min

Simmering was maintained for 45 mins.
To boil and simmer for 45 mins used 96.48 dm³ of gas.
To simmer only = 96.48 - 30.33 dm³ = 66.15 dm³.
Vaporization after 45 mins = 620 mls.

Theoretical energy: latent heat of vaporization = 539 cals/gm
\therefore to evaporate 620 mls = 539 \times 0.62 = 334.2 k.cals
Actual energy = 66.15 dm³ of gas used at 8.16 k.cals/dm³ = 539.8 k.cals.

Efficiency to simmer = \frac{334.2}{539.8} = 62%
It took 539.8 k.cals to simmer 1.5 litres for 2694 secs or 44.9 mins actual energy input = \frac{539.8}{44.9} = 12 . . k.cals/min.

9.3 Results

It was found that the visual appearance of small bubbles rising to the surface at the side of the pan gave an accurate indication of boiling point. Below 100°C, the
bubbles were hardly visible although some vaporization did occur.

The energy calculations are set out in the following table:

**Table 7** Boiling and Simmering Efficiencies on a Gas Stove

<table>
<thead>
<tr>
<th></th>
<th>Actual Energy (k. cals)</th>
<th>Theoretical Energy (k. cals)</th>
<th>Efficiency (%)</th>
<th>Time to boil (mins)</th>
<th>Actual Energy (k. cals/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>To boil 1.5 litres of water:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full gas</td>
<td>252</td>
<td>110</td>
<td>44</td>
<td>5.2</td>
<td>48.5</td>
</tr>
<tr>
<td>Three-quarter gas</td>
<td>252</td>
<td>114</td>
<td>45</td>
<td>4.42</td>
<td>46.5</td>
</tr>
<tr>
<td>Half gas</td>
<td>208</td>
<td>111</td>
<td>54</td>
<td>14.97</td>
<td>13.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Actual Energy (k. cals)</th>
<th>Theoretical Energy Vaporization (gms)</th>
<th>Efficiency (%)</th>
<th>Simmer Time (mins)</th>
<th>Actual Energy (k. cals/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>To simmer the water:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full gas</td>
<td>484</td>
<td>490</td>
<td>264.6</td>
<td>55</td>
<td>10.8</td>
</tr>
<tr>
<td>Three-quarter gas</td>
<td>544</td>
<td>610</td>
<td>329.4</td>
<td>60</td>
<td>12.2</td>
</tr>
<tr>
<td>Half gas</td>
<td>458</td>
<td>490</td>
<td>264.6</td>
<td>58</td>
<td>13.0</td>
</tr>
</tbody>
</table>

9.4 **Discussion**

The table shows the standard method of calculating efficiency. Using a lid on the pan when boiling the water, the efficiency ranged from between 44% and 55%. There is the suggestion that the slower rate of heat input at 'half gas' afforded less heat losses by convection. In the closed environment, there was very little draft, consequently, these figures can be interpreted for minimum convection. The difference between the markings 'full gas' and 'three-quarter gas' are negligible in terms of gas flow.

Interestingly, the actual rate of heat input needed to maintain the simmering process was about a quarter of that to
bring the water to the boil, except with 'half gas', where the heat rate to simmer was the same as to boil.

Repeating the experiments without a lid on the pan showed that the 'half gas' with a rate of heat input at 12.9 k.cals/minute would not boil the water. The temperature stabilized at 97°C where presumably the heat input was equivalent to the heat losses including vaporization losses. Once the lid was placed on the pan the water boiled normally. For 'full' and 'three-quarter gas', the energy used to boil was only marginally greater than when a lid was used, suggesting that a lid has most significance when vaporization starts. In fact during the simmering process, approximately twice the energy was needed to maintain 100°C when no lid was placed on the pan. This suggests that when a lid is used, there may be some heat gain from condensed steam.

The aim of simmering is to have minimum heat input and consequently minimum vaporization, and with a gas cooker this is easier to achieve than with a charcoal fire. Using vaporization as a measure of efficiency is not optimal since with charcoal, the amount of heat released from the fuel depends upon good even combustion and air flow, which are less accurately controlled.

Secondly, the energy required to maintain boiling before vaporization losses occur is not accounted for. Some work on the rate of heat loss from a pan of 1½ litres of boiling water (see chapter 15), suggests that an average figure of 1.6 k.cals/minute is a reasonable figure to use for efficiency calculations. Obviously, greater heat losses occur within the first ten minutes and the heat required to maintain boiling temperature of a gradually reducing volume also decreases with time; therefore the figure can only be a rough approximation. However, if one recalculates the simmering efficiencies, allowing for the energy to maintain 100°C, the efficiencies for simmering alone are around 71%.
Two food cooking trials were undertaken on the gas stove. Ingredients included meat and vegetables which totalled just under two kilograms, and the cooking time accounted for three stages: frying, boiling and simmering which took about one hour.

Separating the rate of heat input for simmering alone, 5.7 k.cals/min was maintained for the food cooking as opposed to approximately 12 k.cals/min for the water test. Again the desirable 'simmering state' was evaluated by visual appearance.

In light of this, a standard water test was repeated with a controlled heat rate of 5.7 k.cals/min. The water only just kept at 100°C, although to the eye, the water was barely simmering at all. It could be that the solids in the food, including salt lowered the boiling point marginally or more likely; since the meat was first fried in fat, a better conductor of heat than water, steam was evaporating from the foodstuff and then condensing in the water, hence providing a heat input. There has been some debate as to whether evaporation losses from foodstuff are a heat loss or a heat gain. In the latter case it is possible that a visual simmering state would be maintained with a lower heat capacity.

Lundburg (44) ascertains that most simmering is accomplished at about 85 to 88°C. Bubbles form but do not break as in boiling. However, preliminary solar cooker trials in Sudan (see chapter 14), showed that women judged the temperature by the rise of small bubbles. Anything less and the food was not assessed to be "cooking fast enough".

For the purpose of using water tests to alter the design variables on the Sudanese charcoal stove, 'simmering' is judged by temperature maintenance at 100°C with minimum evaporation.

With regard to the efficiency of the cooking process itself, very small quantities of heat are required to actually effect the physical and chemical changes necessary in cooking.
However, after the initial high rate of heat input to bring the foodstuff and liquid to the boil, the temperature is maintained by a heat input equal to the thermal losses.

Löf (45) has made some calculations on the thermal losses: estimating an hourly convection loss (outdoors), at boiling temperature, of about 163 cals per cm² of utensil and a surface area of 465 cm² per 0.453 kgm of container contents, the energy input for one hour of food boiling, if one quarter of the water present is vaporized, would be distributed roughly as follows:

- Heating materials to 100°C: 20%
- Convection losses from vessel: 45%
- Vaporization of water: 35%

Löf notes that although variation in the assumed conditions would materially alter this distribution, the figures would still show that most of the heat is dissipated in long duration cooking. Vaporization losses in the experiment reported, accounted for over 50% of thermal losses.

Cooking on a direct heat source is a relatively inefficient process. The use of a lid, insulation with ovens, would lower heat losses and improve the efficiency of the cooking process but cooking habits have to be reckoned with. Actual food temperatures required for most cooking do not vary widely, because the presence of water in all foods limits the cooking temperature to 100°C.

The experiment showed that the gas cooker had at least twice the efficiency of traditional charcoal stoves and was considerably more efficient than the open fire, common throughout the developing world. Several references point out the relative efficiency of cooking on gas and electric appliances.

F.R.I.D.A. notes that the per capita energy content of firewood used for cooking in the Sahel-Sudanese region is larger than the corresponding value for the same domestic
application in the U.S.A.. Makhijani (46) presents some figures: "typically the annual use of wood or any of the other photosynthetic fuels for cooking is about 5 to 7 billion Joules per capita, or about 1 kgm of dry wood per capita per day. This is considerably larger than the 3 billion Joules per capita typical of electric stoves and ovens in the U.S.A. and the 1 billion Joules per capita in U.S. gas stoves and ovens".

Gas and electric appliances are easy to use and easy to control affording less energy to cook to high standards of satisfaction. However, if one were to consider the chain of fuel conversion efficiencies involved rather than the end use alone, it could well be 'ecologically more efficient' to cook on woodfuel.

This touches upon the whole question of what is efficiency? In the strict thermodynamic definition it is fairly easy to measure useful heat over available heat and hence the efficiency of the appliance. However, as has already been noted, the Sudanese charcoal stove is more efficient to use than the open fire which may well take account of the conversion efficiency of wood to charcoal.

If an appliance is easy to use efficiently, operator control, the human factor must be taken into account when designing an appliance. Too sophisticated a design may result in inefficient use whereas a relatively inefficient design but used economically may produce the net result of an overall saving.
CHAPTER 10
IMPROVEMENT OF THE SUDANESE CHARCOAL STOVE

The object of this stage of the research was to seek simple but significant improvements in the fuel use of the Sudanese charcoal stove. It was hoped that improvements noticeable to the operator would receive favourable responses from the consumer trials. Since large improvements in efficiency were sought, the water tests used for the gas stove were considered satisfactory for altering design parameters.

The standard experimental procedure is outlined for the testing of the typical Sudanese charcoal stove and following experiments were repeated in a similar fashion. Although these series of experiments were carried out in a fume cupboard in a laboratory, frequent communications were held with a Sudanese housewife to check various points as the research developed.

The calorific value of the charcoal was taken as 8 kcal/gm and the Sudanese assistant noticed no difference in the combustion and burning between English and Sudanese charcoal; there was some doubt as to whether the former might be more fully carbonized, although field observations showed that women tended to reject uncarbonized wood for burning in a charcoal stove.

It should be noted that there are a large number of different variables that could be tested in the design of a tin stove. The number of possible combinations of different values of each variable is far greater still. However, since large improvements were sought, the combinations could not be examined in detail, and the research concentrated on the effects of altering isolated design parameters.

The following chapters examine the effects of altering the position and size of the draft holes, the use of convection and different grill heights, on the boiling time and maintenance of the simmering process. The research and development
then proceeds to confine the fire and examine the cooking process on a reduced initial quantity of fuel. Later experiments include the use of insulation and secondary air to optimize the amount of heat available for simmering.

However, the first step was to run some water tests on the standard unmodified stove and to become familiar with the burning procedure and those factors affecting efficiency.

10.1 The Standard Sudanese Charcoal Stove

Figure 13 shows the typical stove design used in the Sudan. It has one large draft hole with an area of about 168 sq. cm. and a small triangular hole on an adjacent side of about 45 sq. cm. The Sudanese assistant pointed out that the small triangular air outlet hole was cut in an adjacent side in order to prevent the air flowing through. The air enters the larger hole and is drawn up to the fire.

![Diagram of the Unmodified Sudanese Charcoal Stove](image)

**Figure 13** The Unmodified Sudanese Charcoal Stove
The grill is either an inverted base with holes punched through, or it consists of metal strips interlaced through the sides of the tin about 3 cm below the top.

Several cooking demonstrations by the Sudanese housewife established than an average of 350 gms of charcoal was used to cover the grate at the start of the cooking. The standard experimental procedure is described as follows.

10.1.1 Experimental Procedure

Half a dozen simple water tests were carried out on the standard Sudanese stove starting with 350 gms of charcoal. In each case the fire was started using half a crushed firelighter. This was to afford greater reproducibility and to control the variation in the firelighting conditions due to the human factor. The object was to obtain good even combustion in a way that could be reproduced in further tests.

In Sudan, the stove would be placed in a little wind to help ignition. Otherwise women might use a tin plate to fan the fire. Some hand fanning using a piece of hardboard was also used to start the charcoal burning. This was noted on the test sheet and subjectively evaluated as; hard fanning (HF), fanning (F), some gentle fanning (GF), and no fanning (NF). Towards the end of the test or cooking period, the fire might be further fanned to aerate the coals and further extract any heat. This was recorded similarly at the end of the test.

To weigh the amount of fuel used, the complete stove with the initial 350 gms of charcoal was placed on some scales and the total weight recorded at the start of the test. 1½ litres of water was brought to the boil, the pan removed, and then the stove and charcoal quickly weighed. By deduction, the amount of fuel used during the boiling process was calculated. Further weighings of the amount of fuel used were made in the same way, and at the end of the test the remaining water was measured to give the quantity that had
CHARCOAL TEST SHEET

| WEIGHT OF PAN | GMS |
| WEIGHT OF WATER | 1.5 LITRES/KGM |
| WEIGHT OF STOVE | GMS |
| WEIGHT OF CHARCOAL | GMS |
| WEIGHT OF STOVE & CHARCOAL | GMS |

INITIAL TEMPERATURE OF WATER *C
AMBIENT TEMPERATURE *C

<table>
<thead>
<tr>
<th>TIME</th>
<th>WEIGHT</th>
<th>WEIGHT</th>
<th>WEIGHT</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stove &amp; fuel</td>
<td></td>
<td>Charcoal</td>
<td>Water</td>
<td></td>
</tr>
</tbody>
</table>

Amount of charcoal to boil gms
K.cals @ 8 k.cal/gm k.cals

Amount of charcoal to boil and simmer gms
K.cals @ 8 k.cals/gm k.cals

EFFICIENCY
Theoretical heat = (100 - )°C x 1.5 litres = k.cals.
Efficiency to boil = _________ x 100 = %

Amount of water left = kgms.
Amount of water vaporized = (1.5 - ) = kgms/litres.
Latent heat of vaporization = 539 cals/gm. to evaporate kgms
= x 539 = k.cals.

Total heat = + = k.cals.

EFFICIENCY = \[ \frac{\text{Theoretical heat}}{\text{Actual heat}} \] x 100 = %
been evaporated.

The simmering state of the water at the end of the test was also evaluated by visual appearance and recorded as; simmering steadily (S O.K.), simmering gently (SG), barely simmering (BS) or not simmering at all (NS).

From the measurements of fuel used, water temperature and vaporization, simple heat input/output efficiencies could be determined as shown on the stove test sheet.

10.1.2. Results and Discussion

The results are shown in detail in table 8. Average figures are presented at the side and show a high degree of reproducibility. With further results on altered design parameters, average figures only are given.

The results show that it took an average of 18.5 minutes to boil 1½ litres of water with an efficiency of 10%. In all tests, about one third of the water was evaporated after simmering for one hour. The total efficiency to boil and simmer averaged 18%.

During the boiling and simmering procedure, 53% of the charcoal used was consumed during the boiling process. A further 35% was used during the first half hour of simmering and another 12% during the second half hour of simmering.

Compared with some preliminary charcoal burning trials held outdoors with a Sudanese assistant, less variation was found in the laboratory results. In general, efficiencies tended to be lower among the laboratory tests, suggesting that some air convection is desirable in aerating the coals and hence facilitating the liberation of heat.
Table 8 Results of Tests on the Sudanese Charcoal Stove

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial water</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature (°C)</td>
<td>17</td>
<td>21</td>
<td>21</td>
<td>17.5</td>
<td>17.5</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td><strong>TO BOIL ONLY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (mins)</td>
<td>21</td>
<td>19</td>
<td>20</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>18.5</td>
</tr>
<tr>
<td>Qty charcoal (gms)</td>
<td>160</td>
<td>140</td>
<td>143</td>
<td>144</td>
<td>148</td>
<td>178</td>
<td>152</td>
</tr>
<tr>
<td>(k.cals)</td>
<td>1280</td>
<td>1120</td>
<td>1144</td>
<td>1152</td>
<td>1184</td>
<td>1424</td>
<td>1217</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>9.7</td>
<td>10.5</td>
<td>10</td>
<td>10.6</td>
<td>10.5</td>
<td>8.6</td>
<td>10</td>
</tr>
<tr>
<td>Degree of fanning</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td><strong>TO SIMMER ONLY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qty charcoal in 1st ½ hr (gms)</td>
<td>90</td>
<td>110</td>
<td>96</td>
<td>-</td>
<td>100</td>
<td>110</td>
<td>(101)</td>
</tr>
<tr>
<td>Qty charcoal in 2nd ½ hr (gms)</td>
<td>30</td>
<td>40</td>
<td>37</td>
<td>-</td>
<td>32</td>
<td>29</td>
<td>(34)</td>
</tr>
<tr>
<td>Total to simmer (gms)</td>
<td>120</td>
<td>150</td>
<td>133</td>
<td>131</td>
<td>132</td>
<td>139</td>
<td>134</td>
</tr>
<tr>
<td>(k.cals)</td>
<td>960</td>
<td>1200</td>
<td>1064</td>
<td>1048</td>
<td>1056</td>
<td>1112</td>
<td>1073</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>27</td>
<td>23</td>
<td>26.5</td>
<td>20.5</td>
<td>34</td>
<td>31</td>
<td>27</td>
</tr>
<tr>
<td><strong>TO BOIL AND SIMMER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qty charcoal (gms)</td>
<td>280</td>
<td>290</td>
<td>276</td>
<td>275</td>
<td>280</td>
<td>317</td>
<td>286</td>
</tr>
<tr>
<td>(k.cals)</td>
<td>2240</td>
<td>2320</td>
<td>2208</td>
<td>2200</td>
<td>2240</td>
<td>2536</td>
<td>2290</td>
</tr>
<tr>
<td>Efficiency</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>15</td>
<td>22</td>
<td>18.6</td>
<td>18</td>
</tr>
<tr>
<td>Simmering state</td>
<td>BS</td>
<td>BS</td>
<td>SG</td>
<td>S.OK</td>
<td>S.OK</td>
<td>BS</td>
<td>SG</td>
</tr>
<tr>
<td>Fanning</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
</tr>
<tr>
<td>Evaporation (kgms)</td>
<td>0.48</td>
<td>0.52</td>
<td>0.53</td>
<td>0.4</td>
<td>0.68</td>
<td>0.65</td>
<td>0.54</td>
</tr>
<tr>
<td>Charcoal left (gms)</td>
<td>70</td>
<td>60</td>
<td>74</td>
<td>75</td>
<td>70</td>
<td>33</td>
<td>64</td>
</tr>
</tbody>
</table>

**NOTES:** Average K.cals to boil and cook = 2290 ± 104, where ± = 2σ giving 4.5% variation.

\[
\sigma = \sqrt{\frac{\sum \delta^2}{n(n-1)}}
\]

where δ is the difference from the mean.
It was noticed that the harder the fanning in the initial burning process, the faster the rate of burning such that the water boiled slightly quicker, and more heat was released during the first half hour of cooking, giving greater vaporization. Overall, efficiencies could be increased by a few percent by greater aeration at the beginning of the test.

Similarly, in some tests during the last 15 to 30 minutes, some fanning was necessary to keep the water at a simmer. This was particularly true after removing the pan to take a weighing of the stove. Also during some tests, within the last 15 to 30 minutes, removal of the lid from the pan, prevented the water from maintaining a gentle simmer.

The Sudanese assistant reported that she preferred a fast rate of boiling, but thereafter wanted to stop the fire burning out quickly.

The observation was made during the first 45 minutes or so of testing, that the stove was generally too hot to handle without the use of gloves. After this time, the base tended to cool, although the area surrounding the grate and the top of the stove remained hot. In all stove work, care was taken to ensure that the grate was made with as many holes as possible so as to optimize air circulation.

Another point worth mentioning is that as far as possible, the stove testing utilized similarly sized pieces of charcoal. Too many large pieces of charcoal may take longer to ignite and burn unevenly, whilst very small pieces will not receive sufficient oxygen to keep them burning and the fire is suffocated burning out prematurely. With a bed of charcoal of even size, it is easier to get it burning more evenly, and with an evenly burning bed of coal, the water boils quicker since all heat is being liberated to the pot and not being wasted in igniting the larger pieces of charcoal or remaining unburnt fuel.
Experience showed that good air distribution on the grate got all the charcoal burning evenly, giving good combustion such that the whole bed of coal went to ash. With incomplete combustion, part of the charcoal is reduced to ash while other coals are only just starting to burn. A 5 cm bed of charcoal will absorb all the oxygen it can get, whilst a thicker bed of coals will burn incompletely, forming carbon monoxide.

Having achieved evenly distributed burning within the pieces of charcoal, withdrawal of oxygen slows the heat release, although a minimum level is required to maintain the fire. The rate of burning can be controlled by altering the draft flow or cutting it down altogether. The next series of experiments was carried out to investigate the effects of draft holes of different sizes and in different positions.

10.2 Altering the Draft Holes

Placing the draft holes on opposite sides of the tin, and with full draft (a total area of 213 sq. cm.), there is some suggestion that in windless conditions, this gave a slightly better draw to the fire. Otherwise, no significant differences were observed.

Cutting the draft area by a half gave a slight increase in the amount of water that was vaporized. This suggests that the larger draft area had an adverse cooling effect on the stove and the fire once the simmering process was underway.

With the draft area reduced to a quarter its former size, it took 29 minutes to boil the water, which was too long, although vaporization was minimized. There is a trade off between a fast boiling rate and a slow rate of burning required for simmering. A slow rate of burning throughout will minimize evaporative heat losses but necessitates a slow boiling rate, which is not preferred by Sudanese women.
Some experiments were undertaken on the Sudanese stove with adjacent air holes. The draft area was cut by half by blocking the inlet draft hole such that the total draft area was 121 sq. cm. The experimental procedure was the same as for the standard stove.

Table 9 gives the average results of tests carried out on a stove with the inlet draft hole blocked at the top so as to make it lower. The results show that a faster boiling time of 13 minutes was obtained. The faster rate of burning afforded greater vaporization, although presumably with slightly better combustion, efficiency to simmer alone rose to 33%. Heating the pot to boiling point quickly can minimize heat losses from the pot.

Table 9  Standard Stove with Half Draft in Lowered Position

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Charcoal (gms)</th>
<th>Effic-ity (%)</th>
<th>Charcoal to simmer</th>
<th>Charcoal (gms)</th>
<th>Vapor-ization (gms)</th>
<th>Effic-ity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>164.5</td>
<td>9.7</td>
<td>103</td>
<td>33</td>
<td>305</td>
<td>670</td>
</tr>
</tbody>
</table>

Of interest the experiment was repeated, this time blocking the air inlet hole at the base, so that air entered nearer the grate, (Figure J1).

Results in table 10 show that this stove had an overall efficiency of 23%, with an efficiency to simmer alone of 36%. The rate of vaporization increased with a slight decrease in the total quantity of fuel used. The slight improvement in performance demonstrated the advantage of having air entering where the tin was hottest affording some preheating of the air which aids combustion.
Table 10  Standard Stove with Half Draft in Raised Position

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Charcoal (gms)</th>
<th>Effic-ency (%)</th>
<th>1st ½ hr (gms)</th>
<th>2nd ½ hr (gms)</th>
<th>Charcoal (gms)</th>
<th>Vapor- ization (gms)</th>
<th>Effic-ency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>146</td>
<td>11</td>
<td>114</td>
<td>24</td>
<td>284</td>
<td>730</td>
<td>23</td>
</tr>
</tbody>
</table>

In summary, the half draft area proved satisfactory. Boiling times decreased possibly due to a slightly faster draw and there was an increase in the simmering efficiency. This can be explained by there being less cool air circulating to increase heat losses.
Placing the air inlet at the base of the grill afforded some preheating of the incoming air and hence improved the performance of the stove slightly.

To minimize the rate of burning, or at least slow it as much as possible, the air inlet can be closed altogether once boiling is achieved. However, before testing this concept, some further tests were carried out on the effects of wind or forced convection.

10.3 The Use of Forced Convection

Since all the experiments on the Sudanese charcoal stove were carried out in a laboratory, it was desirable to check the effects of wind or forced convection on the performance and efficiency of the stove. This was done using fans placed some 43 cm from the tin stove while testing.

Figure J2 shows the arrangement. Using an air flow meter, recordings were taken with the fan placed on side 1, 2, 3 and 4. The figures are presented in table 11, and one notices that the air flow was consistently higher on the right side of the fan than on the left side. Obviously, zero air movement was recorded on the side opposite that of the fan.

![Diagram](image-url)
With the fan in constant operation, the water was brought to the boil and kept boiling for half hour. Table 11 shows the results for the standard, full draft (213 sq. cm.) stove.

Table 11 Standard Stove (full draft) with the use of Forced Convection

<table>
<thead>
<tr>
<th>Fan on side 1</th>
<th>Side 2</th>
<th>Side 3</th>
<th>Side 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/sec</td>
<td>Time to boil</td>
<td>Charcoal</td>
<td>Effic.</td>
</tr>
<tr>
<td>Fan on side 1</td>
<td>Side 2</td>
<td>2.54</td>
<td>12</td>
</tr>
<tr>
<td>Fan on side 2</td>
<td>Side 2</td>
<td>1.93</td>
<td></td>
</tr>
<tr>
<td>Side 3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 4</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan on side 3</td>
<td>Side 2</td>
<td>2.34</td>
<td>17</td>
</tr>
<tr>
<td>Side 3</td>
<td>1.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 1</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan on side 4</td>
<td>Side 2</td>
<td>2.64</td>
<td>13</td>
</tr>
<tr>
<td>Side 4</td>
<td>2.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 2</td>
<td>2.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan on side 4</td>
<td>Side 4</td>
<td>2.74</td>
<td>14</td>
</tr>
<tr>
<td>Side 1</td>
<td>2.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 3</td>
<td>1.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10.3.1 The Standard Stove - full draft and forced convection

The results show that the greatest effects of the fan occurred when it was placed on the side with the inlet draft hole. The time to boil was shortened with the use of the fan. The faster rate of burning was maintained during the simmering process with a greater amount of fuel being used and a consequent increase in the rate of vaporization. It is not likely, however, that there was more available heat from the coals since the simmering efficiency remained unchanged.
at about 27%.

Results from the use of the fan on the three remaining sides are variable, and do not show any significant differences. However, when the stove is placed in wind, one might expect greater convective heat losses.

10.3.2. Altering the draft size

With the use of the fan it was found necessary that adjacently placed draft holes were preferrable. As might be expected, holes placed on opposite sides allowed the air to pass through the tin stove and also produced a greater cooling effect, whilst on a tin with adjacently placed holes, more air was trapped and drawn up to the fire.

With the standard tin modified to give a total draft area of 121 sq. cm., and with the fan on the draft side alone, the following results were observed.

Table 12  Standard Stove - Half Draft in Lowered Position

<table>
<thead>
<tr>
<th>Air speeds</th>
<th>Fan on side 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>m/sec</td>
<td>Time</td>
<td>Char-coal</td>
<td>Effic-iency</td>
<td>Time</td>
<td>Char-coal</td>
<td>Effic-iency</td>
<td>Time</td>
</tr>
<tr>
<td>Fan on side 1</td>
<td>mins</td>
<td>(gms)</td>
<td>(%)</td>
<td>mins</td>
<td>(gms)</td>
<td>(%)</td>
<td>mins</td>
</tr>
<tr>
<td>Side 1</td>
<td>2.79</td>
<td>10</td>
<td>140</td>
<td>10.6</td>
<td>149</td>
<td>289</td>
<td>710</td>
</tr>
<tr>
<td>Side 2</td>
<td>1.73</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
<tr>
<td>Side 3</td>
<td>0</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
<tr>
<td>Side 4</td>
<td>1.63</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
</tbody>
</table>

Table 13  Standard Stove - Half Draft in Raised Position

<table>
<thead>
<tr>
<th>Air speeds</th>
<th>Fan on side 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>m/sec</td>
<td>Time</td>
<td>Char-coal</td>
<td>Effic-iency</td>
<td>Time</td>
<td>Char-coal</td>
<td>Effic-iency</td>
<td>Time</td>
</tr>
<tr>
<td>Fan on side 1</td>
<td>mins</td>
<td>(gms)</td>
<td>(%)</td>
<td>mins</td>
<td>(gms)</td>
<td>(%)</td>
<td>mins</td>
</tr>
<tr>
<td>Side 1</td>
<td>2.85</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
<tr>
<td>Side 2</td>
<td>1.62</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
<tr>
<td>Side 3</td>
<td>0</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
<tr>
<td>Side 4</td>
<td>1.93</td>
<td>11</td>
<td>123</td>
<td>12</td>
<td>160</td>
<td>283</td>
<td>780</td>
</tr>
</tbody>
</table>
Again, a slight improvement was noted with the draft hole near the grate in the stove presumably due to the preheating effect of the hotter air inlet area.

The use of the fan afforded greater initial heat release from the coals such that the efficiencies to boil increased slightly. Less charcoal was used for boiling so that more was left for the simmering stage. The amount of water vaporized was also slightly higher with the use of the fan.

In summary, the use of a fan demonstrated the advantage of having initial air flow for maximum aeration of the coals when bringing the water to the boil. These simple efficiency tests did not aim to examine in detail the heat losses by convection which are likely to increase in a windy environment.

10.4 Altering the Grill Height

Having established a preference for a reduced draft area and the need for full aeration at the boiling stage, the next step was to try to significantly improve upon this.

10.4.1 The half level grill

The first area of investigation was to lower the grill to half way down the tin. The object of this was to see whether this would affect the air flow and allow better aeration of the coals to bring about even combustion. Getting a fire started properly such that all the coals are well ignited and heat is not wasted in the ignition of surrounding coals is important in the efficient operation of a stove and any design parameters that can aid this normally tricky operation would be an obvious advantage.

Figure J3 shows the lowered position of the grill. As a check, experiments were carried out for both full (213 sq. cm) and half (121 sq. cm) draft areas.
Figure J3  The Half Level Grill

Table 14  The Half Level Grill (1. full draft 2. half draft)

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>To boil</th>
<th>Charcoal to simmer</th>
<th>To boil &amp; simmer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal (gms)</td>
<td>Effic. (%)</td>
<td>1st 1/2 hr (gms)</td>
</tr>
<tr>
<td>1.</td>
<td>9</td>
<td>168</td>
<td>9</td>
</tr>
<tr>
<td>2.</td>
<td>8</td>
<td>138</td>
<td>11</td>
</tr>
</tbody>
</table>

Compared to the standard full draft stove, the lowered grill made a significance difference in shortening the boiling time, and with a faster rate of burning, tended to burn most of the charcoal within the first half hour. The rate of vaporization increased rapidly.
The half draft version (lower line of figures), was tested for half an hour after boiling, and consistent with earlier results, showed a small improvement in the time and efficiency to boil, although even greater vaporization occurred: the efficiency to simmer rose to 42%, but some of this high rate of vaporization represents too fast a rate of burning.

The half level grill had the effect of a chimney, whereby the air was sucked through the grate at a very fast rate. This had the benefits of a fan aerating the coals and providing good combustion, but had the negative effect of giving too fast a rate of burning for the final simmering stage. The fuel is burning at an excessively and unnecessarily high rate that is is wasteful of heat.

10.4.2. The Three-quarter Level Grill

The next step was to lower the grill only a quarter of the way into the tin giving a three-quarter level grill, (Figure K1).
The results of half hour simmering tests in table 15 show these to be the best of all, with the time to boil remaining short with the efficiencies to boil and simmer being constantly higher than earlier figures for the standard stove with half draft.

Table 15  The Three-quarter Level Grill (half draft)

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>To boil</th>
<th>To simmer</th>
<th>To boil &amp; simmer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Charcoal (gms)</td>
<td>Efficency (%)</td>
<td>Charcoal (gms)</td>
</tr>
<tr>
<td>7</td>
<td>129</td>
<td>12</td>
<td>168</td>
</tr>
</tbody>
</table>

In summary then, a slightly lowered grill gives a faster draw which facilitates aeration and hence combustion increasing the available heat from the coals. A draft door can then be used to shut down the air inlet hole once boiling point is achieved in order to reduce the rate of burning as far as possible.

The higher side to the stove around the pot should also contain some convection heat losses from the fire. The effect would be for hot gases from the fire to circulate around the sides of the pan before all their heat is lost by convection.

As a point of interest, the lower the grate is above the ground, the less the heat losses by conduction, due to the less amount of tin. Also, the less the surface area of tin, the less heat losses by convection. In practice, however, a low stove which utilizes less tin only has a marginal improvement in performance, and from the operational point of view, a higher stove is more convenient.
CHAPTER 11
THR THREE-QUARTER LEVEL GRILL

The previous chapter established the preference for the three-quarter level grill and for half the original draft area. However, these modifications only facilitated even combustion, they did not make large savings in fuel use. The next step was to confine the fire to the base of the pan in order to prevent excessive heat losses around the sides of the pan.

11.1 The Use of an Inner Ring

A circle of tin was cut and placed in the centre of the grill area, (Figure K2). The pan could then just sit on the coals. Using this inner ring, the initial quantity of fuel was reduced from 350 gms to 280 gms.

![Diagram of Three-quarter Level Grill with an Inner Ring](Figure K2)
Results are given in table 16 and show a slight increase in the efficiency to boil, the quantity of fuel used to simmer being reduced to its former lower level with a corresponding decrease in the amount of water vaporized.

Overall efficiency with the inner ring was increased to 32%, the efficiency to simmer for half hour after boiling being 50%, which was higher than all previous figures.

Table 16 The Three-quarter Level Grill with an Inner Ring

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Charcoal (gms)</th>
<th>Efficiency (%)</th>
<th>Charcoal (gms)</th>
<th>Vaporization (gms)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>113</td>
<td>14</td>
<td>103</td>
<td>215</td>
<td>770</td>
</tr>
</tbody>
</table>

Some trials were held with the area outside the inner ring filled with very small stones, but this failed to make any significant contribution to the performance of the stove. It was hoped that the stones might have an insulating effect, but in fact, heat was detracted from heating the sides of the pan, and in the final stage of the simmering process, the insulation only prolonged the simmering time by a fraction.

The next step was to reduce the grill area to the area inside the metal ring, hence reducing the draft area to about two-thirds the area of the grate. Figure K3 shows a cross-section of the top of the stove.

The results in table 17 show a marginal increase in efficiency to boil and a slightly higher rate of vaporization for the same quantity of fuel used for the simmering stage. The concentration of the air flow further facilitated the aeration of the coals and the amount of available heat that was released.
Figure K3  A Cross-section of the Top of the Stove with Reduced Grill Area

Table 17  The Three-quarter Level Grill with Reduced Grill Area and an Inner Ring

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Charcoal (gms)</th>
<th>Efficiency (%)</th>
<th>Charcoal (gms)</th>
<th>Charcoal (gms)</th>
<th>Vaporization (gms)</th>
<th>Efficency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>107</td>
<td>15</td>
<td>106</td>
<td>213</td>
<td>805</td>
<td>32.5</td>
</tr>
</tbody>
</table>

11.2  The Use of Tin Inserts

The use of the inner ring proved successful but the pan was sitting directly on the bed of coals. It was thought that this might hinder aeration and that the hot volatile gases from the fire could not circulate around the base and sides of the pan. Therefore, different sized inserts were cut to a size smaller than the base of the pan, but with a lip so
as to accommodate several pot diameters. In the sides of the tin inserts, triangular pieces were cut out to enable the flames and gases to circulate around the sides of the pan. The overall appearance of the fire resembled a gas ring with a circle of flames surrounding the base and sides of the pot.

![Diagram of Three-quarter Level Grill with Tin Insert]

**Figure L1** The Three-quarter Level Grill with a Tin Insert

Two tin inserts were tried with slightly different heights; 16.5 cm diameter, 5.7 cm high and 15.25 cm diameter, 4.5 cm high.

The results in table 18 show that boiling times were increased marginally on those with the inner ring and the amount of water vaporized was reduced together with overall efficiencies. There did not seem to be any appreciable difference between the two heights of the tin inserts.
Table 18 Three-quarter Level Grill with the Use of Tin Inserts

<table>
<thead>
<tr>
<th></th>
<th>To boil</th>
<th></th>
<th>To boil &amp; simmer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (mins)</td>
<td>Char-coal (gms)</td>
<td>Effic-iency (%)</td>
</tr>
<tr>
<td>5.7 cm high insert</td>
<td>12</td>
<td>116</td>
<td>13</td>
</tr>
<tr>
<td>4.5 cm high insert</td>
<td>12.5</td>
<td>117</td>
<td>14</td>
</tr>
</tbody>
</table>

However, the great advantage of having a small diameter insert is that the initial quantity of fuel can be reduced even further. Using a small insert avoids excessive fuel being used in the initial stages and wasted heat to ignite the whole fire. Therefore, the next step was to see if a further reduction in fuel could offset the slight decrease in efficiency with the height of the pan a centimetre or two above the fuel bed.

11.3 Reducing the Initial Quantity of Fuel to 200 gms

Table 19 shows the results of tests using a reduced quantity of fuel at the start of tests. The slightly longer boiling time was maintained but with a further increase in the efficiency to boil. Compared to the original stove, the quantity of fuel used to boil and simmer for half an hour is reduced by a third.

Table 19 The Three-quarter Level Grill using 200 gms Fuel

<table>
<thead>
<tr>
<th></th>
<th>To boil</th>
<th></th>
<th>To boil &amp; simmer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (gms)</td>
<td>Char-coal (gms)</td>
<td>Effic-iency (%)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>93</td>
<td>17</td>
</tr>
</tbody>
</table>
However, the overall efficiencies to boil and simmer were lower than for the three-quarter level grill with the inner ring, suggesting that the use of the inserts afforded greater heat losses. The overall decrease in the fuel consumption however, greatly compensated for this.

In summary, containment of the fire prevented excess heat being wasted around the sides of the pan and in igniting the remaining fuel. Using a tin insert smaller than the size of the pan forces the user to use minimum fuel. The chimney effect of the lower grill provided a fast concentrated draw of air maximizing even combustion.

At this point, efficiency as measured by vaporization became redundant. The aim was to ensure full even combustion at each test and by altering some design variable see how much useful heat could be obtained from a nominal quantity of fuel. Experience in getting even burning had now been achieved and the next step was to see how long the boiling point of the water could be maintained with minimal vaporization. The latter experiment was repeated measuring the time that the temperature could be maintained after boiling.

An example of the test sheet is included, and temperature recordings were made every minute using a thermocouple inserted in the water so that the lid of the pan need not be removed during the test. As a check, notes were made on the nature of burning, and the water was allowed to simmer until the temperature dropped below 100°C. No attempt was made to fan the fire for further heat release at this stage.

The results of the time and temperature measurements are presented in table 20. The temperature of the water was maintained at 100°C for 52 minutes after boiling, which should be sufficient for a moderate amount of cooking. Vaporization was much the same as before with most occurring during the first half hour after boiling.
CHARCOAL TEST SHEET - TIME AND TEMPERATURE

<table>
<thead>
<tr>
<th>AMOUNT OF CHARCOAL</th>
<th>gms</th>
<th>WEIGHT OF PAN</th>
<th>gms</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITIAL WATER TEMP.</td>
<td>°C</td>
<td>WEIGHT OF WATER</td>
<td>1500 gms</td>
</tr>
</tbody>
</table>

TEMPERATURE RECORDINGS

<table>
<thead>
<tr>
<th>Minutes</th>
<th>Water temp. (°C)</th>
<th>Minutes</th>
<th>Water temp. (°C)</th>
<th>Evaporation of water (gms) (mins)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>17</td>
<td>110</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>18</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>120</td>
<td></td>
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<tr>
<td>20</td>
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<td>22</td>
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<td>25</td>
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<td>26</td>
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<td>27</td>
<td></td>
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<tr>
<td>28</td>
<td></td>
<td></td>
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<tr>
<td>29</td>
<td></td>
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<td></td>
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<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11.4 The Use of Preheated Secondary Air

Since the sides of the tin became quite hot and the use of the tin insert permitted greater air circulation, the use of preheated secondary air through the sides of the tin seemed an obvious parameter for experimentation. Preheating the air before it reaches the fire further aids in the combustion process.

Two sets of experiments were tried with holes the size of a large nail in the base alone and then in the base and sides together. There needs to be enough air holes to admit sufficient oxygen but not so many as to create a cooling effect.

The water was brought to the boil in the ordinary way and then a tin door was placed over the main primary air inlets so that secondary air was preheated through the sides of the tin.

<table>
<thead>
<tr>
<th>Holes in the</th>
<th>Boiling Time (mins)</th>
<th>Evaporation after 1/2 hr (gms)</th>
<th>Evaporation from 1st 1/2 hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>base only</td>
<td>15</td>
<td>411</td>
<td>78</td>
<td>70</td>
</tr>
<tr>
<td>base &amp; sides</td>
<td>14</td>
<td>267</td>
<td>33</td>
<td>70</td>
</tr>
</tbody>
</table>
The results show that the water temperature was maintained for 70 minutes after boiling. However, there was considerably less vaporization with the stove having small holes in both the base and sides. There are two possible reasons for this; firstly that the greater quantity of air holes aided heat losses from the tin and had a cooling effect or that the cooler tin lost part of its chimney effect needed for a good draw and better combustion. The quantity of fuel used by the two stoves remained the same.

In summary, the secondary preheated air gave better combustion and extracted more available heat from the fuel, but too many secondary air holes had an adverse cooling effect. It is likely that outdoor conditions with more convection heat losses will have some effect on the quantity of holes required for preheating.

The tests on the stove with holes in the base and sides were repeated with the air inlet draft hole closed. Table 22 shows the results of these experiments.

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ¾ hr (gms)</th>
<th>Evaporation from 1st ¾ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>275</td>
<td>162</td>
<td>80</td>
</tr>
</tbody>
</table>

The water took a very long time to boil and the slower rate of burning afforded only a slightly longer cooking time - 80 minutes after boiling. However, the rate of vaporization was maintained at a consistent but low rate.

There is a trade off between a fast rate of boiling and a slow rate of burning required for the simmering process. Very long boiling times are not acceptable by Sudanese women.
Using the version of the three-quarter level grill with holes in the base only, further attempts were made to reduce the initial quantity of fuel to 100 gms with the primary air flue open to boil and shut for the simmering stage. The results show that it took 23 minutes to boil the water and that the temperature could only be maintained for 32 minutes after boiling.

Table 23  

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after 1/2 hr (gms)</th>
<th>Evaporation from 1st 1/2 hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>65</td>
<td>--</td>
<td>32</td>
</tr>
</tbody>
</table>

In theory, it is likely that an initial quantity of fuel between 150 and 200 gms would bring the water to the boil in a reasonable time and sustain the simmering process for a small quantity of food. Further fuel could then be added if need be.

11.5 Some Further Experiments using Insulation

The next stage of any research and development of improving the fuel consumption of a charcoal stove would be to try and prevent excessive heat losses from the sides and top of the stove. This necessitates some form of insulation and in the case of preventing heat losses from the top, an insulating lid with flue holes built in. Obviously, if some form of insulation is used there can be no secondary air inlet.

An experimental insulating box with a lid was constructed of tin on the inside and hardboard on the outside. Two circular flue holes made of tin were inserted through the lid and totalled 14 sq. cm. in area. The box and lid were packed with glasswool, and the unit sat on the grill which was made to jut through the sides of the tin. The thickness of the insulation measured 8 cm all round.
Using 200 gms of charcoal with the insulating box alone, the water boiled within a reasonable time. There was slightly more vaporization but no significant extension of the simmering time.

Table 24  The Three-quarter Level Grill with Insulating Box

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>453</td>
<td>50</td>
<td>51</td>
</tr>
</tbody>
</table>
Placing the lid on the insulating box at the boil, although raised fractionally for 15 minutes to allow for excess steam from the pan, gave the following results.

Table 25 Using the Lid on the Box at the Boil

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after 1st ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>450</td>
<td>165</td>
<td>72</td>
</tr>
</tbody>
</table>

The use of the lid afforded greater vaporization after the first half hour of simmering and maintained 100°C for 72 minutes after boiling, some 20 minutes longer than without the use of the box and lid.

Placing the lid on the box at the start of the test, although again raised a fraction to allow for excess flue gases and steam, produced the following results.

Table 26 Using a Lid on the Box at the Start of the Test

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after 1st ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>445</td>
<td>300</td>
<td>85</td>
</tr>
</tbody>
</table>

Again, an even greater rate of vaporization occurred after the first half hour of simmering with the temperature being maintained for 85 minutes after the boil. This would be more than sufficient for food cooking purposes.

The slightly longer boiling time can be accounted for by the fact that the use of the lid hindered the draw of air. The advantage of raising the lid slightly was to allow enough draw to achieve a reasonable boiling time. The lid became hot, giving greater insulating effects, when it was placed on the box at the start of the test.
Reducing the initial quantity of fuel to 100 gms raised the time to boil by a few minutes. With the lid placed on the insulating box at the boil, the fire required fairly hard fanning with a piece of hardboard to get the fire burning.

Table 27 With the Insulating Lid on the Box at the Boil using 100 gms of Charcoal

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>110</td>
<td>5</td>
<td>27</td>
</tr>
</tbody>
</table>

Minimum vaporization occurred and the boiling temperature was only maintained for 27 minutes. Table 28 gives the results using the lid on at the start of the test with an initial quantity of fuel of 100 gms.

Table 28 With the Insulating Lid on the Box at the Start of the Test using 100 gms of Charcoal

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>210</td>
<td>20</td>
<td>44</td>
</tr>
</tbody>
</table>

With the lid on at the start of the test, it was easier to get the fire started, presumably the reduction in heat losses offset the reduction in draw, and the water boiled in 16 minutes. Vaporization nearly doubled and simmering was maintained for 44 minutes after boiling.

Some experiments were made with different chimney sizes that could be blocked to prevent undue heat losses once excess steam ceased. However, flue gases could still be emitted. The idea of this was that the lid could be placed tightly on the box at the start of the test.
It was found that a flue outlet of about 60 sq. cm. gave the best results. It was large enough to allow a reasonable draw and when shut down, prevented heat losses. Overall, however, its performance was similar to the use of the insulating box with the raised lid at the boil, and offered no additional benefits.

It was important to have the flue outlet made of tin. This heated quickly and facilitated the draw. Also the higher the chimney the better the draw.

In practice, the design was a little clumsy, but it proves that the use of insulation can further reduce the quantity of fuel needed at the start of the cooking. Compared with the use of secondary air holes, the use of insulation enabled maximum heat conservation: the water boiled within a reasonable time, with some fanning to get the fire burning well, and kept simmering over twice as long.

In Sudan, the use of glasswool insulation would be prohibitive, although some experiments showed that with no insulation in the lid, the decrease in performance was only marginal. However, in dry windy conditions, the outer hardboard casing could prove hazardous since it could ignite fairly easily. It was not thought that the use of an insulating box with a lid would be practical.

11.6 A Summary of the Main Results

To recap on the main findings from the previous three chapters, it will be remembered that the water tests on the gas cooker showed that efficiencies ranged from between 44 and 54% to boil and 55 to 60% to simmer. Using 350 gms of charcoal on the traditional unmodified charcoal stove, efficiencies were considerably lower. A series of experiments were carried out altering various design parameters to check the effects on the performance and
and efficiency of the charcoal burning process. It was found that by reducing the size of the inlet draft hole and lowering the grill to three-quarter the height of the tin stove, this increased the time and efficiency to boil slightly. However, this had the less desirable effect of maintaining the simmering process at a high rate of burning. Further experiments showed that by confining the fire, the initial quantity of fuel could be reduced to 200 gms, hence making a saving in fuel. The results of these cooking tests and main modifications to the Sudanese charcoal stove are given in table 29.

The results of the water tests on the gas cooker using 'full', 'three-quarter' and 'half gas' have been averaged. As can be seen, the steps taken in the development of the charcoal stove improved the fuel consumption and efficiency to boil within a reasonable time. With the charcoal stoves, most vaporization occurred during the first half hour after boiling. Where less fuel was used for boiling, more was left for simmering. Having achieved the boiling process with a small initial quantity of fuel, further tests measured the time that simmering could be maintained rather than efficiency as determined by vaporization rates. Further tests concentrated on extending the simmering process by means of secondary preheated air and insulation. However, it will be noticed that no modifications to the charcoal stove brought efficiencies close to those achieved with the gas cooker.
<table>
<thead>
<tr>
<th></th>
<th>To Boil</th>
<th></th>
<th>To Simmer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (mins)</td>
<td>Actual energy (k.cals)</td>
<td>Efficiency %</td>
</tr>
<tr>
<td>Gas</td>
<td>8.5</td>
<td>237</td>
<td>47</td>
</tr>
<tr>
<td>Unmodified Sudanese charcoal 18.5 stove</td>
<td>1217</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>( \frac{3}{4} ) level grill, half draft, 350 gms of fuel</td>
<td>7</td>
<td>1032</td>
<td>12</td>
</tr>
<tr>
<td>( \frac{3}{4} ) level grill, half draft, 200 gms of fuel</td>
<td>12</td>
<td>744</td>
<td>17</td>
</tr>
</tbody>
</table>
Chapter 10 established the preference for the draft area of 121 sq. cm. and the slightly lowered grill. Confining the fire to the base of the pan greatly reduced the amount of fuel required and with insulation this could be further reduced to 100 gms.

Insulating the sides of the stove and the use of an insulating lid, only controlled convective heat losses. Some heat would inevitably be lost by conduction and radiation. This lead to new ideas in stove design.

12.1 The Gauze-in-Tin Stove

In order to minimize heat losses by conduction, and at the same time have a good grate with plenty of air spaces, a grill and pan rest was made out of standard chicken wire. Bent double to give strength, it was used to form a circle of 15 cm diameter. Inserted a few centimetres below the top of the cylinder, a piece of chicken wire folded treble to minimize the size of the air holes, was fitted in and 'sewn' in place using ordinary wire. The grill height was about 15 cm. Although made of chicken wire, the stove is referred to throughout as the 'gauze-in-tin stove' for simplicity, (Figure L3).

The wire cylinder was placed inside an open topped tin which had a draft hole with a door cut in one side. The inside of the tin including the base was shiny and therefore a good reflector of radiant heat. It was noticed that women used ash to clean their pots and pans sometimes, and this could also be used to clean the inside of the tin stove.

Some experiments were carried out on this new stove, the flue door being left open to boil and closed for the simmering stage.
Figure L3  The Gauze-in-Tin Stove
The results using initial quantities of 200 gms and 100 gms of charcoal, are given in the table below.

Table 30 The Gauze-in-Tin Stove

<table>
<thead>
<tr>
<th></th>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using 200 gms of charcoal</td>
<td>12</td>
<td>435</td>
<td>120</td>
<td>73</td>
</tr>
<tr>
<td>Using 100 gms of charcoal</td>
<td>18</td>
<td>128</td>
<td>5</td>
<td>36</td>
</tr>
</tbody>
</table>

Using 200 gms of charcoal, this simple stove was faster to boil than the three-quarter level grill with secondary preheated air, and although the time to simmer was about the same, it produced slightly more vaporization.

Using 100 gms of charcoal took longer to boil, although it was fairly easy to start the fire and obtain even combustion. Compared to the three-quarter level grill with secondary air holes, it fared comparably in the time simmering was maintained for, and again the rate of vaporization was almost double.

The gauze or chicken wire insert allowed very good aeration with minimum conductive heat losses. The surrounding tin trapped hot air from the fire and re-radiated some of the heat back onto the fire. It should be noted that without the outer tin, the water could not be brought to the boil on the gauze insert alone. On boiling, the flue door was closed and secondary air entered from the top of the stove around the pan and was preheated by the time it reached the fire.

In all, this simple unit seemed to have a rather fast rate of burning, but nevertheless compared well with the three-quarter level grill.
12.2 The Brick Basket

There was some uncertainty as to the future availability of empty oil tins for stove making. This together with the desire for insulation led to the construction of the 'brick basket'.

A double layer of chicken wire rolled to form a cylindrical shape was filled with broken bricks. In Sudan, the bricks are lighter than those in the U.K. and in suburban and even rural areas there is no shortage of broken bricks. Figure M1 shows the stove in several stages of completion. The grill was made of a round metal plate with a good number of holes punched in it, or it could be made of gauze as for the previous stove. The grate simply slotted into place so that it stood some 10 cm from the base of the stove.

Originally, it was thought that sufficient air might enter through the spaces between the bricks to permit the fire to burn satisfactorily. Table 31 shows the results of experiments using 200 gms of charcoal.

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>360</td>
<td>85</td>
<td>68</td>
</tr>
</tbody>
</table>

Compared with the three-quarter level grill, the brick basket took longer to boil the water but maintained the simmering process for some 18 minutes longer. The longer boiling time can be explained by the fact that there was no hot tin to facilitate a fast draw of air. The fire was a little more difficult to get burning evenly, requiring some fanning with a piece of hardboard. Compared with the gauze-in-tin stove, the brick basket offered no advantage in its performance.
Figure M1 The Brick Basket
In order to reduce the time to boil, the brick basket was placed on a circle of five bricks 12 cm high. One of the bricks could be removed during the boiling process and replaced once a slower rate of burning was desired. The results are shown below.

Table 32  The Brick Basket on a Circle of Five Bricks

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>363</td>
<td>90</td>
<td>70</td>
</tr>
</tbody>
</table>

With the brick basket on a circle of bricks, one of which was removed for the boiling process, the fire was easier to start and there was no adverse effect on the simmering time.

Using 100 gms of charcoal to start the test, the fire was very hard to start, but compared to the gauze-in-tin stove using only 100 gms of charcoal, the simmering process was maintained for a few minutes longer showing that the hot broken bricks did retain some of the heat.

Table 33  The Brick Basket using only 100 gms of Charcoal

<table>
<thead>
<tr>
<th>Boiling time (mins)</th>
<th>Evaporation after ½ hr (gms)</th>
<th>Evaporation from 1st ½ hr onwards (gms)</th>
<th>Simmering time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>115</td>
<td>10</td>
<td>43</td>
</tr>
</tbody>
</table>

Compared with the three-quarter level grill using secondary preheated air and 100 gms of fuel, the brick basket fared very well.
In summary, the brick basket took longer to boil than comparable tests on the tin stoves, but with only 100 gms of charcoal at least, it maintained the simmering process slightly longer, due in part to the slower rate of burning and the heat retention of the bricks.

This stove also had the advantage of being light enough to lift and move easily, with the use of two wire handles, but heavy enough that it could not be easily knocked over. If small children touched the stove, the outside bricks were cool to the touch. This stove served the purpose of replacing the need for tin, and had the merit of being comparably safe to use.
CHAPTER 13

PHYSICAL TESTING OF THE CHARCOAL STOVES IN SUDAN

The charcoal tests carried out in the laboratory gave a high degree of reproducibility. Before taking the newly developed stoves to be tried by Sudanese women, a series of water tests were held under normal operating conditions in Sudan.

13.1 The Experimental Procedure

The experimental procedure was the same as in the laboratory with the exception that the equipment used to take the measurements was slightly different. A spring balance and tin plate was used to measure the charcoal to the nearest 5 gms and a mercury in glass thermometer inserted through the lid of the pan recorded the temperature.

In all other respects, the experiments were repeated identically to those in the laboratory.

Ambient conditions were different. The initial temperature of the water was generally around 35°C and all tests were carried out in a corner of a Sudanese yard which afforded some shade and wind break. However, throughout the tests there was some variability in air movement. Sometimes there was a slight breeze although it was not usually very strong.

An initial quantity of 200 gms of charcoal was used for all tests. Time to start the fire ranged from 3 to 5 minutes and is included with the boiling time. The time to maintain the temperature of 100°C was recorded as a measure of performance. Each test was terminated when the temperature of the water started to fall and fanning to remove the ash, which acts as insulation, covering the remaining coals, no longer prolonged the cooking process. The remaining
coals were then weighed on the spring balance and the remaining water measured in a plastic jug.

For each stove and design parameter, six tests were held and the mean results calculated.

13.2 Results and Discussion

The laboratory experiments showed that there was some doubt as to the number and position of secondary air holes for the three-quarter level grill in outdoor conditions, since too many holes seemed to aid heat losses. Therefore, two versions of this stove were tried in the Sudan, one with air holes punched generously around the base and sides of the tin, and another with air holes punched around the sides nearest the grill. This was in fact three lines above the grate to the height of the insert and one below the grate. The results are given below.

Table 34 Outdoor Experiments on the Three-quarter Level Grill

<table>
<thead>
<tr>
<th></th>
<th>Boiling time (mins)</th>
<th>Simmering time (mins)</th>
<th>Evaporation (gms)</th>
<th>Fuel used (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾ level grill with full secondary air</td>
<td>12</td>
<td>68</td>
<td>600</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>72</td>
<td>765</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>91</td>
<td>640</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>67</td>
<td>730</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>74</td>
<td>530</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>100</td>
<td>500</td>
<td>175</td>
</tr>
<tr>
<td>MEAN^1</td>
<td>13</td>
<td>79</td>
<td>630</td>
<td>183</td>
</tr>
<tr>
<td>¾ level grill with secondary air confined to grate area</td>
<td>10</td>
<td>85</td>
<td>730</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>78</td>
<td>750</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>109</td>
<td>720</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>88</td>
<td>650</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>93</td>
<td>700</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>67</td>
<td>710</td>
<td>195</td>
</tr>
<tr>
<td>MEAN^2</td>
<td>12.5</td>
<td>87</td>
<td>710</td>
<td>188</td>
</tr>
</tbody>
</table>
NOTES TO TABLE 34:
1. Average simmering time = 79 mins ± 11. At 2σ this gives 14% variation.
2. Average simmering time = 87 mins ± 9.7. At 2σ this gives 11% variation.

The stove with the secondary air holes confined to around the grill seemed to perform marginally better; more water was vaporized from the same quantity of fuel indicating that greater heat had been utilized from the coals. Figure M2 shows the three-quarter level grill in several stages of construction.

Figures for the outdoor testing of the gauze-in-tin stove and the brick basket are given in the table below.

### Table 35 Outdoor Testing of the Gauze-in-Tin Stove and the Brick Basket

<table>
<thead>
<tr>
<th></th>
<th>Boiling time (mins)</th>
<th>Simmering time (mins)</th>
<th>Evaporation (gms)</th>
<th>Fuel used (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauze-in-Tin Stove</td>
<td>12</td>
<td>63</td>
<td>650</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>77</td>
<td>610</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>70</td>
<td>700</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>66</td>
<td>710</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>85</td>
<td>500</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>95</td>
<td>700</td>
<td>180</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>14</strong></td>
<td><strong>76</strong></td>
<td><strong>645</strong></td>
<td><strong>170</strong></td>
</tr>
<tr>
<td>Brick Basket</td>
<td>12</td>
<td>63</td>
<td>650</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>77</td>
<td>610</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>70</td>
<td>700</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>64</td>
<td>710</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>81</td>
<td>500</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>73</td>
<td>640</td>
<td>185</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>13</strong></td>
<td><strong>71</strong></td>
<td><strong>635</strong></td>
<td><strong>175</strong></td>
</tr>
</tbody>
</table>

NOTES: 1. Average simmering time = 76 mins ± 10. At 2σ this gives 13% variation.
2. Average simmering time = 71 mins ± 5.8. At 2σ this gives 8% variation.
Figure M2  The Three-quarter Level Grill
Throughout all the tests held in Sudan, it is noticeable that there is more variability between the tests than in the laboratory. This is undoubtedly due to the greater air movement.

However, during these outdoor tests, there was very little difference between the performance of the three stoves. All performed very much the same although it is likely that greater air movement cooled the brick basket and decreased the insulation effects of this stove.

Of interest, no difference was observed between the use of Sudanese and English charcoal.

No tests were carried out in the Sudan using an initial quantity of 100 gms of charcoal. Since it was impossible to put more than 200 gms of charcoal in the stove at the start, it was decided to test the stoves for maximum fuel use only.

From the original 350 gms of charcoal typically used in the Sudanese stove, these three new stoves utilized only 200 gms of fuel to boil and simmer for over one hour. This represents a saving of 43% assuming that Sudanese women find the stoves easy to use properly.
14.1 The Principles of Solar Energy

The intensity of the solar radiation on a unit surface perpendicular to the solar rays is called the 'solar constant'. At average sun distance this energy is 1.94 cals/cm²/min.

However, the sun's rays do not fall normally at the surface of the earth. Latitude and the day of the year affect the declination of the sun's rays. The intensity of the solar radiation also depends on the azimuth, the angle between the projection of the earth-sun line and the north-south line. Azimuth is measured from the south in the northern hemisphere such that the azimuth line is eastward in the morning and westward in the afternoon.

Passing through the atmosphere, the U.V. radiation, which is less than 0.3 microns in wavelength is all absorbed primarily by ozone, and the long wave infra red beyond 2.6 microns is all absorbed by the water vapour in the solar atmosphere.

Some of the incoming radiation is scattered and the direct beam radiation reduced in intensity. The amount of radiation depends also upon the length of the atmospheric path which the rays pass through. At the equator at noon, when the sky is clear, solar radiation striking the horizontal surface is greatest, because the passage through the air is minimum.

At all latitudes the sun moves from east to west and sweeps through an arc of 15° every hour. In the early morning and late afternoon, the rays pass obliquely through a longer path in the atmosphere resulting in more absorption and scattering.

In summary, the solar radiation reaching the earth's surface is between 1.5 and 0 cals/cm²/min (47). With clouds, total
radiation is greatly reduced and most of the light that gets through will be scattered.

Loss of intensity caused by the radiation striking the horizontal receiver at an oblique angle can be reduced by tilting the receiver. Maximum radiant energy per square centimetre necessitates keeping it at right angles to the sun's rays, intercepting the same amount of radiation.

If the receiving surface is inclined 60° from the normal, the intensity of radiation on the surface will be half as much, and if it is inclined at 45° from the normal, the calories received per minute will only be 70.7% as much.

Sudan is near the equator and solar radiation consists mostly of direct radiation making the use of direct focusing appliances particularly appropriate. Taking the lowest figures from table 1 (page 13), it can be assumed that average insolation is about 0.9 cals/cm²/min.

14.2 Discussion of Solar Equipment

As chapter 8 showed, the design of solar equipment has essentially developed along two lines. The direct focusing cooker uses a reflector to concentrate radiation onto the cooking vessel. According to Löf (44), solar energy is intensified by a factor typically in the range of 20 to 100 and is not dissimilar to cooking on a direct heat source.

The direct focusing cookers generally had a collection area of 1 to 3 metres in diameter. They provide a relatively high heat source and to work efficiently must be nearly optically perfect. The parabolic curve needs a little skill to draw accurately. However, the long focus cooker has the disadvantage that frequent adjustments must be made to follow the sun. It can be unstable with heavy weights or in strong wind. The shorter focal length, as with the sun basket, has the disadvantage of it being difficult to reach the pot, since it has to be placed right inside the parabolic shell.
The long focus collector with less curvature is usually easier to make, and with less surface area is more economical on reflector surface.

Either glassmirror, polished aluminium sheet metal or aluminiumized plastic film was used as a reflector surface in the solar units reported in chapter 8. Daniels (46) reports that the reflectivity of glassmirror, silvered on the back, to be in the order of 92%, and aluminiumized Mylar to be about 70%. The surface of a plastic film is much less smooth, and when applying it to a parabolic shell, small wrinkles can cause part of the reflected light to miss the target. Glass will withstand scratching, weathering and years of exposure to ultra violet light much better than Mylar and most other plastics.

In Sudan, sheet aluminium could be obtained from a factory, and in the 'souqs', small shaving mirrors were available. Aluminium foil could be found in some expensive shops in Khartoum. Ideally, when developing a solar unit, it should be made of locally available materials. Apart from keeping the costs low, it is desirable that an enterprising individual can build the unit himself.

The units reported in chapter 8 were either made out of a plastic shell, masonite or paper maché. In Sudan, readily available materials included hardboard, which was used for making cupboards even in rural areas, and in Khartoum itself glue was available.

The oven type cooker is an insulated box with a transparent window on the side exposed to the sun. Additional radiation reflected into the window by flat reflectors arranged around it results in a solar intensification factor of 2 to 4. This unit relies on trapping the long wave solar radiation and raises the question of suitable insulation. It has already been mentioned that the expense of glasswool would be prohibitive in the Sudan.
The window for a solar oven can be made of glass or plastic, and acts to reduce the heat losses by convection and radiation. Glass is transparent to most of the sunlight except ultraviolet, but it is opaque in the longer infrared, thus acting as an effective heat trap. Two or more covers are more effective than one, but each transparent covering reduces the incoming radiation by absorption. According to Daniels, this is in the region of 8% because of reflection at the two glass/air interfaces. For both high transmission of light and low cost, a glass window should be as thin as possible for a desirable mechanical strength.

There is available strong sheets of plastic which have the advantage of being light, unbreakable and inexpensive. However, deterioration in sunlight and weathering has been a serious handicap. Some of the common plastics such as polyethylene, polyvinyl chloride and polystyrene have a very short life when exposed to outdoor weather. With the use of a coating to absorb ultraviolet light, plastics are reported to last three times as long.

The transmission of light through plastic depends on the refractive index of the material and the reflections at the two air/plastic interfaces. The absorption within the material is less than with glass because the films of plastic are much thinner than the glass plates.

It has been suggested that a solar oven could utilize heat storage material. In Sudan, bricks and sand are readily available but it is doubtful that these would contribute much to the performance of a solar oven. In any case, the receiving surfaces should be as black as possible to absorb the radiation and not re-reflect it.

Apart from the physical parameters, it has already been pointed out that fairly large quantities of food are prepared in the Sudan and a solar cooker must accommodate a large pot. The Sudanese nearly always cook a stew or sauce and prefer a fast boiling time. Ideally, the less time spent on the
cooking process the better. These factors tended to point to a direct focusing cooker being the most suitable for the Sudan. During the preliminary fieldtrip, an imported solar cooker was demonstrated to about 100 women to test their initial opinions.

14.3 Preliminary Trials with the Sun Dish

The sun dish was a direct focusing cooker. Its approximate parabola was made of polished aluminium segments which folded up something like a fan. The pan support and frame of the cooker was also made of heavy aluminium and adjustments could be made for focusing the dish. The diameter of the sun dish was about 1.1 metres. The reflector of the cooker was not a true parabola so that the reflected rays fell diffusely onto the pot.

Some water tests were undertaken on the roof of the University of Khartoum during the winter month of October.

Table 36 Results of the Sun Dish Trials

<table>
<thead>
<tr>
<th>Quantity of water (litres)</th>
<th>Timing of the test</th>
<th>Maximum temperature (°C)</th>
<th>Time to heat to max temp. (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.10 - 10.45</td>
<td>95</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>10.55 - 11.20</td>
<td>94</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>12.30 - 13.10</td>
<td>94</td>
<td>40</td>
</tr>
<tr>
<td>1</td>
<td>13.25 - 14.00</td>
<td>91</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>12.30 - 12.55</td>
<td>97</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>13.00 - 13.50</td>
<td>91</td>
<td>50</td>
</tr>
</tbody>
</table>

Average insolation was about 1.22 cals/cm²/min., and boiling temperature could not be obtained. Average time to heat one litre of water from ambient temperature (35°C), to near boiling point was about 35 minutes. Temperature recordings were taken every 5 minutes until two consecutive temperatures over 90°C were recorded. An increase in
temperature over 90°C is more sensitive to wind and intermittent cloud than is the initial heating up period when temperature rise is rapid. However, it is apparently a common finding with solar cookers that temperatures do not quite reach boiling. Intermittent cloud and fluctuating wind did have a marked effect on the performance of the solar cooker. In addition, some operational difficulties were experienced with adjusting the reflector, and during strong wind, the dish did not stay in position.

The next step was to try some food cooking on the sun dish. A common Sudanese method was imitated and some of their usual ingredients used. The following sets out the procedure and the progress of the cooking operation.

**Time - am**

10.00 Using a 4 litre cooking pan, groundnut oil was poured into it until it covered the bottom of the pan.

10.10 Within 10 minutes the temperature of the oil was 155°C and half a kilogram of stewing beef was added. The beef was lightly fried for 10 minutes.

10.20 1 kilogram of mixed vegetables i.e. onion, potatoes, and tomatoes were added.

10.25 Seasoning and ½ litre of water was finally added to the pan. At this point, the temperature dropped to 55°C.

10.30-11.10 The temperature continued to rise reaching over 90°C by 11.00 am. The food required little stirring, although a little less water would have been preferable.

12.00 By this time, the temperature was stable around 97 to 98°C.

The total quantity of food weighed two kilograms and was left to simmer for a further 1½ hours until the vegetables were near pulp which is how the Sudanese prefer to eat them.
To cook a meal for \(3\frac{1}{2}\) hours seems to be a very long time indeed. Temperature readings were taken every 5 minutes and it is possible that continual opening of the lid prolonged the cooking time. However, the next step in these preliminary trials was to introduce the cooker to Sudanese women and let them evaluate its performance for themselves.

With an English speaking assistant, the sun dish was taken to an education centre where it was demonstrated to around 100 girls and women. In this way it was possible to gain some idea of women's reaction to the cooker.

Pre-trial reaction to the solar cooker was quite favourable. Women pointed out the advantages of a smokeless fuel, and did not feel the need to adjust the reflector every 20 minutes would be an inconvenience. The size of the cooker seemed quite acceptable too.

Women were asked if they thought that cooking in the sun would be a serious disadvantage. Perhaps it was a little difficult for them to evaluate the operational use of the cooker without trial, because nobody commented on this. One woman did foresee that it might be dangerous with children around, since they might burn themselves on the reflector.

The cooker was set up at the centre and several of the women given a free hand in preparing the food. The ingredients were exactly the same as before, although women found rather more herbs and spices to season the food. They also pulped the tomato before adding it to the stew.

Cooking started at 10.00 am. The meat was lightly fried in the oil for about half an hour and then the vegetables and about \(\frac{1}{4}\) litre of water were added. Although the food appeared to be well cooked after 2 hours, the women insisted that it was not sufficiently cooked, and the food was not eaten until 1.00 pm, some three hours after the initial preparation. The stew was reported to be very good, but the long cooking time was felt to be quite a disadvantage.
Figure M3  Demonstrating the Sun Dish at an Education Centre
Some shelter from the wind could have been found at the education centre from the building walls. However, for the purpose of demonstrating the cooker to so many women, it was not convenient to move the cooker to a more confined area. Secondly, the women were extremely curious to see how the food was cooking, and with the constant arrival of newcomers, the lid of the pan was continually being removed for much longer periods of time than during the food cooking experiment at the university.

Although these factors lengthened the cooking time, it remains that solar cooking still took longer than fuelwood cooking. The women regarded this as the main disadvantage.

The preference for a fast cooking time suggested a larger collection area. It was unlikely that a solar oven would be suitable for the cooking habits of Sudanese women. The next step then, was to carry out some experiments to determine a suitable collection area.
Preliminary to any work on solar cookers, some energy calculations were required to determine an effective solar collection area.

15.1 The Energy Required for Boiling

A high initial heat source is required to heat the water from ambient temperature to boiling point within a reasonable time and allowing for the fact that some evaporative cooling occurs at around 97°C.

Taking the 'half gas' flow figures from chapter 9, actual heat input of about 14 k.cals/min brought 1.5 litres of water to boil in 15 minutes.

Figures for the three-quarter level grill using an initial quantity of 200 gms of charcoal brought 1.5 litres of water to boil in 12 minutes at a calculated heat rate of 62 k.cals/min.

The charcoal stoves consistently required more energy to boil the water than the gas stove, the latter having almost complete combustion, better control and fewer heat losses. The theoretical energy to boil this quantity of water is only about 120 k.cals and one can assume that convectional heat losses from the pan are similar for both the gas and charcoal stoves.

Assuming an insolation level of 0.9 cals/cm²/min, to obtain a heat rate of 14 k.cals/min would require 1.5 m² of solar collection area. Löf stated that solar collection units are about 50% efficient, so that in order to reproduce the performance of a gas stove, a solar collection area of about 3 m² would be required. This figure may be a little on the high side because the pan is usually blackened to
absorb solar energy and with gas, there are more convectional heat losses around the sides of the pan. However, an insulated oven area as in the combination cookers could reduce the required collection area.

Once water has reached boiling, the source of heat is generally lowered to a minimum input. The theoretical energy required to maintain 100°C consists of energy to prevent cooling and energy to maintain a minimal amount of vaporization.

15.2 The Heat Required to Maintain 100°C

Cooling curves were used to measure the heat loss from 100°C. 1.5 litres of water was brought to the boil on a gas cooker, and with thermocouples attached to the side and centre of the pan, temperature recordings were taken every minute. On boiling, the gas was turned off and the temperature drop recorded for 30 minutes. This was repeated three times and a further three tests were carried out with the pan being placed on a wooden board. At the end of the test, the quantity of water was checked for any vaporization that may have occurred.

Ambient temperature throughout all the tests remained at about 22°C.

15.2.1 Results and Discussion

Generally speaking, heat loss was faster in the centre of the pan than at the sides. A range of heat loss rates were determined over the 30 minute period. Between 40 and 80 gms of water were lost in vaporization while bringing the water to boil.

During 30 minutes, the rate of cooling averaged 1.4 k.cals/min on a wooden board and 1.25 k.cals/min when the pan was left on the grill.
Since the rate of heat loss was faster during the initial cooling period, the cooling during the first ten minutes is separated (table 37). If a heat source is to maintain water at 100°C then it must be effective during the fastest rate of heat loss.

During the first ten minutes, the rate of cooling averaged 1.95 k.cals/min on a wooden board and 1.35 k.cals/min on the hot grill.

<table>
<thead>
<tr>
<th>Heat loss during 30 minutes</th>
<th>Centre of pan °C</th>
<th>Side of pan °C</th>
<th>Mean °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a wooden board,</td>
<td>30</td>
<td>29</td>
<td>29.5</td>
</tr>
<tr>
<td>1436 gms of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lost an average of</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On a hot grill,</td>
<td>28.5</td>
<td>23</td>
<td>25.8</td>
</tr>
<tr>
<td>1457 gms of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lost an average of</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat loss during 10 minutes</th>
<th>Centre of pan °C</th>
<th>Side of pan °C</th>
<th>Mean °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a wooden board,</td>
<td>14.2</td>
<td>13</td>
<td>13.6</td>
</tr>
<tr>
<td>1436 gms of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lost an average of</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On a hot grill,</td>
<td>11</td>
<td>7.5</td>
<td>9.3</td>
</tr>
<tr>
<td>1457 gms of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lost an average of</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The slower heat loss on the hot grill is possibly comparable to the hot pan support of the direct focusing cooker tested in the Sudan during the preliminary fieldtrip. Ambient temperature in Sudan is higher and heat loss from water is possibly faster than from food, suggesting that a lower average figure for heat loss be taken for design purposes. However, on the other hand, the figures assume no air movement which would affect the rate of cooling.

In view of these points, it would seem reasonable to take the average of the heat loss figures during the first ten minutes as a standard for later calculations. The range of
heat losses during the ten minutes was from 7.5 to 14°C, giving an average heat loss of 11°C. Allowing for vaporization losses one can say that 1446 gms of water lost 11°C in ten minutes equivalent to 1.6 k.cals/min.

As a check, a haybox was designed of different widths of insulation to see how much the rate of cooling could be slowed. A pan of water was placed in the haybox with 8 cm of glasswool insulation, which reduced the rate of cooling by about a half. Doubling the thickness and density of the insulation only made marginal improvements. In short, the rate of cooling was still fairly fast during the first ten minutes after boiling.

15.3 The Energy to Maintain a Nominal Rate of Vaporization

To maintain 100°C does incur some evaporative cooling and one can expect a moderate level of vaporization in maintaining the simmering process. It is therefore necessary to determine the heat loss that this would represent and the required increase in heat input.

Again, taking the results from the chapter on the gas cooker trials, using 'full gas' to boil the water, an average of 490 gms evaporated in some 45 minutes, equivalent to 10.9 gms/min.

Using 'three-quarter gas' to boil the water, 610 gms evaporated in 44.5 minutes, equivalent to 13.7 gms/min.

Using 'half gas' to boil the water, 490 gms evaporated in 35 minutes, equivalent to 14 gms/min.

It is interesting to note the higher vaporization rates with the slower gas input, presumably because more time was spent near the boiling point.

However, taking the average of these figures, approximately 530 gms of water evaporated in 41.5 minutes, which is equivalent to 12.77 gms/min. Therefore one can say that to
maintain 100°C after bringing 1.5 litres of water to boil, one can expect vaporization of about 13 gms/min equivalent to a heat loss of 6.9 k.cals/minute.

During tests on the three-quarter level grill using an initial quantity of 200 gms of charcoal, most evaporation occurred during the first half hour after boiling, after which the rate decreased. 430 gms of water evaporated in the first 30 minutes giving an approximate rate of 14 gms/min, equivalent to a heat loss of 7.7 k.cals/min. This is very similar to the figure produced by the gas trials.

As chapter 9 showed, steam that evaporates from food recondenses in the water providing a heat gain. In view of this, one might expect these heat losses by evaporative cooling to be on the high side for food cooking. However, during some food cooking trials, an average of 35% of the liquid was eventually evaporated during 36 minutes and is comparable to the rate of vaporization from the water tests. It was also noted that the slower heat input resulted in a slightly higher rate of vaporization as would be the case with a solar cooker. A larger quantity of water would also take a longer time to boil, possibly incurring more evaporative cooling once a high temperature of about 97°C had been achieved. With all these considerations, it was decided to use the figure of 6.9 k.cals/min as reasonable heat loss by evaporative cooling.

15.4 Theoretical Heat to Boil and Maintain 100°C

To summarize, one can expect heat loss by cooling to be 1.6 k.cals/min, and evaporative cooling losses to be approximately 6.9 k.cals/min giving a total of 8.5 k.cals/min.

At insolation of 0.9 cals/cm²/min and heat losses of 8.5 k.cals/min, 0.94 m² of solar collection area is required. Assuming 50% efficiency, a collection area of 1.9 m² is necessary to maintain the simmering process.
Actual heat input on the gas stove was 11 k.cals/min. To parallel this heat input, 2.4 m\(^2\) of solar collection area would be required.

In summary, one can assume that a solar collection area should be in the range of 1.9 to 2.4 m\(^2\), depending on how fast a rate of boiling is required and what means of insulation are used.

Most of the direct focusing units reported in chapter 8 had smaller collection areas. This throws some doubt on some of the fast boiling times reported especially in light of the preliminary trials with the sun dish with about one square metre of collection area.
CHAPTER 16
EXPERIMENTS ON SOME SOLAR DESIGN PARAMETERS

The previous chapter established that a fairly large collection area would be required for a direct focusing cooker if its power is to simulate that of a direct heat source such as gas. The alternative is to see what contribution heat retention factors such as insulation and windows could make to a smaller collection area.

The availability of hardboard in the Sudan suggested that a single flat plane design could be readily made. Aluminium foil was also available for a reflective surface.

16.1 The Selection of a Flat Plane Collection Area

The background research established that the average pot diameter fell in the range of 21 to 23 cms. Using this as a guide, figure N1 shows the maximum reflector lengths for a given angle such that the reflected ray strikes the pan on the top opposite corner.

The diagram assumes that the reflectors are based a few centimetres below the base of the pan to give maximum area for the reflectors. It can be seen that beyond an angle of 60°, increasing the angle and consequently the length of the reflector does not contribute significantly to the collection area.

The maximum length of a reflector at an angle of 60° is 58 cm. Using small cardboard models of the scale 1 in 4, several reflector arrangements were made up. The first consisted of four extended reflectors at 60° such that the collection area under the reflectors was rectangular. The second arrangement consisted of interlocking triangles at 60° giving eight flat plane reflectors in all, and the third arrangement was similar but with interlocking triangles at 70°. The collection area for each arrangement are calculated in figures N2, N3 and O1 respectively.
Figure N1  Maximum Reflector Lengths
Area under 1 corner of the reflector = \(41.4^2 - 12.6^2 = 1555.2 \text{ cm}^2\)

Total area under reflector arrangement = \(4 \times 1555.2 = 6220.8 \text{ cm}^2\).

Primary reflective area = \(4(28.8 \times 12.6) = 1451.5\)

Area requiring second or third reflections = \(6220.8 - 1451.5 = 4769.3\)

If the primary reflective area is 50\% efficient and the remaining area 25\% efficient then the effective collection area is \(\frac{1451.5}{2} + \frac{4769.3}{4} = 1918 \text{ cm}^2\).

Figure N2  The Collection area under Four Extended Reflectors at \(60^\circ\).
Area under the reflector arrangement = $4(1555.2 - 18^2/2) = 5572.8 \text{ cm}^2$.

Area requiring second reflections = $8(10.8 \times 28.8) = 2488.32 \text{ cm}^2$.
Primary reflector area = $5572.8 - 2488.32 = 3084.48 \text{ cm}^2$.

If the primary reflective area is 50% efficient and the remaining area 25% efficient, then the effective collection area is $\frac{3084.48}{2} + \frac{2488.32}{4} = 2164 \text{ cm}^2$.

Figure N3  The Collection Area under Eight Reflectors all at 60°.
Area under the reflector arrangement = \(4(1555.2 - 28^2/2) = 4652.8\) cm\(^2\).

There are no second reflections with this arrangement, so assuming 50% efficiency, this reflector area gives an effective collection area of \(\frac{4652.8}{2} = 2326.4\) cm\(^2\).

Figure 01 The Collection Area under Eight Reflectors, Four at 60° and Interlocking Triangles at 70°.
As can be seen, the latter arrangement of eight flat plane reflectors using interlocking triangles at 70° has no second reflections and gives the maximum effective collection area of 0.23 m². Adding the area of the inner square allowed for a large pot, the total collection area is 2961 cm² or nearly 0.3 m². This is considerably smaller than the collection areas reported for the direct focusing cookers in chapter 8, and very much below the required collection area calculated from the work on the gas stove.

In summary, one can conclude that using flat plane collector arrangements, 0.3 m² is about the maximum area that one can achieve. This is too small to reasonably reproduce the cooking process unless perhaps design features are incorporated to reduce heat losses.

First of all however, some attention was given to the reflectivity of standard aluminium foil compared to aluminiumized plastic film commonly used to re-radiate heat from the back of radiators.

16.2 The Reflectivity of Aluminiumized Surfaces

Using a spectrophotometer, the reflectivity of various aluminiumized surfaces was measured. These surfaces included aluminium foil obtainable from any grocers; 'Heatmirror', obtainable at most D.I.Y. or plastics merchandize shops, and another aluminiumized plastic film called 'Nasir', obtainable by mail order.

Small sections of each material were cut and applied to 4 sq. cm. pieces of card by various methods. The cards were then slotted into the spectrophotometer which measured the reflectivity in the visible range (350 to 850 nanometres) and the near infra red range (900 to 1500 nanometres).

Figure 02 shows the baseline to be fairly accurate, there being 100% transmission with no reflective material in the instrument. There is a break between the visible and near infra red ranges, which although consistent for the
baseline tends to dip marginally for the later graphs. There is a suggestion then that the instrument was not wholly accurate. However, since a large difference was sought between the different surfaces and means of application, the graphs were considered satisfactory for comparable information.

Figures 03 to P3 show that there was very little difference between the reflectivity of the standard aluminium foil and Heatmirror. However, the aluminium foil performed marginally better in the near infra red range, which has greater heating capacity than the visible. Both materials could be easily folded onto the card. Using spray glue to apply the materials, again a very smooth surface was obtained with only a marginal decrease in reflectivity for the Heatmirror, although when the aluminium foil was spray glued on the card, the reflectivity seemed to improve. Handling the aluminium foil was difficult since it easily creased when folding it onto the card.

Figure 02 The Baseline
Figure 03  The Reflectivity of Heatmirror folded on Card

Figure P1  The Reflectivity of Heatmirror Spray Glued on Card
Figure P2  The Reflectivity of Aluminium Foil folded on Card

Figure P3  The Reflectivity of Aluminium Foil Spray Glued on Card
Nasir aluminiumized plastic film would not fold easily onto the card, but using spray glue, it had a maximum reflectivity in the range of 92 to 93% for most of the visible range, but was a little higher in the near infra red range. Using paper glue to attach the Nasir material, it was less easy to smooth out the wrinkles and reflectivity fell to around 85% even in the near infra red range, (Figures R1 and R2). In Sudan, clear liquid UHU glue was available and this could be applied quite thinly. It was also stronger than spray glue. In practice however, the Nasir aluminiumized plastic film was considered too expensive for field use.

Figure R3 shows the effects of first crumpling the aluminium foil a little and then re-smoothing it with the hand, as well may be the case in the field. As one can see, the reflectivity decreased by about 5%. However, fairly hard rubbing as might be the case in cleaning the reflective material with a damp cloth, reduced the reflectivity by some 15% particularly in the near infra red range, (Figure S1).

Figure S2 shows the degradation of aluminium foil after 2½ years use on the inside of an office window. Reflectivity was down by 10 to 15% although the degradation seemed more severe in the visible range than the near infra red.
In practice, foil exposed to all weathers and strong ultra violet light in Sudan, would probably deteriorate quicker. As one can see, attempts to clean the foil by lightly wiping it with a damp cloth only worsened the reflectivity of the material (Figure S3).

As a check, some experiments were carried out covering the aluminium foil with different plastics. This was to see whether a thin plastic film would be useful as a protective cover without decreasing the reflectivity. Using standard kitchen cling film, reflectivity decreased by between 2 and 10%. Using Superglaze plastic, no reduction in reflectivity was observed.

In summary, several application methods were tried and the importance of a smooth surface demonstrated. UHU glue was
Figure R1  The Reflectivity of Nasir Spray Glued on Card

Figure R2  The Reflectivity of Nasir Paper Glued on Card
Figure R3  The Reflectivity of Aluminium Foil Crumpled and Reflattened

Figure S1  The Reflectivity of Aluminium Foil Rubbed Smooth
Figure S2  The Reflectivity of Aluminium Foil after $2\frac{1}{2}$ Years of Exposure

Figure S3  The Reflectivity of $2\frac{1}{2}$ Year old Aluminium Foil after being Cleaned
available in Sudan and this was considered to be satisfactory since it was strong, yet thin enough to spread smoothly if handled with a little care. Although there was little difference in the reflectivity between standard aluminium foil and Heatmirror, the latter was easier to attach smoothly and easier to clean without causing any decrease in the reflectivity.

16.3 The Spectral Transmission of Several Common Plastics

There has been some consideration of the use of plastic windows to retain the heat in a small solar unit. Basically, in the hot box design with a glass window, the solar rays of short wavelength penetrate through the glass sheets and get absorbed by a blackened surface. The absorbed solar radiation degrades into thermal radiation, which is of higher wavelength and is unable to pass through the glass sheet. However, glass is easily broken and too expensive to use in the Sudan.

With plastics there is a trade off between translucency and melting point. The more ultra violet admitted, the less tolerance for heat. However, one needs a plastic with maximum transmission in the short wavelength range up to 3 microns. Thereafter, a plastic needs to be a poor transmitter of the longer wavelengths since 80% of re-radiated heat lies between 3 and 20 microns. The peak wavelength of re-radiated heat from a black body at boiling water temperature lies at 7.7 microns. Although a good transmitter above 3 microns would admit more solar radiation, this advantage would be offset by the greater amount of re-radiated heat that would be lost.

Using the spectrophotometer again, several samples of commonly available plastics were tested for their spectral transmission over the visible and infra red ranges. Figures T1, T2, T3 and U1 show the spectral curves for each of the following plastics; medium weight polythene, Superglaze (0.15 mm gauge), Transglaze PVO (0.2 mm gauge), and Transglaze rigid (0.76 mm gauge).
Figure T1  The Spectral Transmission of Medium Weight Polythene
Figure T2 The Spectral Transmission of Transglaze PVC (0.2 mm gauge)
Figure T3  The Spectral Transmission of Superglaze Plastic (0.15 mm gauge)
Figure U1  The Spectral Transmission of Transglaze Rigid (0.76 mm gauge)
The visible transmission is shown in the top graphs, such that the minimum area under the curve shows maximum transmission. The lower graphs show the infra red range of spectral transmission such that the minimum area under the curve shows the desired minimal transmission or maximum absorbance.

As one can see, the medium weight plastic gave the best transmission of ultra violet light but was also the best transmittor in the infra red range, which is not desirable for preventing heat losses.

Transglaze PVC (0.2 mm gauge) and Superglaze plastic (0.15 mm gauge) performed similarly in transmittance in the visible and infra red ranges, while the rigid Transglaze sheet was least transmittant to ultra violet under 400 nanometres, but was also better in absorbing the infra red.

These plastics were selected for further testing as windows in a small solar collection unit.

16.4 Testing Various Design Features for use with a Small Collection Area

Having established that the best flat plane reflector arrangement was to have four rectangular sides at 60° with interlocking triangles at 70°, the next step was to see how various design features could contribute to the performance of the solar unit.

To simulate the sun's rays falling on a horizontal surface, ten 250 watt stage lamps were erected some 3 metres above the ground. The stage lamps were suspended as shown in figure U2.

Although the spectral power distribution of the stage lamps was different to that of sunlight, with the peak of the energy being in the wavelengths above the visible, the stage lamps were useful for the comparative testing of the effects of
different design variables. The average lux measured on the
ground beneath the stage lamps was 2,700. On a brilliant
day, one could expect over 100,000 lux from natural sunlight.
However, this is only a measure of the light and the stage
lamps contained more energy in the infra red range.

![Figure U2 The Arrangement of the Stage Lamps](image)

The experiments were set up using a data logger to record the
temperature of various surfaces and the water temperature
every minute. For every variable under study, tests were
repeated 3 to 5 times and the average results computed.

16.4.1 The Use of a Blackened versus a Non-blackened Pot

The first variable to test was the heat gain of an ordinary
aluminium pot that had been used for the charcoal tests and
which was blackened on the underside, against a pot which had
specifically been painted with matt black paint. The pots
were placed under the lamp arrangement with no solar reflector unit. Each contained 1.5 litres of water and the heat gain of the water was measured over a one hour period.

After one hour under the stage lamps, the water in the black pot had gained some 6.5°C more than the water in the non-painted pot. The water reached an average temperature of 43°C, a heat gain of 25°C. The blackened lid was some 15 to 20°C hotter than the sides of the pan throughout, which in turn was 5 to 10°C hotter than the water.

This experiment demonstrated the importance of a blackened lid for absorbing the energy, and the painted black pot was used for the following experiments.

16.4.2 The Use of Reflectors

The reflector arrangement using four rectangular pieces at 60° and four interlocking triangles at 70° was made up out of hardboard with the smooth side on the inside of the unit. The reflectors could be easily joined together using small pieces of wire threaded through regularly spaced holes at the edges of the reflectors. Figure U3 shows the completed unit.

Two reflective materials were used for testing on the unit under the stage lamps; standard aluminium foil and Heatmirror. The results of these tests are shown below.

<table>
<thead>
<tr>
<th>Table 38</th>
<th>Comparing Reflective Surfaces in the Solar Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum temperature</td>
<td>Heat gain in 60 minutes</td>
</tr>
<tr>
<td>Time to reach</td>
<td>(°C)</td>
</tr>
<tr>
<td>Aluminium Foil</td>
<td>99.4</td>
</tr>
<tr>
<td>Heatmirror</td>
<td>99.4</td>
</tr>
</tbody>
</table>
Figure U3  The Flat Plane Solar Unit made with Hardboard Reflectors
The heat gain of the water above 90°C was very slow and boiling temperature could not quite be reached. The data logger allowed very small differences in temperature to be measured and each test was terminated when two successive recordings of the same temperature were noted.

Both surfaces produced a heat gain of nearly three times that with no reflector unit during the first 60 minutes. The use of the reflector arrangement increased the collection area seven fold. This effected a three fold increase in the heat gain of the water.

The unit took a long time to bring 1.5 litres of water to maximum temperature, although using the Heatmirror, the time was shortened by some 10 minutes. Since the reflectivity of the two surfaces was very similar when measured with the spectrophotometer, the better performance of the Heatmirror reflected the greater ease of application which this material afforded. It was less easy to apply large sections of foil smoothly.

As a check, these experiments were repeated in Sudan. The Heatmirror reflective material performed considerably better than the standard aluminium foil. However, even with the Heatmirror, it took considerably longer, 100 minutes to reach the maximum temperature of 94°C.

16.4.3 The Use of Heat Storage Material

Some attention was given to the use of preheated stones which could give up some of their heat for cooking. Heat storage materials consisted of loose black stones in a metal ring and contained in a black tin. Sand in a black tin was also tested. The temperature of the stones was measured by attaching a thermocouple to the centre of several medium sized stones. On average the temperature on the outside of the stones was some 20°C hotter than on the inside. The heat storage material was heated for one hour in the solar unit before starting the water tests.
Table 39 The Use of Preheated Stones/sand

<table>
<thead>
<tr>
<th>Temperature of the stones/sand</th>
<th>Max\text{\textsuperscript{m}} water temperature</th>
<th>Time to reach (\text{Max}\text{\textsuperscript{m}}) water temperature (°C)</th>
<th>(\text{Max}\text{\textsuperscript{m}}) water temperature (°C)</th>
<th>Time to reach (\text{Max}\text{\textsuperscript{m}}) water temperature (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black stones in metal ring</td>
<td>95</td>
<td>98.9</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Black stones in black tin</td>
<td>111.8</td>
<td>99.2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Sand in black tin</td>
<td>102</td>
<td>99.4</td>
<td>73</td>
<td></td>
</tr>
</tbody>
</table>

As the table shows there was not a great deal of difference between the three means of heat storage. It was noticed that good thermal contact between the stones and the base of the pan was important. The stones gave up some of their heat to the pan and water initially, but after some 65 minutes, started to gain heat again. In all, the use of the preheated material in the solar unit using standard aluminium foil reflectors shortened the time to reach maximum temperature by some 8 minutes.

16.4.4 The Use of Plastic Windows

Despite the fact that the spectral power distribution from the stage lamps was different to that of sunlight, some tests were carried out using a plastic window inserted in the unit. Figure V1 shows the solar unit with a plastic window.

The tests were made using the Heatmirror reflective surface and each of the four plastics examined for their transmittance in the previous section were used for a window. In fact, each plastic performed similarly. There appeared to be no significant difference between them and overall, none made any difference to the time to reach the maximum temperature. There was some suggestion that a single sheet of polythene hastened the time to reach 95°C by 5 to 9 minutes. When
Figure V1  The Flat Plane Solar Unit with a Plastic Window
double layers of polythene and Superglaze were used, these lengthened the time to boil. The temperature beneath the window in the 'oven' was only in the 70's, and one concludes that the unit was not powerful enough to warrant any insulating effects from the use of a window.

When the polythene and Superglaze windows were tested in the Sudan, the maximum water temperatures obtained were 79°C for the polythene and 86°C for the Superglaze window. These temperatures were lower than those obtained using no window and it can be concluded that the use of plastic windows made no contribution to the performance of this small unit.

The use of preheated stones with a plastic window marginally improved the performance of the unit with preheated stones alone.

In summary, one can say that the use of this flat plane solar collection unit took a long time, over one hour using Heatmirror reflectors, to boil 1.5 litres of water. The use of preheated stones reduced the boiling time by a few minutes but the use of plastic windows tended to slow the boiling time. It is doubtful whether a sealed insulated unit with external reflectors would significantly hasten the boiling process. In conclusion, it is the size of the collection area which makes most contribution to the cooking power of a solar unit.
CHAPTER 17
THE DEVELOPMENT OF THE QUASI PARABOLA

At this stage, solar cooking was seen to be a potential complementary means of cooking, somewhat like the microwave with its limitations in baking is to gas or electric cooking. If solar energy had the disadvantage of being too slow for long heavy cooking, it had the advantage of providing a cheap heat source for cooking lighter foods. It was therefore considered important not to make any assumptions as to the most suitable design of solar cooker, but simply to present the Sudanese women with a choice of units and let them make the evaluations.

One way of overcoming the very small collection area obtained from single flat plane designs was to construct a unit with a large oven area that could hold two or three pots. The Solar Energy Development Group in London had constructed such an oven, 0.17 m$^2$ in area and 13 cm high with 4 cm of insulation. Eight polished aluminium reflectors augmented the collection area by 0.6 m$^2$. This solar oven was loaned for the consumer surveys in the Sudan.

In addition, the sun dish was available for further testing in the Sudan, and a third solar cooker was designed to complement the survey testing. Bearing in mind the preference for fast cooking and the need for a large collection area, a quasi-parabolic cooker with hardboard sections was thought to be a feasible design. Experience with the sun dish showed that the long focal length made the pan support unstable in wind. The light parabolic dish was also easily blown off focus. It was therefore thought advantageous to build a heavier structure with a short focal length such that the pan support could sit on the ground.

Figure V2 shows the parabolic curve. The sun dish had a shape similar to the curve $y^2 = 4px$ where $p = 4$. The sun basket on the other hand, had a deeper shorter focal length as in the curve where $p = 1$. 
Figure V2: The Parabolic Curve $y^2 = 4px$
Figure V3  The Quasi-parabolic Curve
Figure V3 shows the permutation of the latter curve such that four segments at 25°, 45°, 55° and 60° reflect all rays onto the area of the pot. This sketch was used to construct an octagonal shaped basket. Eight struts of this sectioned curve were cut out by a carpenter in the Sudan and then segments of hardboard were nailed between the struts to form a quasi-parabola. Figure W1 shows the inverted parabola.

The quasi-parabola incurred some second reflections. Had the unit been made with sixteen segments, the width of the top reflectors could have been reduced to involve only primary reflections. However, this would have made the design considerably more complicated to make and it was decided to keep to an eight segment design.

Figure W2 shows the collection area under one segment of the unit, from which the total collection area is deduced. Considering second reflections, the total effective collection area is 0.54 m². Assuming 50% efficiency for all primary reflections, this is similar to the effective collection area of the sun dish.

The pan rest consisted of a blackened paint tin which was filled with sand. The pan sat on the tin and the cooker was tilted into focus by propping it with a brick at one or two sides.

The short focus of the cooker meant that it only needed to be adjusted every 30 minutes. To make focusing more accurate, two pieces of string were attached to the top of the cooker such that they crossed the central point at right angles. The shadow of the cross was then pointed at the centre of the pan lid. This provided an easy and accurate means of focusing.
Figure W1  The Inverted Quasi-parabola
Area under reflector: $8(60.8 \times 25.4 - 10.8 \times 4.6) = 11957 \text{ cm}^2$
Secondary reflections: $8(34.8 \times 14.8) = 4120 \text{ cm}^2$
Primary reflection: $11957 - 4120 = 7837 \oplus 50\% \text{ efficiency} = 3919 \text{ cm}^2$
Secondary reflections $\oplus 25\% \text{ efficiency} = 1030 \text{ cm}^2$

Total effective collection area = $3919 + 1030 + 8(10.8 \times 4.6) = 5346 \text{ cm}^2$

**Figure W2** The Area under the Quasi-parabola
In summary, the quasi-parabola was heavier than the sun dish. It had a low focal point and was easy to adjust. It had the disadvantage of being large and not that economical on material. However, it provided a third locally built unit to be included with the solar oven and sun dish in the consumer survey.
CHAPTER 18
THE PHYSICAL TESTING OF THE SOLAR UNITS IN SUDAN

Before taking the solar cookers to Sudanese women for evaluation, the quasi-parabola, sun dish and solar oven were tested for their physical performance. The standard water tests using 1.5 litres of water were carried out between the months of April and June, which included the hottest time of year in the Sudan.

The three solar units were set up and testing took place between the times of 10.00 am to 12.00 noon, 12.00 noon to 2.00 pm and between 2.00 pm to 4.00 pm. Ambient water temperature was between 31 and 38°C. Where the water reached 100°C within a reasonable time, the water was 'simmered' for about one hour to measure the rate of vaporization. The results are presented in the tables in this chapter.

The quasi-parabola was tested with both Heatmirror and aluminium foil reflectors. With the Heatmirror reflectors, it was fairly easy to obtain 100°C between 10.00 am and 2.00 pm. After this time however, it was not possible to tilt the cooker sufficiently to accommodate the lower sun angles. Wind and cloud also affected the performance of the cooker at this time of day. During the morning it took 45 to 55 minutes to boil 1.5 litres of water and the vaporization after one hour was quite high.

Using aluminium foil reflectors, the boiling times were slightly longer, between 50 and 65 minutes in the morning, and the amount of water that evaporated was less.

The sun dish performed very similarly to the quasi-parabola with the Heatmirror reflective material. However, with the sun dish, it was possible to attain boiling after 2.00 pm. This was due to the sharper focusing of the sun dish and the fact that the dish could be tilted to accommodate the lower sun angles. However, considerable difficulty was experienced in keeping the dish in focus and two pieces of wire were needed to prevent it being blown off focus by the wind.
### Table 40: The Quasi-parabola with Heatmirror Reflective Material

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature</th>
<th>Vaporization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(°C)</td>
<td>(gms)</td>
</tr>
<tr>
<td>10.00 am - 12.00 noon</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>12.00 noon - 2.00 pm</td>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>2.00 pm - 4.00 pm</td>
<td>78</td>
<td>60</td>
</tr>
<tr>
<td>MEAN</td>
<td>87</td>
<td>45</td>
</tr>
</tbody>
</table>

**NOTES:** The average time to boil 1.5 litres of water between 10.00 am and 2.00 pm = 50 mins ± 7.5. At 2σ this gives 15% variation.

Figure W3 shows the quasi-parabola and the sun dish undergoing tests on the roof of a Sudanese building.
Figure W3  The Quasi-parabola and the Sun Dish
### Table 41 The Sun Dish Water Tests

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Maximum Temperature (°C)</th>
<th>Time to Reach (mins)</th>
<th>Vaporization (gms)</th>
<th>Vaporization (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00 am - 12.00 noon</td>
<td>99</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>55</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>150</td>
<td>60</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>55</td>
<td>176*</td>
<td>60</td>
</tr>
<tr>
<td>12.00 noon - 2.00 pm</td>
<td>100</td>
<td>45</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>40</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>40</td>
<td>230</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>30</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>45</td>
<td>210</td>
<td>60</td>
</tr>
<tr>
<td>2.00 pm - 4.00 pm</td>
<td>100</td>
<td>75</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>70</td>
<td>120</td>
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<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>250</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>30</td>
<td>250</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>55</td>
<td>100</td>
<td>65</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>55</td>
<td>180</td>
<td>60</td>
</tr>
</tbody>
</table>

**NOTES:** * Average of three figures. The average time to boil 1.5 litres of water between 10.00 am and 2.00 pm = 50 mins ± 7.3. At 2σ this gives 15% variation.

The solar oven could only hold small pans and consequently only one litre of water was used for test purposes. Too much tilting of the oven with a larger quantity of water would have resulted in spillage.
With one litre of water, only on two days in April did the oven succeed in bringing the water to the boil. Boiling took about 80 minutes between 10.00 am and 12.00 noon, and 60 minutes between 12.00 noon and 2.00 pm. Otherwise, temperatures were generally in the 90's, although after 2.00 pm when tilting became a problem, maximum water temperatures were in the 80's.

Oven temperatures varied between 70°C and 100°C at the start of each test and generally rose to between 100°C and 120°C during the test period. During the afternoon test period however, the oven temperature fell throughout.

With no window in the solar unit, 1.5 litres of water could be accommodated in a larger pan. It took a very long time, 90 to 100 minutes for the water to reach the maximum temperature of 70°C, and there was still a limit as to how much the oven could be tilted in the afternoon without spilling the contents of the pan. It was noticeable that all units needed to be tilted more in the month of June than in April.

Figure X1 shows the solar oven being tested together with the sun dish.

In summary, the quasi-parabola with the Heatmirror reflective material, and the sun dish fared very much the same. The sun dish needed stabilizing in wind and focusing was difficult but it did boil water in the late afternoon. This limitation of the quasi-parabola was not seen to be a serious disadvantage since by 2.00 pm, women had usually finished cooking.

If one takes the best figures for the quasi-parabola, the unit raised the temperature of 1.5 litres of water by 61°C in 45 minutes. Therefore the theoretical energy required was 103.5 k.cals or 2.3 k.cals/minute. The total collection area of the parabola was 12355 cm², and assuming insolation at 1 cal/cm²/min, since this was the hottest time of year.
Table 42 Results of Water Tests on the Solar Oven

<table>
<thead>
<tr>
<th>Time to temperature</th>
<th>Maximum temperature</th>
<th>Maximum oven temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum temperature</td>
<td>MEAN</td>
</tr>
<tr>
<td></td>
<td>(°C)</td>
<td>(°C)</td>
</tr>
<tr>
<td></td>
<td>Time to reach (mins)</td>
<td>MEAN</td>
</tr>
<tr>
<td>10.00 am - 12.00 noon</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>114</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
<td>87</td>
</tr>
<tr>
<td>12.00 noon - 2.00 pm</td>
<td>88</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>100</td>
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<tr>
<td></td>
<td>91</td>
<td>100</td>
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<tr>
<td></td>
<td>96</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>98</td>
<td>90</td>
</tr>
<tr>
<td>MEAN</td>
<td>96</td>
<td>80</td>
</tr>
<tr>
<td>2.00 pm - 4.00 pm</td>
<td>84</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>83</td>
<td>80</td>
</tr>
<tr>
<td></td>
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</tr>
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<td></td>
<td>72</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td>MEAN</td>
<td>83</td>
<td>88</td>
</tr>
</tbody>
</table>

NOTES: The average time to boil 1 litre of water between 10.00 am and 2.00 pm = 82 mins ± 10. At 2 this gives 13% variation.

and time of day, the actual energy available to the pot should have been approximately 12.4 k.cals/minute. This gives an efficiency to boil of 18.5%. Heat losses by vaporization were equivalent to 1.2 k.cals/minute such that the total efficiency to boil and simmer 1.5 litres of water for one hour in the quasi-parabola was about 28%.
Figure X1  The Sun Dish (foreground) and the Solar Oven
These figures are not dissimilar to the efficiency of cooking on a charcoal stove. However, it remains that solar cooking took some 30 minutes longer to boil the water compared to a direct heat source. Some of the fast boiling times reported for solar cookers in chapter 8 could not be obtained, and since these tests took place under optimal conditions, it is unlikely that the solar cookers would perform any better in other parts of the world.

The solar oven was particularly slow in cooking and although it was unlikely to be popular with Sudanese women, it had the advantage of requiring less attention such that it could be left for long periods of time. It was therefore considered worthwhile to include this cooker with the consumer surveys.

An assortment of different sized aluminium pans were used for the physical tests. They had been previously painted with local matt black paint, and were later given to the women taking part in the consumer testing of the solar cookers.
THE CONSUMER SURVEYS
Following the research and development of several charcoal burning stoves together with the comparative testing of three different solar stoves in Sudan, the next step was to involve the local consumer to assess the feasibility of the appliances with regard to their suitability in providing the typical range of daily meals. The 'appropriateness' of the appliances to the local situation could only be assessed by the user and indeed efficiency, as measured simply in terms of available and useful energy, depends as much on the optimal use of an appliance as on its technical ability.

Comparative consumer trials of both the new charcoal and solar stoves was to gain information relating to user opinions, performance and handling, and design features with a view to further modifications or improvement. In particular, concerning the solar stoves, it was considered necessary to identify the most important attributes or design priorities within the socio-cultural context of Sudanese cooking.

Working in a relatively unformulated area, where there was no previous experience to serve as a guide, a small intensive study was considered more satisfactory than a large, possibly superficial survey. The object was not to produce statistics from which inferences could be made about the population as a whole, but to gain insights about the individuals and community which would enable diverse bits of information be drawn into a unified interpretation. Sometimes referred to as a descriptive study (48), the intention was to paint a picture rather than make quantitative analyses. However, it was uncertain how women would respond to being interviewed. Very often before a large survey is undertaken, a small pilot study enables the investigator to check the suitability of questions. This is considered the only sure way of establishing the correct wording (49). Among Third
World consumers where one is working in a foreign language through an interpreter, a pilot study would be essential. Working in a foreign culture with an unsophisticated respondent and with some uncertainty as to the suitability of standard survey techniques, the consumer surveys could only be of an explorative nature.

19.1 Selecting the Samples

The consumer trials of the charcoal and solar stoves were undertaken as two distinct and separate surveys within different communities. This was to avoid any interaction between the attitudes and opinions from one survey to another and ensured that the results were unbiased from previous tests. However, both surveys employed similar methods with a small sample of women trying each stove in turn.

Normally, where a survey is required to produce statistics on a large number of respondents, a sample would be selected by a random selection method. This ensures that different types of people in the population are adequately represented in the sample. Obviously, the more heterogeneous the population, the larger the sample required to represent the different stata, for example, age, sex, region.

In Sudan, it was not possible to draw a random selection of women. The research was limited to two communities within easy access of Khartoum. There was no sampling frame of lists or indexes, from which to draw a sample and as a foreigner, an introduction was required to each family. This meant that women were asked to participate in the survey by the initial contact. In these close knit homogeneous communities, a randomly selected sample need not be any more representative of the community than volunteers. However, it is possible that the women who volunteered to participate in the survey were the more interested and responsive to new ideas, in which case any selection bias incurred would be of a positive nature. Time restricted the number of respondents to five or six since a fairly intensive study of each individual's circumstances was required.
In the case of the charcoal survey, it would have been preferable to take the stoves to a rural village. However, an introduction to such a community was not available and the survey was undertaken among a very old and agricultural based village which had become part of the urban sprawl of Khartoum. As far as possible, co-operation from the initial family established that the respondents were not among the richer members of the community.

With regard to the solar survey, the cost effectiveness of solar cooking could only be realized after an initial capital investment, and suburban wage-earning families, who were nevertheless poor, were considered to be suitable for the solar stove testing.

These families were young and newly established. They had migrated from the rural areas and to some extent were socially mobile. It was thought that they might be more receptive to novel ideas and innovation since it is very often these groups who initiate the 'trickle down' of ideas to the more rural areas. Introduction was by way of one of the translators employed for the consumer trials. He was known to the community and there was no problem in meeting the families.

19.2 The Experimental Design

The experimental design for testing the three charcoal stoves and the three solar stoves was not dissimilar to a longitudinal study (49), whereby women were given each stove to try for a few days and then asked for their opinions before testing another stove. This had the advantage of collecting data at the time of interest without the need to rely on a respondents ability to recall the past. It also enabled women to make a comparative judgement on the performance of the three stoves. However, this approach often conditions the respondent such that she may become more conscious and critical with time, such that later assessments are biased. Since the trial period for each stove was fairly short and there were only three units
involved, the advantages of having comparative information was thought to outweigh the disadvantages.

During the physical testing of the charcoal stoves, there appeared to be very little difference between the performance of the three stoves. It therefore did not seem to be important as to which order the stoves were tried. In this survey, the three stoves were given to three families to try for two days, after which they were asked for their opinions on the stove. The stoves were then exchanged and the procedure repeated until all families had used each of the three stoves. Finally, the survey was repeated on another three families such that the order of trial for each stove was balanced.

Since the underlying object of the survey was to establish the economic use of fuel with the new stoves, it was decided to try and quantify this by checking the amount of fuel used on the traditional stoves with that used on the new stoves.

To do this, women were given two 4 kilogram bags of charcoal before using the new stoves to check their usual daily fuel consumption. The women were told only to use fuel from each of the bags on each of two days. Then for each of the following days, when using each of the new stoves, they were told to use charcoal from six separate bags. By labelling the bags of charcoal in Arabic, 'Day 1 - Monday', 'Day 2 - Tuesday', as appropriate, and by weighing the remainder of charcoal for each day, measurements could be made as to how much charcoal was being used with each of the new stoves compared to their usual stove.

These physical measurements provided a useful check on the feedback from the women but they did not take account of day to day variation in cooking habits and fuel use. Therefore, the women were specifically asked how typical their cooking had been on each day, and whether they had used only the new stove or included one of their usual stoves when taking charcoal from the daily portion. Ideally,
these physical measurements should have been taken over a longer period of time, but two days for each stove was all that could be allowed within the experimental design.

Findings from the physical tests of the three solar units showed that whereas the quasi-parabola and sun dish boiled water in a relatively fast time, the solar oven was more suitable for the long slow cooking of rice and legumes which could be left unattended. It was therefore expected that the solar oven would not really be suitable for cooking the typical Sudanese meals in a reasonable time. However, the inclusion of this cooker in the consumer survey added another dimension to the survey and further loaned credibility to the comparative opinions expressed. It was felt that after trying one of the more powerful cookstoves, respondents may not give the oven a fair trial. Consequently, it was decided that all the women would first try the oven and then proceed to the sun dish and the quasi-parabola. In this way, each family tried the cookstoves in the same order.

The oven was taken to the first family, left with them to try for three complete days, and then the family was interviewed as to their usage and opinions of the oven. The family was then left the sun dish to try, while the oven was taken to the second family. In this way, each family tried each of the three cookers for at least three clear days and in the same order.

19.3 The Questionnaire and Administration of the Interview

Organizing the response or feedback from the consumer trials was by semi-structured interviews. The purpose of providing the interview with some structure is to ensure that all people interviewed respond to the questions that need to be answered. At the same time, the procedure should not be so rigid that respondents are unable to develop their own views at length. There are several advantages to informal interviewing. Firstly, it enables the investigator to dig deeper and gain a richer understanding of the subject matter
than formal methods would allow. In the study of complex attitudes, formal interviewing might limit the investigation to a very superficial level. An informal approach succeeds better in getting to the heart of a respondents opinion. Secondly, rigid questioning does not ensure that all questions have the same meaning for all respondents, but an informal approach permits the interview to be in the hands of the investigator to be adapted if necessary. An informal approach in a pilot study will also show what points are worth attacking at a later more structured stage. On the other hand, responses are more difficult to analyse and quantify. However, since the research was more interested in the characteristics of the individual rather than the aggregate, a descriptive analysis was considered appropriate.

A questionnaire was drawn up covering demographic information, fuel use and cooking habits. It then went on to ask questions on three broad areas of interest; stove usage, overall and spontaneous opinions, performance and handling and design, (see appendix II and III). This provided a structure within which the interview ensured that each subject was fully covered. Questions started on factual items while they were fresh in the respondent's mind. They then proceeded with broad opinion questions narrowing down to specific issues known as the 'funnel sequence'.

The questions were open ended to encourage respondents to talk freely about each topic. The problem was to keep the questions as simple as possible without being vague or ambiguous. Obviously, working in a foreign language made this task more difficult. However, there was ample opportunity for probing should a response be irrelevant or incomplete.

The need for honesty was paramount. Questions were explained or restated when there was doubt as to whether they had been understood properly. Similarly, probing was occasionally necessary to obtain a full and satisfactory answer. As appropriate, or when doubtful as to the truthfulness of a reply, prompting took the form of; "You are being too kind,
I'd much rather you were honest. If you don't tell me what you disliked about the stove, how can I improve it for you?". Very often, this type of check was met with a look of surprise but did occasionally generate some more information.

Learning the key words of the answers in Arabic, such as; "It cooked fast", "It was too slow", "It was good", provided a check that the interview was being administered properly since it was generating the right sort of replies. It also enabled the interviewer to make some subjective evaluation of the strength of attitude held. With a basic understanding of the key words, the tone of voice often revealed the true attitudes of the women.

The questionnaire had questions translated into Arabic alongside. They needed to be sensible in the local language, and were checked by Sudanese women in England before the administration of the survey. A few alterations and modifications were made. The questionnaire also left space for the translation of the responses to English.

19.4 The Translator

The success of the interview very much depended on a fluent translator, who could quickly translate answers and further probing or explanatory questions and maintain the flow of the interview. It was important to keep the respondent interested once some rapport had been established.

The translator was briefed as to the nature and purpose of the survey. He was given the questionnaire to study before the start of the survey. The importance of his role as an impartial participant was stressed, and it was pointed out that the value of the survey depended on his accurate translation of the spoken word. With a translator from the local community, he used the local everyday Arabic language. However, it was specifically emphasized that he should translate the exact question and response. He was not allowed to probe or ask further questions of his own judgement. This was to keep the process as straightforward
as possible and minimize any bias from his own attitudes. It also enabled the interview to remain in the hands of the investigator. Since this was an exploratory study and the questionnaire served only as a guide, the interview could not be administered by the translator alone.

However, the behaviour of the interviewer and translator very much affected the attitude of the participants. Positive enthusiastic attitudes shown by the investigators evoked interest and co-operation from the women. On entering the family home, it was usual to sit down and accept a glass of water, which is the custom. Since the strangers were regarded as guests, it was important to respond in the appropriate manner. After exchanging greetings, and sometimes chatting about life in Sudan, the interviews proceeded. The attitude and interest of the translator was important. Working as a team, and with equal responsibility, he appreciated the importance of his role. Had the translator not been regarded as an equal participant in the administration of the survey, this might have decreased his interest and motivation. Payment to the translator was on a daily basis and was slightly higher than the local Sudanese rate.

Both translators for the solar stove survey and the charcoal stove survey were interested in the subject area and enjoyed the work. An English graduate was employed for the former survey and an English teacher for the latter survey. Overall, the programmes were carried out very smoothly, although it was noted that the graduate grasped the need for a formal though flexible means of questioning a little better than the English teacher who was very enthusiastic about the work but took a little longer to settle into a formal style.
CHAPTER 20
RESULTS OF THE CHARCOAL STOVE SURVEY IN SHAMBAT

The village in which the charcoal survey was held was called Shambat. Situated 10 miles from Khartoum, the stoves were taken to the village and families were engaged for the survey. It will be remembered that each of the six families tried the three stoves for two days each in a random order. Appendix II gives the questionnaire that was used for each of the stoves. Physical weighings of the amount of charcoal used for each day over an eight day period were made.

The results are first analysed for each of the charcoal stoves and then the overall preferences of the women are reported. As a token of appreciation for taking part in the survey, the women were each given a stove of their choice to keep for continued use.

It is believed that the character of the women and their reaction to participating in the survey is worth reporting. With such a small sample and frequent visits to the homes of the women, it was possible to become well acquainted with each one. Each held different attitudes to the white woman and the novelty of testing improved cookstoves. There was quite a difference between the women in Shambat and those in Jebra who tested the solar stoves. The Shambat sample reacted with great excitement to the presence of the white woman and enjoyed including her in traditional activities and customs to the extent that asking formal questions about stove use was quite often very difficult. Friends and neighbours crowded round in each others homes such that it was virtually impossible to identify a single family. Women were easily influenced by each other and being very curious and excited by the novelty of the survey, there were times when responses were treated with caution. Compared with the women testing the solar stoves, the women in Shambat inspired less confidence. However, the results are analysed for each of the three new stoves and are presented below.
20.1 The Brick Basket

Questions on the use of each stove centred first of all on overall opinions, likes and dislikes. This was designed to tap the more salient attitudes first.

When asked for their overall opinion to the brick basket, all showed a positive attitude with varying degrees of enthusiasm. Only one mentioned the economical use of charcoal. However, when asked for particular likes about the stove, most responses focused on the speed to boil and the fact that the outside of the stove kept cold. Two women mentioned that the brick basket was easier to use than their usual stove. Dislikes were less forthcoming, although two women mentioned that for a large pot, the base was too high above the fire. Another woman commented that because the neck of the stove was fairly narrow, it was necessary to fill the stove twice with charcoal.

Compared to their usual stoves, women liked the fact that the brick basket was fast to cook and "kept the heat inside". One woman continually commented that with the brick basket, there were no sparks flying from the fire. When asked, most women said that they preferred the brick basket to their usual stove although one mentioned that she had developed the habit of using her normal stove.

Women were next asked specific questions about their use of the brick basket. All women reported that the stove was faster to boil food, and one woman noted that the fast boiling time made her start with less charcoal the next time she did her cooking. This suggests that it may have taken women a little time to adjust to using less fuel for a reasonable boiling time. All mentioned that they needed to add a few pieces of extra fuel to keep the fire burning and complete the cooking process. When asked about fuel consumption overall, five of the six women reported using less charcoal with the brick basket; one woman claimed that she used half as much as usual.
On handling and design features, only one woman found the stove difficult to use saying that lifting the pan out of the stove could burn her hands. When asked about the size and weight of the stove, all women mentioned that the brick basket was heavy to move, although in all but one case, this presented no problem.

To conclude the interview, women were asked whether they had any further comments to make about the brick basket. Two women mentioned a preference for a less deep stove such that pans could be more easily removed and a large pan would sit nearer the fire. One woman noted the advantage that the stove was very stable in wind while another said that she had difficulty in removing left over charcoal from the grate after cooking.

Overall, the most noted attributes of the brick basket were its speed of cooking and the fact that it was perceived to keep the heat in. Economy of fuel use was mentioned when specifically asked about, but all women reported the need to add a few pieces of extra charcoal to maintain the cooking process.

20.2 The Gauze-in-Tin Stove

Overall opinions to the gauze-in-tin stove were again favourable. One woman thought that it was the best stove, but another complained that it was not suitable for large pans. When specifically asked what they liked about this stove, the responses of the women were split between; "fast to burn" and "uses less charcoal". Two women maintained that the stove was on the small side but otherwise there were no real dislikes to the gauze-in-tin stove.

Compared to their usual stoves, women's responses were varied. Two women repeated that it was faster to cook than their usual stove and one noted that it was more economical. Otherwise, answers generally reflected the fact that
the usual stoves had worn; "with my usual stove, the tin is damaged", or "this stove has small gaps and does not let the charcoal fall through". One woman noted that the gauze-in-tin stove "kept the heat inside". All preferred the new stove to their usual stove, but one woman said that she did most of her cooking on her normal stove just out of habit.

When specifically asked about the speed of the boiling stage on this new stove, all but one woman said that it was a little quicker than usual. One woman mentioned that although the stove was no faster in bringing the food to the boil, the fire kept burning longer. Another woman commented that the rate of burning was too fast because she needed to stir the food frequently.

Four of the six women reported the need to add more charcoal during the cooking process but overall, all women said that they used less charcoal than usual with the gauze-in-tin stove; some said it was a little less and others reported using a lot less fuel than usual.

On handling and design features, few comments were forthcoming. All the women found the stove easy to use although one mentioned that she found difficulty in lighting the fire since the gauze had to be lifted out of the tin. Again, two women commented that the stove was not suitable for large pans.

When asked for further comments, again the small size was mentioned and one woman noted that since the heat was kept inside, it was not dangerous with children around. Overall however, women had very little to add to the interview.

In summary, the speed and economic use of fuel were the main attributes of the stove, while its small size was the main disadvantage.
20.3 The Three-quarter Level Grill

Again overall opinions to the three-quarter level grill were positive with varying degrees of enthusiasm. Qualifications or explanations for their favourable impressions included; "the holes are too big", "it is fast to get the charcoal alight" and "it uses less charcoal". One woman did not like the stove.

When specifically asked what the women liked about the stove, four of the six women commented on the economic use of fuel, while one noted that the stove gave a "slow, quiet burning fire", and another noted the advantage of having a door on the stove to stop the spread of heat.

Dislikes were very few but two women commented that small pieces of charcoal fell through the grate, and for one woman this implied that the stove used too much charcoal.

Compared to their usual stoves, three women noted the more economic use of fuel with the three-quarter level grill, and the fact that "it reserved heat; all the heat is concentrated to the pan". Other comments reflected the fast time to boil, but one woman again complained that small pieces of charcoal fell through the grate and the stove used too much charcoal compared to her usual stove. Not surprisingly, all but this one woman preferred the three-quarter level grill to their usual stoves.

When specifically asked about the performance of the stove, all noted that it was faster to bring the foodstuff to the boil on the new stove, and that overall, it was quicker to cook the food. All women reported the need to add a few pieces of extra charcoal and the woman who did not like the stove said that she needed to add three handfuls of extra fuel. She also complained that the stove burnt too fast. Three of the six women reported using much less charcoal than usual, while another two said they only used a little less.
On handling and design features, all noted that the stove was easy to use and two commented on the ease of lighting the fire. One woman thought that the stove was a little small, but otherwise the women had few comments to make on the design.

Further comments about the stove were few. One woman liked the door to "slow the fire" and another perceived the hot tin as being a positive attribute.

Overall, economic use of fuel was a noticeable attribute together with the speed of lighting the fire. The only dislike seemed to be the large grate holes and this was corrected.

20.4 Overall Preferences

At the end of the stove trials women were asked which stove they liked the best and why. They were also asked which stove was the most economic and which one they would like to keep as a present for taking part in the survey, (appendix III). Final preferences were evenly split between the three stoves.

The two women who preferred to keep the brick basket were Faisa and Gemila. For Faisa, the brick basket was the first of the new stoves that she tried. She explained her preference for the brick basket because "it uses less charcoal", "remained cold on the outside" and presented "no danger". When asked, Faisa perceived that the brick basket was the most economical of the three stoves saying that she could save up to half of her monthly fuel use. There is some doubt as to her perceptions of economy since this was not a salient point in her initial observations of the brick basket although she readily noted the fuel saving attributes of both the tin stoves. Faisa tried a fair range of foods on all three stoves, although she seemed to gain confidence as the survey progressed giving each successive stove a fuller trial.
Gemila reported that she liked the brick basket best because it was "just like an oven". Again when asked, she thought this stove was the most economical on fuel. She least liked the three-quarter level grill because it "used too much charcoal". However, fuel economy was not a feature that she spontaneously reported for any of the stoves during the interviews. She continually noted that the brick basket "kept the heat in", and this may have influenced her perceptions of economy. However, Gemila did mention that she did not need to add further charcoal for cooking with the brick basket because the "fire lasted long enough".

Both Illham and Jerida preferred to keep the gauze-in-tin stove for continued use. However, when asked the question, "Which of the three stoves do you prefer?", both women chose the brick basket because the sides of the stove remained cold. Asked about the most economic stove, the gauze-in-tin stove was said to use the least fuel. Jerida stated that with the gauze-in-tin stove, she could save up to one third of her daily fuel consumption and it was this factor that made her decide to keep the gauze-in-tin stove.

Illham was in fact the poorest woman of the sample. Some of her youngest children were suffering from malnutrition. Her evaluations of the stoves seemed quite reliable, since she tried the gauze-in-tin stove last and immediately commented that it was the best one. Economic use of fuel was very salient in her mind. She also noted that there was no need to add extra charcoal while using the gauze-in-tin stove, although there is some suggestion that the rate of burning was a little too fast. During the interviews, Illham said that the gauze-in-tin stove saved about one third of her daily fuel needs although she initially thought that the three-quarter level grill saved half her fuel needs. Her normal stove was very worn and this influenced her favourable impressions of the new stoves.

The slight inconsistency between the interviews and final
choice for Iliham was also the same for Jerida. Although apparently less concerned with fuel saving attributes than Iliham, Jerida made the original comment that the three-quarter level grill used only half her usual amount of fuel. Jerida tried the gauze-in-tin stove last, and only when prompted did she make the point that this stove used a "lot less charcoal". It is possible that both women were influenced in their perceptions of fuel saving by the fast time that the gauze in tin stove brought the foodstuff to the boil.

When asked which stove they would like to keep, both Howa and Kiltoum chose to keep the three-quarter level grill. For Howa, the three-quarter level grill was the first stove that she tried and she said that she preferred this stove because "it was a good size and easy to move". She said that the brick basket burnt her hands when carrying it, although when specifically asked, she thought that the brick basket was the most economic. However, during the interviews, fuel economy was more of a salient point after trying the two tin stoves than after trying the brick basket. Howa immediately noticed the fact that they used less fuel. Again, it is likely that the cold sides of the brick basket was perceived as being heat saving and therefore economic. Howa had no real dislikes with any of the three stoves.

Similarly, Kiltoum had no real dislikes of the three stoves. She liked the three-quarter level grill best because "it uses less charcoal". She saw this stove as being the most economical stating that she could use one third less charcoal for her daily cooking needs. Kiltoum noted that the brick basket burnt too fast. Throughout the stove trials, Kiltoum spontaneously remarked on the fuel saving attributes of the three-quarter level grill, although when specifically asked she initially thought that the brick basket made a 50% fuel saving.

From these final questions on stove preferences and choice, it would appear that women were most influenced by first impressions. There is a little inconsistency between their preferences and specific responses to questions on likes and
fuel economy. In fact, fuel economy was not the most important influencing factor for all the women. However, there are some significant observations to be made here. The fact that the new stoves were all reported to be easy to start the fire and fast to bring the foodstuff to the boil, may have given the impression of being economic on fuel consumption. The fact that less time was spent on the cooking process suggested that less fuel was being used. Occasionally however, there was some indication that fuel was being burnt at too fast a rate. Secondly, with the gauze-in-tin stove and particularly the brick basket, the comments that the women made showed their appreciation of the fact that the heat did not spread out from the sides of the stove. This again may have given the impression of heat retention and hence 'economy'.

It should be noted that throughout the interviews economic use of fuel seemed to be more noticeable for the gauze-in-tin stove and the three-quarter level grill than for the brick basket.

For the reasons given above, the survey attempted to quantify the women’s responses by weighing the amounts of charcoal used. Using charcoal from 4 kilogram bags gave the women a term of reference, by which to make their evaluations. Some noted that they would generally use a whole bag for their daily cooking but with the new stoves, they could manage with only half or two-thirds of a bag.

20.5 Physical Measurements of Charcoal Consumption

Table 43 shows the amounts of charcoal used for each of the new stoves in the order that they were tried for each of the six women. Each stove was tried for two days. On the two days prior to the testing of the new stoves, women were asked to use charcoal from the 4 kilogram bags in order to check fuel consumption on their usual stove. The preferred stove for each woman is underlined.
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<td>Fuel Consumption on Traditional and New Stoves (kgms)</td>
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<td><strong>Usual stove</strong></td>
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<td>Gemila</td>
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<td>Howa</td>
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- Level grill
- Brick basket
- Gauze-in-tin
The women were asked two questions, firstly whether they used charcoal from the bags for the new stove alone or whether they used the charcoal for a second stove as well. Illham, Jerida and Kiltoum said that they did use some of the charcoal for a second stove. Women were also asked how much cooking they did on the new stove, whether it was more than usual, the same amount or less than than they would usually do on one stove. Their comments served as a rough guide on day to day variation in cooking habits.

Table 43 shows that there was quite a difference in daily fuel consumption both between the women and from day to day for the same consumer. Sometimes women were unable to evaluate how typical their daily cooking had been and at least three of the six women claimed to use the charcoal provided for a second stove. Since women claimed to use extra fuel while cooking, there may have been considerable left over charcoal from one day to the next, and this may have affected the weighings. In short, the experiment was very difficult to control, and the physical measurements do not show a fuel saving of any significance with the new stoves.

Of interest, women claimed to cook two or three times a day using two stoves for the main meal. Since the traditional charcoal stove could only hold about 350 gms of charcoal, this would represent a daily fuel consumption in the region of 1 to 1.5 kilograms, yet the Shambat women were using about twice this amount. This suggests that with large quantities of food, cooking times may have been considerably longer than the 60 to 70 minutes obtained in the laboratory experiments. On the other hand, since an initial quantity of 200 gms of fuel represents a 43% saving, women's claims to save about one third of their daily fuel with a new stove is not unreasonable.

However, the fact remains that the physical measurements did not show a decrease in fuel use. The women may have had false concepts of 'economy' as discussed in the previous
sections. Favourable impressions with regard to convenience and aesthetic appeal may have become generalized to their perceptions of fuel consumption. On the other hand, the limited time available for testing may not have been sufficient to show a fuel saving with the new stoves and the experiment was difficult to control.

These results are disappointing, and it was decided to repeat the physical measurements of fuel consumption among the Jebra women who were smaller consumers of charcoal. Since the follow-up survey aimed to clarify the results from the Shambat women, greater steps were taken to control the experiment. The methods and results are presented in chapter 22.
CHAPTER 21
RESULTS OF THE SOLAR COOKER SURVEY IN JEBRA

The suburban community which took part in the testing of the solar cookers was situated in Jebra some 10 miles from the centre of Khartoum. The area consisted of fairly new families who did not have the extended kin as the families in Shambat had. Since the Jebra families consisted mostly of the nuclear unit, they were easy to interview.

The Jebra women tended to be very sober in their attitude towards the white foreigner. They were welcoming but more reserved than the Shambat women. The translator employed for the survey knew the women in Jebra and he asked them to participate in the survey. Apparently, the women had some doubts as to their ability to use a solar cooker. Preconceptions had them believe that it would be very technical and beyond their grasp. They were surprised and happy to find all the equipment easy to use, but the fact remains that they had volunteered to participate in a survey, which they feared would be difficult for them. This raises the point that the women may have felt an obligation to take part, and the underlying attitude of wanting to please the white guest necessitated the constant checking of responses.

Overall, it is believed that respondents were both serious and sensible in their attitudes to the solar cooker trials. They were inquisitive yet open minded about solar cooking.

Five families were engaged for the solar cooker trials, and since each cooker was left with a family for three clear days and in the same order, the solar survey took longer to complete than did the charcoal stove survey in Shambat.

Again, responses are first analysed by each cooker. At the end of the trials women were asked some final questions as to which cooker they preferred and why. The reaction and attitudes of each woman is then given some consideration.
The questions asked for each interview are given in appendix IV. Questions first centred on the frequency of use of each cooker, the foods cooked and the time of day when cooking was done. They then pursued the general opinions of the women, their likes and dislikes. Questions went on to cover aspects of performance and handling and design features. Finally, to conclude the interview, women were asked to volunteer further comments.

21.1 The Solar Oven

The women were first asked how often they used the solar oven during the three day period. All five women reported using it twice a day on two or three days. A great variety of foods were cooked including potatoes, macaroni, rice, custard and egg. Two women reported using the cooker to heat water for tea and also to wash the baby. Corn was also boiled with milk and one woman said that she cooked stew; "it was effective for boiling as a preliminary stage in the preparation of vegetables".

When asked what food preparation the solar oven was suited for, women tended to repeat the same foods; "it was a great benefit, very useful for all little things and light food". "It is suitable for long slow cooking but there is not sufficient heat for 'asida' (porridge)".

Two women only used the solar oven between 10.00 am and 12 noon, but the remaining women used it throughout the day.

Women were asked for their overall opinions to the cooker, and their responses were cautious. The general consensus of opinion was that the oven was "convenient for light foods". One woman noted that it was "simple, requiring no effort". Dislikes centred on its slow cooking time and that it was "difficult to cook stew". Comments were also made about the difficulty of assembling the unit and the fact that it "cannot be used after 3.00 pm; cloud interferes with the cooking".
All the women agreed that it took longer than usual to cook with the solar oven, and two women noted that it "is easy to use only when the sun is hot at midday". Ease of use was perceived in terms of time to cook and convenience. "It is difficult to make stew in time because there are many stages, but the cooker is easy to operate", and "it is difficult if there is dust - I think it reduces the heat".

Only one woman found it difficult to place pots in the oven, "because the sides of the oven are hot", although three of the five women commented that this is dangerous because one can burn the hands. Asked about the ease of cleaning the oven, all reported that this presented no difficulty.

All the women thought that the design was simple and one noted that it was economic. Another woman complained that the oven could not hold a large pan, although for most of the women cooking light foods, the capacity of the oven to hold two or three small pans was sufficient. Two women complained about the weight of the oven; "it is heavy to move inside in the evenings. I need to do this because the children may play with it and there is the dust".

All women said that they had no difficulty in moving the oven however, and wind presented no problem to the stability of the appliance.

When the women were asked if they had any further comments to make, one said that she would prefer "a larger oven so that I can use a large baking tray but the depth is alright". Another comment was, "I would prefer to have a lighter oven but I like the fact that the pans are in a safe place and out of reach of the children".

Overall, the women gave the solar oven a full trial and its slow cooking was the only real disadvantage. It was suitable for a range of light foods but not for cooking stew. Convenience was mentioned by several women but only one referred to its fuel saving attributes and the fact that it was simple, requiring no effort to operate. Overall attitudes
were mildly enthusiastic but much prompting was required to obtain full information.

21.2 The Sun Dish

The sun dish was claimed to have been used on all three days although only once or twice a day. Again a variety of foods were cooked on the sun dish including stew and beans. When the women were asked what foods were suitable for cooking with this stove, responses were varied from "all foods" to "only tea". One woman commented that the sun dish cooked soup quickly. Cooking started between 8.00 and 11.00 am until 3.00 in the afternoon.

Overall opinions to the sun dish were more varied than to the solar oven. While several women found it "very good", "stronger than the other one", others found it "difficult to adjust", "slow and uneasy".

When asked what women liked about the sun dish, responses were, "useful, quick, better than the first one, easy to reach the pan"; "I liked everything about it", and "there is no need to use charcoal".

Dislikes mostly concerned the difficulty of focusing and instability in wind. Two women complained that compared to the solar oven, the sun dish could only hold one pan and they were compelled to stand in the sun.

Only three women said that cooking with the sun dish took longer than usual, while the other two women said that it took about the same time. Asked about the ease of operating the sun dish responses were again varied. While one woman said that the cooker was "easy to put together but I cannot stand the heat of the sun", another said that "it was easy to put the pan on and stay in the shadow". Light food was said to be quick to cook as was cooking when the sun was hot. "It was difficult to cook after 3.00 pm", one woman commented.
Reaching the pot presented no problem and only one woman thought that the reflections were "dangerous to the eyes". Again, no woman found the cooker difficult to clean. For most women the design was simple but one said that "it was complicated; I failed to understand the design in terms of assembling and taking apart".

The size of the cooker was said to be "big considering it only takes one pan" by two women, but the others had no comment to make about the size of the cooker.

The portability of the light unit seemed to be a positive attribute but there was some inconsistency in women's replies to the question on stability in wind. Although most said that the cooker "resists wind", earlier complaints show that the sun dish gave the impression of being unstable.

Women were finally asked if they had any further comments to make about the sun dish. Two women mentioned that it would be better if the cooker could take two pans, and one said that she "would like to have a ridge around the top of the pan support to prevent the pan from falling and make it more stable in wind".

In summary, attitudes towards the sun dish were slightly more favourable than those to the solar oven, and this was due to the faster cooking time. The sun dish was more suitable for cooking stew and there was quite a wide range of comments made about the cooker. The negative comments about the cooker related to instability in wind, the difficulty of focusing and the fact that it could only hold one pan. If the cooker had been difficult to focus, this would explain why some women found it suitable only for making tea.

21.3 The Quasi-Parabola

Three of the five women claimed to use the parabola on four days which must have included the day of the interview.
Generally it was used twice a day from early to mid morning until 3.00 in the afternoon. One woman claimed to use the cooker to prepare breakfast, which was not generally the case with the previous two cookers. Again a fair range of foods were prepared on the parabola including stew. When asked which foods the cooker was suitable for cooking, two women mentioned stew, and another said, "it takes time to make stew", while others mentioned light foods such as rice and tea.

Asked for their overall opinion of the solar cooker, most women said that it was "alright". Women liked the "good heat obtained", "it gave more heat than the others, it is easy to adjust". One woman mentioned that the stove "saves charcoal". "It is very good but rather slow", reported another.

Dislikes focused on the size and that it was slow to cook stew. "It is too big, if it rains, I cannot move it in the house. It needs a special place".

On performance and handling, two of the five women claimed that it took the same time as usual to cook with the parabola, while most said that it took longer than usual.

Several women claimed that it was easier to focus the sun dish and overall the operation of the cooker presented no problem. One woman complained however; "the only difficulty is the weight. It is heavy to move from place to place. In the evening, I want it out of the way. I need the space".

Most women found the pot within easy reach although one commented that the "pan rest was unstable when I wanted to stir the food". Occasionally, women noted that the reflections from the cooker were uncomfortable to the eyes, but otherwise the parabola was not dangerous to use.

Women did not think that the parabola was difficult to clean. "I cleaned it with cotton wool and water", one woman said.
Asked about the general design of the quasi-parabola, most women said that it was "simple" or "attractive". "My father wants to make one like it", said one woman, "it can save on wood and charcoal". Another woman said that "it was not good, it was not easy, the shape is not attractive. If there is a change in the weather, it does not work".

On the question of size, several mentioned that the parabola was too big and that it was heavy to move. However, two women said that it was "easy to move because there was no need to dismantle". Most women thought that the cooker was stable in wind, although one woman mentioned that "with wind accompanied by dust, there is less heat".

Asked for further comments about the quasi-parabola, one woman noted, "the reflector is not resistant. Children can tear it. If water spills on the reflector, this reduces the power". Two women commented on the fuel saving attributes of the solar cooker but another repeated that the cooking took too long.

In summary, the interviews generated a very wide range of comments on the quasi-parabola. Again its comparative fast speed of cooking was its main attribute, while its large size the main disadvantage. This was particularly so for the women who had little space in their yards. Focusing was said to be easy and compared to the sun dish, the cooker was stable in wind. Several women noted the advantage of saving charcoal but overall, this was not seen to be the most important attribute of solar cooking. The unreliability of solar cooking in adverse weather conditions was also mentioned.

21.4 Final Opinions on Solar Cooking and Stove Preferences

After trying each of the solar cooking units, women were asked some general questions about solar cooking and their preferred unit (appendix V).
Nadia thought that solar energy was "easy to use, a good idea to try", but "charcoal is quicker". She also thought that solar cooking gave a different taste to the food but could not explain. She stated that she wanted a solar cooker that was "easy to move and put away in the house because I need the outside space".

Nadia preferred the sun dish best because "the pan is easy to reach" and she least liked the quasi-parabola because it was "too big". She considered that a solar cooker should be able to cook all foods although her spontaneous reaction was that solar cooking was useful for rice and custard. There is the suggestion that she perceived the main advantage of solar cooking for light foods only.

Nadia was initially curious with an open mind towards solar cooking. She appeared to undertake the solar cooker trials conscientiously, but by the end of the survey she still seemed unconvinced.

Nadia used all the cookers for light foods, although from the interviews it would appear that more variety was tried on the solar oven. None of the cookers were used for breakfast and there is some indication that smaller light foods were cooked between meals.

Throughout the interviews, Nadia volunteered more favourable comments about the sun dish than the other two cookers which is consistent with her final choice. She did criticize the sun dish for being unstable in wind and said that she preferred a cooker to hold two pots. Originally, she thought that the sun dish took the same time to cook as charcoal, but it was the size and portability which influenced her final choice.

When finally asked how she felt about using energy from the sun to cook her food, Zenab stated that it was "very nice - it gives heat near to that of charcoal". She too wanted a cooker that could be easily moved because of little space.
When asked which cooker she preferred, Zenab stated that the quasi-parabola was "easy to use; it boiled quickly". She least liked the solar oven because it was slow to cook. Zenab said that she would use a solar cooker for most foods but the ability to cook stew was the most important requisite of a solar cooker.

Zenab was usually to be found preparing food with her mother. She gave the impression of being quite meticulous and conscientious about her daily duties and probably regarded the solar cooker trials as part of her routine. Totally disinterested in the white visitor, she was rather more critical of solar cooking than some of the other women.

Zenab tried the cookers on an increasing number of days which is consistent with her final preference. She seemed to gain confidence as the survey progressed and used the quasi-parabola throughout the day.

Zenab said that she covered the quasi-parabola with a sheet when it rained. Throughout the interviews when asked about the ease of using a solar cooker, the questions were very often interpreted with respect to the time involved in the cooking process. The only dislike of the quasi-parabola was its weight, although Zenab also criticized the oven for the same reason. The oven was also said to be "difficult to put together". Although Zenab said that the sun dish "resisted the wind", initially it was thought to be unstable. Zenab's final comment on the quasi-parabola was that it can be used on days when there is a "shortage of charcoal in the rainy season". She therefore saw solar cooking as being complimentary to traditional cooking as a standby. The capacity of the parabola to hold only one pot was sufficient for Zenab.

The third woman to participate in the survey was called Fatima. She lived a little apart from the other women, but was the most interested in the solar cooking experiment. Asked how she felt about using heat from the sun to cook her food, she commented that "it is easy and cheap". "There is no difference
between solar cooking and traditional cooking. If one takes care, one can cook in the usual way". Again however, Fatima wanted a solar cooker that was easy to move; "I need to move it away from the children, wind and rain". Unlike some of the other women, Fatima had no problem with space. She had a very large yard.

Fatima liked the quasi-parabola best because "it gave more heat". She least liked the sun dish because it was "unstable in wind". Fatima considered that it was important for a solar cooker to cook all foods.

Fatima was certainly the most welcoming of all the women. She undertook the trials in an investigative manner, but more often than not left her eldest daughter to do the bulk of the cooking while she visited friends and neighbours. Fatima was very creative and undertook sewing to supplement her income. Her husband was like minded running a taxi after working hours. He was also interested in opening a canteen and considered the possibility of using a solar cooker for this purpose. Fatima was relatively rich compared to the other women, but she was the only woman who constantly commented on the fuel and cost saving attributes of solar cooking. She casually chatted about the strong heat of the sun and how she had not realized that it was hot enough for cooking.

Fatima increasingly made more comments with each cooker, a reflection of her interest and enthusiasm. She used all the cookers throughout the day although since she said that she always bought breakfast from a canteen, it is likely that she simply used the solar cookers for tea in the morning.

Fatima particularly liked the convenience and little effort required for cooking with the solar oven. She was the only woman to appreciate the advantage of being able to leave the cooking unattended. When specifically asked, the sun dish was said to take about the same time as usual to cook food but the quasi-parabola was said to cook some foods quicker:
"soup, chick peas and lentils are quicker than usual", Fatima said. This is likely to be a little optimistic but if Fatima left the food to cook while socializing with friends or undertaking her sewing, it is possible that she lost track of the time.

Fatima made some interesting comments about the size of the preferred quasi-parabola; "it is nice but if you could find a smaller one, with reflectors closer to the pot, it should be stronger". She was the only respondent to question the relationship between the size of the reflectors and their distance from the pot. She thought that if the reflectors were closer to the pot, the cooker would be more powerful.

Another point of interest, although all the women claimed that the cookers were easy to clean, Fatima was the only woman to return the equipment as she was left it, cleaned and ready to take to the next family. However, since the cookstoves were collected in the early morning on a day the women were previously informed of, it is possible that they did not see the need to clean the cookers for cooking.

Fatima criticized the depth of the solar oven for being too shallow. Since she was the only woman to try cooking the daily stew in the oven, it follows that she would find it too small for a large pan.

Amira was the only pregnant woman to participate in the survey. The daily cooking was understandably quite a chore for her. She undertook the minimum number of tasks preferring to rest in the shade as much as possible. Her final attitude to using heat from the sun to cook food was only mildly enthusiastic; "it is alright if you are not pregnant", she said. Compared to traditional cooking, Amira said that solar cooking took longer. She also preferred a portable design that could be placed near the shade. Of the three cookers she tried, Amira also preferred the quasi-parabola because "it gave more heat". She also added later that it was easier to focus but complained that dust got in the food if she took
the lid off the pan. This suggests that she may not always have used a lid for cooking which would inevitably have lengthened the cooking process. Amira least liked the sun dish because the "adjusting is difficult", she said. When asked what she might use a solar cooker for, she stated that it would be very good for rice which she prepared everyday to eat with stew.

Despite her advanced state of pregnancy, Amira claimed to undertake a fair range of cooking on the solar units, although the quasi-parabola was the only one on which she cooked stew. She thought the sun dish was only suitable for making tea and her comments that it was difficult to focus suggests that it was not used properly. During the interviews, Amira did not feel that any of the solar cookers were suitable for the foods she tried on them. Amira did not volunteer many positive comments about solar cooking and although she preferred the quasi-parabola, during the survey she said, "it was slow to make stew". She did however, perceive the advantage of not needing to use charcoal. Amira was the only woman to be particularly critical of the need to stand in the sun.

Nowell, the last woman to take part in the survey, was a very young wife. She was not particularly impressed with solar cooking. "It is alright but cooking on charcoal is easier. I dislike being exposed to the sun but I like the fact that there is no smoke from solar cooking". During the final questions, Nowell did not seem sure whether she wanted a portable design of solar cooker or not. At first she claimed that she preferred to have a cooker that remained in one position because "I can arrange the food ingredients near it", but later she said that she preferred to be able to move a cookstove near the shade. Responses from her interviews would tend to confirm a preference for a portable design.

Nowell preferred the sun dish of all the solar cookers. She said that it was "faster to cook and easy because the pan is
outside". She least liked the quasi-parabola because it was "slow to cook". Nowell felt that a solar cookstove should be able to cook stew and heat water for tea. She also commented that it was impossible to make 'asida' and 'kisera' with a solar cooker.

Nowell was the woman who thought that the quasi-parabola was only suitable for making tea. She commented that "it is slow, but very good when the weather is hot". Nowell did not find the parabola "attractive" and there is the suggestion that during her trial of this cooker, the weather changed and this influenced her final poor evaluation of the quasi-parabola. She said "it took three hours to cook rice and if there is a change in the weather it does not work".

Nowell was one of the few women who did not find the sun dish unstable or difficult to focus. She did say that she preferred a cooker to take two pots. Overall, Nowell was not particularly forthcoming with comments about solar cookers and the interviews only generated a limited amount of information.

21.5 A Summary of the Design Priorities for a Solar Cooker

The survey was successful in obtaining information to enable some conclusions to be drawn concerning the necessary attributes of a solar cooker.

Three of the five women preferred the quasi-parabola, but in most cases the priority was for a more powerful cooker which could cook the food within a reasonable time. The speed of cooking was the most important requisite. Only Fatima perceived the advantages of being able to leave the food to cook while undertaking other activities. For most women, life revolves around the preparation of food and childrearing. Any form of cooking in Sudan is not a pleasant task because of the heat. Tending a hot stove or being exposed to the sun as in solar cooking is not comfortable.
Therefore the speed within which the task can be completed becomes important, though to a European mind, women would appear to have all day to prepare their food.

The quasi-parabola was specifically designed to be relatively powerful, stable in wind and easy to focus. That the sun dish was very light and easily blown off focus probably meant that it was very often out of focus and not providing maximum heat. Several women mentioned this in their dislikes of the sun dish though when specifically asked, the sun dish was said to "resist" wind. It was nevertheless unstable and gave the impression that the pan might fall. The ease of reaching the pot was an advantage.

Women did not particularly like the size and weight of the quasi-parabola so there is a trade off between stability in wind and portability. The cooker needs to be stable and easily focused but at the same time portable. Women felt the need to be able to move the cooker from place to place during the day to follow the shade. They also wanted to move the cooker into the house to protect it from wind and rain and to move it out of the way of children. Most families only had one small room and at night, women said that they needed the space in their yards for their children to sleep. The size of the yard, within which the solar cooker trials were held, affected women's perceptions of size. Those women with very little space generally criticized the quasi-parabola as being "too big", whilst women with larger yards were less concerned with the size of the cooker. In light of this, it is unlikely that women could accommodate two solar cookers to meet their need to prepare two dishes at the same time.

The most important requisite of a solar cooker was to be able to cook the daily stew. However, a very wide range of other foods were prepared; rice, tea, soup, macaroni, eggs, potatoes, milk, custard, hot water etc. Several women commented that solar cooking was "convenient and useful for
all little things". This was also true of the solar oven which had the advantage of being able to hold two or three small pans. Although solar cookers were not generally used for the preparation of breakfast, there is the suggestion that small dishes were prepared during the day. It was also significant that the solar cookers were used up until 3.00 pm after the main meal. Several women complained that they were not able to use a solar cooker after this time.

Overall, it was pleasing that the women gave the cookers such a fair trial, and it is likely that this reflected their curiosity for a novel cooking method rather than an obligation to satisfy the foreigner. The women were open minded yet critical of the solar cookers and the survey generated a range of comments towards the cookstoves. Some women were more positive than others depending on their personality and circumstances. However, their attitude and approach to the survey inspired confidence in the results.
CHAPTER 22
FOLLOW-UP CHARCOAL STOVE SURVEY IN JEBRA

Chapter 20 reported the results of the charcoal stove testing in Shambat. It will be remembered that all the women claimed to use less fuel on the new stoves both during the interviews and when asked for their final opinions and preferences. With the new stoves, they claimed to use about one third less charcoal, although sometimes it was about half their usual amount. The physical weighings of the amounts of charcoal they used over an eight day period was difficult to control and did not support the fuel saving claims made by the women. Sometimes the women were inconsistent in their answers and the Shambat women had not been easy to interview as the Jebra women had been.

It was therefore decided to run a small follow-up survey among the Jebra women. From the initial questions on fuel use during the solar cooker survey, it was established that the women in Jebra used considerably less fuel than the Shambat women. This was in part due to the smaller size of the families, but it was hoped that the Jebra women would be able to clarify the findings from the earlier survey.

By this stage however, time was very short and three women, Zenab, Fatima and Afia were each given one stove to try for three days. Nadia, a fourth woman had the opportunity to try two stoves. Before the stove trials, each woman was asked detailed questions about their usual fuel consumption. They were shown plastic bags of charcoal each containing 250 gms, and were asked to estimate how many bags they would normally use for breakfast, dinner, supper etc. Physical weighings of the amounts of charcoal used over three days were also made as before. Detailed questions were asked as to how much cooking they did and whether there was any left over charcoal.

The same method was repeated for each woman trying one of the new stoves over a period of three days. The women
were also asked for their opinions, likes and dislikes of the new stoves. The results are presented for each women's use of one of the new stoves.

22.1 Zenab's Use of the Brick Basket

During the preliminary interviews, Zenab estimated that one sack of charcoal would last her 15 to 20 days. She said that in one day she would normally use about five of the 250 gm bags of charcoal, one for tea, two for breakfast, and two for dinner. On some days, she said that she might use an extra bag for supper. Usually, she only used one stove for cooking but about once or twice a week if she had guests, she would use two stoves. Zenab mentioned that she kept a small stove for making tea. When asked if she had any left over charcoal from her daily cooking, she said that she sometimes did and to extinguish it she would put it in a hole in the sand.

Zenab's use of charcoal on her usual stove during the three days prior to trying the brick basket was as follows:

<table>
<thead>
<tr>
<th>Day</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.75 kgms</td>
</tr>
<tr>
<td>2</td>
<td>0.55 kgms</td>
</tr>
<tr>
<td>3</td>
<td>1.25 kgms</td>
</tr>
</tbody>
</table>

Zenab said that she only used one stove throughout the three days and that days 1 and 3 represented normal cooking. On day 2 she only prepared dinner and tea. Left over charcoal was put back in the bag to be weighed so these measurements of fuel should be accurate.

Zenab's use of charcoal during the three days that she used the brick basket was as follows:

<table>
<thead>
<tr>
<th>Day</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 kgms</td>
</tr>
<tr>
<td>2</td>
<td>1.8 kgms</td>
</tr>
<tr>
<td>3</td>
<td>2.2 kgms</td>
</tr>
</tbody>
</table>

Again Zenab said that she only used the one stove and that left over charcoal was put back in the bag. She mentioned
that on day 3 she had guests and did more cooking than usual, but otherwise, three plastic 250 gm bags of charcoal were sufficient for a day's cooking on the new stove. However, as can be seen, the physical weighings do not support her claim.

Asked for her overall opinion of the brick basket, she said it was "beautiful". She liked the fact that "it burnt easily and used a small quantity of charcoal". Zenab went on to say "it is better than my usual stove because it does not waste charcoal. With my traditional stove, the wind burns all the charcoal". Zenab had no dislikes of the brick basket.

Zenab said that she did not need to add any extra charcoal while cooking; "I put a small quantity in at the start and there was a small amount left", she said. Asked how much charcoal she used overall, she said, "less - a lot less, about half the usual amount". Zenab felt that the stove would be particularly useful during Ramadan when a lot of food is prepared for the evening meal because it was very economic.

In summary, Zenab fully appreciated the fuel saving attributes of the brick basket. Economy of fuel was very salient in her mind. However, once again the physical weighings of the charcoal used on both her traditional stove and the brick basket did not support her claim that she could use half as much fuel on the new stove.

22.2 Fatima's Use of the Brick Basket

Fatima, it will be remembered was one of the most resourceful women of the solar cooker survey. She said that one sack of charcoal would normally last her 15 days. After showing her the 250 gm bags of charcoal, she estimated that she would use about four a day, one for morning tea, one for cooking stew and two for dinner. Fatima usually bought breakfast from a canteen and sometimes she also bought a
prepared meal for supper. She said that she usually used only one stove although sometimes she would use two. Fatima generally had only a little fuel left from her meal preparation and she would extinguish left over charcoal by sprinkling it with water or by covering it with a pan. Ash was not thrown away but used to clean buckets.

During the three days before trying the brick basket, Fatima's use of charcoal was as follows:

<table>
<thead>
<tr>
<th>Day</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.825 kgms</td>
</tr>
<tr>
<td>2</td>
<td>1.125 kgms</td>
</tr>
<tr>
<td>3</td>
<td>0.725 kgms</td>
</tr>
</tbody>
</table>

Fatima said that she only used one stove and that on the first day she did less cooking than usual only preparing a light dinner. Again left over charcoal was returned to the bag for weighing.

Fatima used the brick basket for three days and her consumption of charcoal was as follows:

<table>
<thead>
<tr>
<th>Day</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25 kgms</td>
</tr>
<tr>
<td>2</td>
<td>0.80 kgms</td>
</tr>
<tr>
<td>3</td>
<td>1.00 kgms</td>
</tr>
</tbody>
</table>

She said that the amount of cooking undertaken on all three days was fairly typical and that she only used the brick basket for cooking. However, during these trials Fatima said that the little charcoal left over was used the next day, so it is likely that the first days weighing was slightly on the high side. When asked how much fuel she used in terms of the 250 gm plastic bags, she claimed to use only three with the brick basket.

When asked for her opinion of the brick basket, Fatima also said that it was "beautiful". She stated that the fire was easy to light and that the stove was a little quicker to boil. Again Fatima had no dislikes of the brick basket. "I prefer this brick stove to my usual stove", she said.
Fatima claimed that she needed to add a very little extra charcoal to the stove while cooking, but that overall, the brick basket used the same amount of fuel as her usual stove. Fatima was the only woman not to perceive an economy with a new stove.

In summary, Fatima claimed to use about 1 kilogram of charcoal per day and the physical weighings would tend to confirm this figure. While Fatima preferred the brick basket to her usual stove because it was a little quicker to boil, she did not notice any obvious difference in fuel consumption.

22.3 Afia's Use of the Three-quarter-Level Grill

Afia was a young wife who had only two children. She was the only woman to possess a small electric ring, which she claimed to use only for morning tea. One sack of charcoal would last her 35 days, she said. When asked how many of the small plastic bags of charcoal she would use per day, Afia answered two or three, two for dinner and maybe another for supper. "Usually, I buy breakfast from the canteen", she said, "it is convenient and the children like 'ful' (beans). If I make breakfast, I would use only one bag of charcoal".

Left over charcoal was extinguished with water but Afia said that when she cooked meat, there would be less left over fuel, However, on Saturdays and Wednesdays when no meat was available, "more charcoal is left because I have no need to cook for so long". Afia said that she used only one stove normally to prepare her meals, although on Friday, the weekend, she would use two stoves.

On the three days prior to trying the three-quarter level drill, Afia's use of charcoal was as follows:

<table>
<thead>
<tr>
<th>Day</th>
<th>kgms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Only on the first day did Afia claim to undertake more cooking than usual. She added that there was no left over charcoal from her meal preparation.

Afia's use of charcoal on the new stove was as follows:

- Day 1: 0.45 kgms
- Day 2: 0.40 kgms
- Day 3: 1.45 kgms

Afia said that she only used the new stove for cooking and that there was no left over fuel. On day 3 she said that she used more charcoal than usual because her small electric heater had broken. When shown the bags of charcoal and asked to estimate how many she needed with the new stove, she answered, "two bags are enough".

Interviewed about her opinion of the three-quarter level grill, Afia said, "It is very good, I am using it all the time". She liked the stove because "it used less charcoal". Afia had no dislikes of the three-quarter level grill and maintained that it was better than her usual stove.

When asked whether she needed to add extra charcoal while cooking, she answered, "only occasionally did I need to add more. The small quantity at the start is enough to cook with". Overall, Afia said that she used about one third less charcoal with the new stove.

In summary, Afia's claim to use about one third less charcoal with the new stove is supported by the physical measurements of her fuel use. Economy of fuel was very salient in her mind, even though she was a very light consumer of charcoal.

22.4 Nadia's Use of the Two Tin Stoves

Nadia was the first woman to participate in this survey and although the physical measurements were taken on the three-quarter level grill, Nadia also tried the gauze-in-tin stove...
For several days.

When asked about her usual fuel consumption, Nadia said that one sack of charcoal would normally last about 20 days. Shown the small plastic bags of charcoal she said that she would use about five a day equivalent to 1.25 kgms. One bag was sufficient for early morning tea, another for breakfast, two for dinner and another for supper. Nadia said that she would usually only use one stove, but if she is short of time or has guests, then she would make two stews on two stoves. In the latter case, Nadia said that she would need to use another two bags of charcoal. Nadia mentioned that there was usually a lot of charcoal left over from her cooking. She did not like to extinguish it with water because this damaged the tin, so she either covered it with ash or with a pan.

Nadia's use of charcoal on her usual stove was as follows:

- Day 1: 1.7 kgms
- Day 2: 1.7 kgms
- Day 3: 2.2 kgms

Nadia stated that on the third day, she used more charcoal than usual, but that she had no left over fuel.

Using the three-quarter level grill, Nadia's fuel consumption was as follows:

- Day 1: 2.0 kgms
- Day 2: 1.0 kgms
- Day 3: 1.85 kgms

Again she said that there was no left over charcoal and on the second day she made only 'asida'. Otherwise, the quantities of fuel used were fairly typical. When asked how many bags of charcoal she would need for the three-quarter level grill, she said, "four". Since this represents only one kilogram, Nadia's estimates throughout would appear to be on the low side.

When asked her opinion about the three-quarter level grill, Nadia replied, "it is quicker than usual and saves a
considerable amount of charcoal". She said that she sometimes needed to add a little extra charcoal and went on to say, "from the start you put a smaller quantity of charcoal than usual and add more if need be. There is only a small amount of left over charcoal".

While the interviews progressed, Nadia was left the gauze-in-tin stove to try. She immediately nicknamed it the "gas stove of the white woman" and said that she preferred it to the three-quarter level grill because it was "fast" and obtained a "quick, even combustion". When asked about the amount of charcoal the gauze-in-tin used, she said, "I only needed to add more charcoal when cooking stew. I have adjusted to the idea of using a little less charcoal for small, light foods. There is no left over charcoal because I put less in at the start". She concluded that the stove saved about one quarter of her daily fuel, "I am forced to use only the right amount", she said.

However, when asked which of the two stoves she thought was the most economic, she said that the three-quarter level grill burnt slower. The gauze-in-tin stove burnt fast and needed more charcoal but the ring in the three-quarter level grill was small and "you start with less charcoal", she said.

In summary, Nadia's estimates of her daily fuel use were on the low side compared with the physical weighings. These again did not show the fuel saving which she claimed. Interestingly, Nadia thought the three-quarter level grill was the most economic because of the small initial quantity of fuel and its slow burning. However, she preferred the gauze-in-tin stove because it was "fast" and concluded, "I am less concerned with economy. I only care about convenience". There is some inconsistency in Nadia's replies since both the inserts of the tin stoves were the same size and if the gauze-in-tin stove had a slightly faster rate of burning, it should not have affected the rate of cooking. However, Nadia made her opinions clear, and convenience was the most important attribute of a charcoal stove.
22.5 Summary of the Follow-up Charcoal Stove Trials in Jebra

The object of this small survey had been to try and clarify the fuel saving claims made by the women in Shambat. Again physical measurements of fuel consumption were made over a three day period for both the traditional stove and one of the new stoves. Women were shown small quantities of charcoal in plastic bags and asked to estimate their daily fuel use. This was followed by detailed questions concerning the use of charcoal for cooking.

The Jebra women tended to remark upon the fuel saving attributes of the new stoves rather more than the Shambat women did. Economy of fuel was much more important than speed of cooking and heat containment. Secondly, none of the women said that they needed to add much extra charcoal while cooking. Afia and Nadia in particular commented that with the new stoves it was only possible to start the fire with a small amount of charcoal and that this was sufficient.

While Nadia admitted that she preferred the speed to boil of the gauze-in-tin stove to the slow burning of the three-quarter level grill, even though she considered the latter to be the most economic, Fatima was not influenced. She also thought that the brick basket was a little quicker to boil but did not perceive any economic advantage.

The four Jebra women used less charcoal than the Shambat women and their perceptions of economy did not seem to be influenced by the speed to boil or heat retention. They did appreciate however, the ability to cook on small initial quantities of fuel, which was the most significant development from the laboratory research.

The estimates of the amount of fuel the women used daily were a useful guide. In some cases they proved quite accurate compared to the physical weighings, while Nadia in particular tended to underestimate her daily fuel consumption.
The variation in fuel consumption from day to day was quite considerable, and despite the failure of the physical measurements to identify a consistent decrease in fuel use, it is likely that the women were using a little less fuel with the new stoves. However, the amount of fuel saved is likely to be a function of how efficiently charcoal is used traditionally. Fatima, who proved to be one of the most resourceful and creative women during the solar cooker trials could possibly have been very careful with her use of charcoal, so much so that an improved stove could only help her to make better use of the charcoal but could not make a significant contribution to any fuel saving.

In summary, the followup survey in Jebra confirmed that women were able to perceive a fuel economy with the new stoves. Again it was reported to be about a third less fuel used. It is doubtful whether physical measurements over a two or three day period were long enough to take account of the day to day variation, but this follow-up survey demonstrates the difficulties in quantifying fuel savings.
CHAPTER 23
DISCUSSION OF THE METHODOLOGY AND RESULTS FROM THE CONSUMER SURVEYS

The application of standard consumer research techniques in the Sudan necessitated a very flexible approach. While the questionnaires provided a guide to the interviewer, they were not adhered to rigidly. The interviews were of a semi-structured nature. Respondents frequently did not understand the questions, giving answers that were illogical or irrelevant. However, with a fluent translator the questions were restated or explained until a sensible answer was obtained. Since the women were unfamiliar with a formal style of questioning, explanation of both questions and answers demanded a quick translation to maintain rapport and the flow of the interview without biasing the results.

Usually after the initial interview, the following interviews progressed very well. Women improved with experience and gave increasingly sensible articulated answers. As confidence in the interviews grew, the interviewer tended to make greater use of probing phrases seeking further explanations so as to build up a more complete picture and understanding of the consumer viewpoint. In fact, as the responses revealed the complexities of the perceptions towards the cookstoves and especially the charcoal stoves, the interviews tended to become more flexible. Very often, most of the salient points were covered in the early questions making the later more specific questions a little repetitive. Although efforts were made to clarify some of the complex attitudes and opinions, very often respondents were unable to explain their viewpoint.

Despite the asset of a fluent translator, working in a foreign language with an unsophisticated respondent necessitated a certain amount of probing behind the answers to identify the strength of attitude. Frequent checks were made on honesty. Perhaps more with the Shambat women, there was doubt as to whether their opinions were being expressed truthfully, or whether they were influenced by other women.
or were possibly adhering to the social norm of obliging the foreign visitor. Certainly the responses and opinions from the Jebra women were more varied and less homogeneous than those of the women living in Shambat.

Sometimes a 'halo' effect could be identified; that is where more than one characteristic is to be evaluated, women carry over a general impression from one attribute to another. Gemila, for example, was so impressed with the brick basket because "it kept the heat in", that she had to be much persuaded to continue the survey and give the tin stoves a fair trial. When she did, her attitude to the remaining stoves was biased and she tended to comment on negative attributes to reaffirm her original preference. When questioned about fuel consumption, the brick basket was said to be the most economical in line with her overall positive attitude to that stove.

Other women too needed persuasion to continue the survey after taking a liking to one particular charcoal stove, and in fact this represented more of a bias in the results than any obligation to please the foreigner and give the right answers.

Overall, after numerous checks for honesty and true opinions, it is believed that the only obligation felt was that to participate in the survey in the beginning. This was particularly true for the Jebra women who were apprehensive about the technology of solar cooking. Since the translator was a personal friend, the Jebra women undertook the solar cooker survey with a sense of duty. However, the results were satisfactory. The women were unbiased and each gave the three solar cookers an extremely fair trial.

The translator was not known to the Shambat women and possibly this was a disadvantage, since the women felt no loyalty to undertake the charcoal stove trials in a serious manner. They may have felt detached from the interview procedure not relating to either the translator or the interviewer. With the Shambat women it was difficult to maintain a formal style of questioning and even more difficult to establish
any rapport.

There were however certain advantages of the survey being carried out by a foreigner. A stranger can very often identify characteristics of a community that might otherwise be overlooked by an investigator reared in that culture. An outsider will be more sensitive to social customs and practices that are more or less taken for granted by members of the society. There were also advantages in being a white woman. In the sexually segregated world of Sudan, a white woman was accepted in the male world as a respected guest and also admitted to the female world by virtue of sex. This was a unique advantage and enabled observations to be made in both the male and female realms. In fact, taking a strange male translator to interview the Shambat women was not initially approved by the husbands of the women. The women themselves were totally unconcerned but the men were hesitant and allowed the survey to progress only because of the needs of the foreign visitor. It was explained that the British visitor was a little naive as to Sudanese customs and this approach together with the duty of hospitality enabled the interviews to progress without any awkwardness.

On the other hand, there were certain disadvantages in being British. At one time a British colony, attitudes towards British people are very favourable. There is the underlying attitude that any product from London must be superior and the presence of the white woman did raise expectations among certain women. Illham, the extremely poor woman among the Shambat sample, was very apologetic about her state of poverty. When first introduced, she felt awkward about answering questions on her fuel use and cooking habits but she simply assumed that the British person had come to help her and after realizing the nature of the trials, Illham tidied her kitchen area and co-operated very well. So as not to disappoint her high expectations, Illham was given all the left over charcoal from the survey, but in fact she responded by giving the visitor a gift of a dozen eggs.
Expectations of a superior product coming from England was not obvious amongst the Sudanese women though this may have influenced opinions and will be discussed later. Certainly Nadia's nicknaming the gauze-in-tin stove the "gas stove of the white woman", showed that she had certain ideas of Western technology which she aspired to.

With a small sample of women, it was possible to spend enough time with them to get to know each woman's character fairly well. Indeed, because of the alien cultural background and different language, it was necessary to know each one as an individual so as to make some meaningful interpretation of the results. A larger quantitative survey would only have extracted superficial information and indeed the very nature of a pilot study in an unknown field is to check the appropriateness of the methodology. Certainly, a detailed knowledge of the cultural background and the survey participants enabled some interpretations to be made about the results of the cooker trials. However, the experimental design used for the two surveys seemed successful as did the flexible interview structure. The necessity for a fluent translator has already been stressed.

It has already been said that the women living in Shambat came from very traditional families with extended kin living in the same household. They found the presence of the white woman novel and wanted to plait her hair or paint her with henna. The women were more interested in showing off their children or entertaining the guest than trying the new stoves. They were outgoing and gregarious and at times needed considerable coaxing to make them respond to formal questions. The women were far more concerned with amusing themselves than seriously considering the use of the new stoves. In fact, the translator, an English teacher, remarked that the interviews were a bit like the classroom, where the interviewer was trying to exercise control and the respondents treating the situation as something of a game.
It is not surprising then that the responses from the charcoal stove trials in Shambat should be treated with caution. To recap, there was some inconsistency between the responses given during the interviews and the final questions on preference and the most economic stove. Only about half the women seemed to consider fuel consumption as the most important attribute and there was some concern that women perceived economy in terms of a fast boiling time and heat retention attributes. Four of the six women preferred the brick basket because it kept the heat in, although two of these women chose to keep the gauze-in-tin stove because it used less charcoal. The other two women chose to keep the three-quarter level grill although one thought that the brick basket was the most economic.

Women tended to make fuel saving claims about the stoves as they tried them, but by the end of the survey they modified their opinions. There was the suggestion that women needed a little time to adjust to the use of a small initial quantity of fuel although none of the Shambat women specifically mentioned this point. Certainly during the second fieldtrip in Sudan, it was noticed that after cooking on a traditional Sudanese stove, the use of one of the new stoves made quite an impact. Immediately, one noticed the difference in the combustion of the fuel in the new stove and the ease of bringing the pot to the boil on less charcoal certainly gave the impression of a noticeable fuel saving. After using the new stove for a few days however, the initial benefits became less prominent and one quickly settled into the habit of using the new stove with little less charcoal at the start. This may explain some of the inconsistency between women's initial impressions and their final evaluation.

Secondly, since the women in Shambat had large families and were heavy consumers of charcoal, the larger quantities of food cooked may have necessitated longer cooking times. Most of the women said that they needed to add a little extra charcoal and it is possible that with a lengthy cooking time some of the fuel saving attributes of the new stoves were lost. On a traditional stove a lot of heat is wasted in
igniting the remaining coals, but once burning well, it would sustain the cooking process until completion. It could be that the long cooking times permitted little overall fuel saving because of the need to add extra fuel. With a large quantity of liquid and foodstuff, there may be greater evaporative cooling since a greater mass spends more time near the boiling point. This would necessitate a corresponding increase in the heat input to effect the simmering process. However, it would not be surprising if the women added more than necessary fuel to the fire to keep it burning at a visibly high rate. This too may have counteracted the initial fuel saving benefits and explain the the high fuel consumption figures obtained from the physical measurements. Women would be impressed by the initial ease and speed of lighting the fire but if they felt the need to keep a good fire burning for a long time, this may not affect much of an overall fuel saving. Economic and efficient use of fuel is in part a function of how resourcefully a charcoal stove is used by the operator.

Thirdly, there is the point that the ease and speed of lighting the fire and bringing the pot to the boil initiated the 'halo effect', in that it influenced other favourable impressions of the stoves with regard to overall fuel consumption. Likewise, this could be true of the heat retention attributes of the brick basket. It is possible that perceptions of a product from England had an influence on women's favourable attitudes. The translator noted that if the stoves had a union jack painted on the side, they would sell very well in the market. This attitude that better products come from Britain may have facilitated the 'halo effect' and hence women's claims to overall fuel saving. From the surveys, this is difficult to establish however.

Despite the complexity of perceptions towards economy and fuel saving, the aesthetic appeal of the brick basket should not be underestimated. Since it is so hot in Sudan, and any means of cooking must be an uncomfortable task, a stove that prevents heat spreading is likely to be very popular.
However, it would appear that for a large pot which sits fairly high above the fire was not a desirable design feature since some heat was lost through the air gaps in the broken bricks. This suggests that the slanting sides of the stove designed to accommodate different sized pots is not optimal, and that a larger pan simply requires a larger stove. However, a solid clay stove may overcome the problem of lost heat through the sides of the stove, which would enable the slanting side design feature to be incorporated.

There was a suggestion that the two tin stoves had too fast a rate of burning yet it is difficult to see that this could be true of the brick basket since there was no hot tin to facilitate a chimney effect.

Several women noted that using their traditional stoves was a habit which they had become accustomed to. Although they preferred the new stoves there was resistance to breaking an established habit. It was also true that the advantages of the new stoves merely reflected the poor state of the women's usual stove. Illham complained that the grate had worn on her traditional stove, but this could have been easily remedied with some of the chicken wire she used to fence her goats.

These points together with the fact that economic use of fuel was not as important as one might have expected warrants some comment. Although meal preparation and fuel use are central to a woman's daily life, this is considered as her duty rather than an area for home economics. The male is the provider and any fuel saving advantage of a new stove would benefit the male provider rather than the woman. In this sexually segregated community, women have little to do with the lives and work of the men. Sometimes the women were uncertain about the monthly income or the price of fuel which the men purchased. Since there is little sharing or joint decision making between husband and wife, there is little joint responsibility for the household economy. The women see themselves as subservient to the male world and their duties of childrearing and meal preparation are part of the domestic role. Perhaps it was too much to
expect women to offer articulated opinions on new stoves when cooking is regarded as a necessary duty rather than an area for better household management. The women are not accustomed to managing their affairs for their own satisfaction but simply to serve the men. In the end, any benefits to the household economy, like economic fuel use or animal husbandry, directly benefits the male wage-earner who can realize a cash saving.

It is the duty of the women to serve the men and meal preparation or the household economy is not regarded as an area for resourceful planning or opportunity. The Shambat women lived in each other's houses and their satisfaction came from their socializing and amusement with female friends and children rather than household management. Significantly, the men showed only a little interest in the survey. The women were not inhibited with the men around but they did behave a little more seriously.

The interviews and physical measurements of fuel use must have had the effect of making women more aware of their fuel consumption which had previously not been as important as their social activities. It is possible that women had little real concept of their usual fuel consumption and this might further offer some explanation for the results. Indeed, it was noticed that women who had passed into grandmother status offered more favourable comments about the new stoves than did their daughters. They seemed to be particularly keen to obtain one of the new stoves for future use. The grandmothers were also more fuel conscious. They had passed through the stage of childrearing and serving the men and held articulated views on the running of the household. That the older women continually pursued the foreigner for a new stove loaned credibility to the fact that a fuel saving of some degree was obtainable with an improved stove.

By contrast, the Jebra women lived in nuclear families usually just with their husband and children. They were
welcoming to the foreign visitor but not particularly excited. Curious, yet open minded towards solar cooking, they undertook the trials seriously. Originally it was hoped that these young families, who had migrated from the rural areas and were hence to some extent socially mobile, would be the most responsive to novel ideas. This would appear to be true. Less rooted in tradition, the women were open to new ideas and change. They spent less time living in one another's houses and compared to the Shambat women, there was less female socializing. The Jebra women were housewives in the Western interpretation of the word since their lives focused on the domestic front rather than entertainment within a female segregated world. The women were easy to interview and since there was less socializing, they seemed uninfluenced by their neighbour's opinions of a particular solar cooker. The answers and attitudes shown during the solar cooker trials are therefore considered reliable. Only in one case did there seem to be any 'halo effect'. The two women who preferred the sun dish had very little space, and initial impressions of the quasi-parabola were unfavourable due to its size. This biased their attitudes towards the functional attributes of the cooker, since it should have been at least as powerful as the sun dish.

Nevertheless, overall, the women gave the solar cooker a fair trial. Considering that the theoretical evaluation of solar cooking established that the collection area was too small to reproduce cooking on a direct heat source, the responses from the consumer survey were very favourable. Originally it was thought that solar cooking could provide a useful complementary means of cooking, and this was confirmed from the trials. Women seemed to prepare a greater assortment of light foods than at first expected. In the preliminary interview to collect background information on cooking habits and fuel use, they claimed to cook twice a day for breakfast and dinner, but the solar cooker trials established that a range of light foods was prepared. It is possible that the availability of a free heat source encouraged them to cook more often, yet several women commented that they were unable to cook after 3.00 pm. This suggests that a cooker able to
accommodate low sun angles in sometimes very windy conditions would be preferable. However, that the women found the solar cookers convenient for a range of light foods supports the findings from the Upper Volta survey, (chapter 8).

During the interview, women qualified their attitudes to solar cooking with reference to the weather conditions. The effects of wind, cloud and dust were seen to decrease the power of the solar cookers. The survey was undertaken during the summer when sand storms were frequent. The unreliability of solar cooking during adverse weather conditions was more of a problem than had been expected.

It must be said that the effects of wind and dust had been underestimated. The cookers needed cleaning daily for optimal performance. With regard to the quasi-parabola with reflective foil, this was a particular disadvantage. The reflectivity of the plastic surface deteriorated much quicker than expected and it is probable that the Heatmirror surface would not have lasted more than a few months. Standard aluminium foil was certainly unsuitable for solar cooking in harsh Sudanese conditions. A reflective surface needs to be very strong and durable. It is therefore likely that only mirror and polished aluminium would be satisfactory for solar cooking purposes. This however has the disadvantage of adding to the cost.

Among the Shambat women, it was noticed that the poorer women were the more fuel conscious selecting the stoves that they perceived to be the most economic. However, with regard to the economic saving that could be realized with solar cooking, this was only a salient point for Fatima, who due to the initiatives taken by herself and her husband to supplement their income, was relatively rich. Among the other Jebra women, the fuel and cost saving attributes of solar cooking were mentioned at some point during the survey but were second to various aspects of convenience.

Convenience in terms of speed to cook and ease of operation
were by far the most important requisites of a solar cooker. However, had the survey been carried out during the rainy season when there is generally a shortage of charcoal and prices are very high, more emphasis might have been given to the economic convenience of solar cooking. Indeed, during the physical testing of the solar cookers, several people from the richer elite class living in Khartoum showed an interest in solar cooking. They liked the concept of using heat from the sun and said that with a solar cooker they could avoid the tedious chore of queuing for butagaz. Again convenience was seen to be more important than any cash saving.

Overall, women's spontaneous opinions of solar cooking were positive but not very enthusiastic. Much prompting was required to obtain explanations and detailed information. However, as the interviews progressed, the women showed themselves to be quite articulate in volunteering more comments. The survey generated a range of opinions to the solar cookers and particularly towards the quasi-parabola. While some women were generally positive commenting on the advantages of solar cooking, others tended to select points of criticism. For example, while some women complained that they did not like standing in the heat of the sun, another said that this was no problem because the cooker could be placed near the shade. While some women appreciated the advantages of a convenient complementary source of fuel for cooking, other tended to emphasize the disadvantage of being dependent on favourable weather conditions. Nadia, Fatima and Zenab were inclined to make the most of the available technology despite its limitations. They evaluated the technology with a positive attitude, while others evaluated the solar cookers as a substitute for the speed and reliability of charcoal cooking. Those biased towards traditional habits held poor perceptions of solar cooking while others were more adaptable to the new technology. It could be that positive attitudes reflected a bias towards technology from England, yet the women were still critical of various aspects of solar cooking.
It would seem that these different perceptions are more a reflection of the women's disposition towards life than any parameter of solar cooking. Perceptions and attitudes are related to values and this was also apparent when the Jebra women tried the improved charcoal stoves. The Jebra women appreciated the significance of certain developments and modifications in the designs in the same way that they were conceived by the author, while the Shambat women tended to favour aspects of convenience and aesthetic appeal.

Perhaps the Jebra women who used less charcoal anyway, and who certainly made efforts to utilize left over fuel, were more economy conscious. Living mostly in couples rather than among members of their own sex, where the domestic duties are shared, it could be that they were more aware of their fuel use than the Shambat women. Taking a personal responsibility for the household economy, they attributed greater importance to fuel saving than to the more aesthetic features of design.

In the other hand, Nadia clearly stated her preference for convenience rather than fuel economy. Again in Jebra, the men were the sole providers and any cash saving from decreased fuel use would be of direct benefit to the male. However, aspects of convenience directly facilitate the woman in her day to day duties and these would be immediately appreciated.

With the exception of Fatima, women had no income of their own. They were generally submissive in the presence of the men and cooking seemed to be more of a chore for some than others. These factors tended to affect women's disposition towards the survey and in their evaluation of the cookstoves. By contrast, Fatima had her own small income and seemed to enjoy a relationship of mutual respect and sharing with her husband, who took considerable interest in his wife's trials of the solar cookers.

Despite the close knit cohesive communities, among which the stoves were tested, it is obvious that one can obtain
slightly different results between different communities. One cannot ignore the social and cultural factors which impinge on women's perceptions of life. Even among the same community, attitudes and values varied affecting the evaluation and use of the new and improved technology. The low self image of women in the male dominant world is a major factor in women's view of their daily chores and the role of technology. The young families living in Jebra were more open and responsive to change than were the Shambat women. Indeed, some of them, Fatima in particular, seemed to share quite Western values.

With regard to cookstoves in Sudan, the appropriateness of a unit was found to be as much a function of various psychological perspectives as simple economic and technical definitions. There was no intrinsic satisfaction in cooking by sunshine that many Western technologists feel, but this reflects a difference in values between two very different types of people. Appropriate cookstove technology for Sudanese women needs to satisfy their particular values and aspirations. Even so, the fact remains that a unit which is useful, convenient and appreciated by one woman will seem an alien piece of technology to another.
CHAPTER 24
CONCLUSIONS AND IMPLICATIONS

Against a background of fuelwood scarcity and increasing ecological problems, the research set out to study the feasibility of solar cooking and effect modifications to the traditional charcoal stove that would ultimately alleviate the demand for fuelwood. The 'appropriateness' of household technology was of particular interest and the research used modified social survey techniques to test the appliances among Sudanese women.

With regard to the charcoal stoves, the research established a methodology for the research and development of several modifications; noticeably, limiting the initial quantity of fuel to a minimum and by various design features obtaining the maximum extraction of heat from this quantity. The laboratory research also showed that in theory greater use of insulation could further improve the available heat to the pan, although insulating devices would possibly make the unit clumsy to use.

In all, three new charcoal stoves were developed and physical tests in the Sudan showed that they all performed fairly similarly.

It was noted that there were a great number of variables in the burning of charcoal in a simple stove and it is possible that a fuller analysis of these variables could lead to further improvements in fuel consumption. However, the research experienced considerable difficulty in quantifying the effects of these fuel saving attributes. Even if simple stove modifications show a significant fuel saving in a laboratory, it is extremely difficult to measure this in the field. There are heavy and light, efficient and inefficient consumers of charcoal, and this research used several quantitative methods to identify a fuel saving among different users. It remains a difficult measurement to take in the field and probably needs to be taken over a long period of time. However, further laboratory experiments
are required to determine the extra fuel needed to maintain the simmering of large quantities of foodstuff, and whether a fuel saving can be realized with prolonged cooking times.

The objectives of a pilot study are to gain insights into subject areas that need fuller exploration at a later stage. One such area is the complexity of women's perceptions to economy. Although the survey covered various aspects of fuel saving attributes, women's choices and preferences were greatly influenced by their first impressions. Since all the stoves performed fairly similarly and preferences were evenly split, it would seem reasonable to give each woman only one stove to try. The test period would have to be long enough to allow each woman time to adjust to using less initial fuel and possibly several interviews at staggered intervals during the test would establish whether perceptions of economy and fuel consumption changed with time. The various attributes of the stoves with regard to economy and convenience need clarifying and a longer study with only one stove is likely to be more fruitful.

However, the survey demonstrated that aesthetic appeal and aspects of convenience were extremely important in the consumer acceptance of improved charcoal stoves. The favourability of the brick basket, an attempt to find a substitute for tin which may become less available in East Africa, has implications for the development of clay stoves.

With regard to the solar cooker trials, the physical tests showed that their performance was less than optimal. Tested during a Sudanese summer, it is unlikely that better solar conditions could be found, yet the cookers failed to reproduce the speed and reliability of cooking on a direct heat source. The use of cheap materials such as aluminium foil was seen to be unsuitable for daily use. Considering the need for strength and durability and women's preference for a solar cooker that could accommodate low sun angles throughout the day, Tabor's cooker made of small shaving mirrors might offer a better technical solution. However, Tabor's cooker would not be very portable.
Considering the limitations of the three solar cookers tested among Sudanese women, responses were quite favourable. Though the solar oven did not fare well in this community, it may well have advantages in more rural areas where women can leave their rice to cook while working in the fields. All the cookers seemed to be reliable in cooking small quantities or light foods and some women appreciated the convenience of having another source of energy to cook with.

As chapter 8 showed, there is now sufficient technology on solar cooking. It is unlikely that any further technical development would facilitate the consumer acceptance of solar cooking. Therefore a realistic appraisal must consider them as a useful convenience for the somewhat better off rather than a solution for the very poor who are short of firewood. Solar cooking does not give reproducible results due to varying weather conditions and they are not suitable for heavy duty cooking.

Both the consumer surveys showed that a wide range of comments and opinions were obtained from very small samples. To gauge the importance and significance of some of the points raised, for example, the desirability of a two pot solar cooker, necessitates a larger sample. On the other hand, a small sample enabled an understanding of each woman's circumstances, lifestyle and values. This was important to evaluate the perceptions of the new technology and is also an area in which further research should be directed.

The complexity of the psychological/technical interface suggests that a serious study start with the social anthropology and social psychology of the people. Having identified some of the important values of both men and women, the application of science to technical problems is more likely to produce acceptable innovations. This is in contrast to the present role of the humanities, which tend to be involved only in the implementation of technology rather than at the design stage. Simple assumptions by Western technologists, for example, that women desire economy above everything else,
are simply unrealistic. The research demonstrated the need for a complete open mind and interdisciplinary approach to the consumer/technical interface. Even so, this research started with a question, "what is appropriate technology?". This question warrants some discussion.

Appropriate technology has captured the hearts and imagination of Western technologists. The application of science as a tool to improve and make more efficient the use of traditional technology was seen to be very feasible. However, it was also found during the consumer surveys that women's attitudes, acceptance and use of the technology reflected their values and perceptions to their world as a whole rather than any aspect of technology. For a Westerner to appreciate a piece of technology as appropriate requires a judgement. He brings his values to bear in his evaluation and these values are a sum total of history in the North/South divide.

Traditionally, appropriate technology has taken a technical and economic definition based on a Western perspective of Third World problems and with Western values. Conceived in the Western world and a result of hundreds of years of education and development, it is not surprising that it is not always esteemed in the same light by Third World peoples. To regard the acceptance of appropriate technology as either a technical or social problem is to ignore the historical, cultural and psychological perspectives which come to bear on the evaluation of a piece of technology.

Values are the instruments by which people interpret and experience their world. For a piece of technology to be accepted it needs to be psychologically appropriate. Technology needs to suit the values of the user. As the research showed, convenience was far more important to the Sudanese women than was efficiency and economy. For the charcoal cookstoves to be deemed convenient they needed to suit the local values regarding the utilization of time and physical comfort. However, with regard to the solar cooker technology, it was discovered that convenience was only perceived by a few women. Selective perception was seen to
be a reflection of women's general attitude towards life.

It has been said that appropriate technology needs to meet the hopes and aspirations of the people. However, as people become better informed and more politically aware, they come to see themselves on the bottom rung of the international ladder and soon come to aspire to Western norms. The acquisition of Western technology and education surpasses any desire to develop indigenous technologies. Perhaps only China has successfully developed appropriate technologies for a peasant population but this involved closing the door to the Western world and massive government organization.

Technical solutions cannot be imposed upon people externally, no more than can political ideologies or social codes. Ideally, technical improvements and innovations need to evolve from the hearts and minds of the people themselves. To be accepted as psychologically appropriate, technology needs to represent a positive enhancement of their simple life and to suit their horizons and self image. Aspiration to Western status symbols and emulation of Western norms will inevitably make simple technical improvements "inappropriate and inadequate".

However, perhaps what is really required is for the West to set an example to Third World countries. The lack of human satisfaction associated with technology in highly industrialized countries renders them psychologically very inappropriate. Furthermore, the pursuit of economic objectives by, for example, treating oil as expendable income rather than capital, is no example to set the Third World. The development of alternative energy sources, such as wind and wave power, and the arrival in Western Germany of 'green politics', which pertains to the view that man must live in harmony with his environment, are the beginnings of such an example, which could conceivably 'trickle down' to Third World policy makers.
At the village level where needs are very simple, and there is no aspiration for superior technology, it is perhaps not surprising that convenience is highly desired. Once basic material needs are satisfied, then convenience is a priority.

On a very personal and individual level, technology needs to represent a positive enhancement of a person's lifestyle, values and self-image, and the in-depth interviews of the consumer surveys enable some statements to be made about the psychological appropriateness of technology. As a woman may choose a dress for covering, style, price, quality etc., these factors alone do not determine the psychological comfort of wearing the dress. In the same way that a dress may 'wear' a woman rather than the woman wearing the dress, technology can 'wear' a person rather than the person feeling psychologically comfortable with the technology. This was seen to be true during the solar cooker survey.

Whereas some women were open and responsive to opportunity and the utilization of a solar cooker to suit them, others perceived only its drawbacks. For several women, the use of a solar cooker suited their existing view of the world reinforcing their already positive attitudes to their lives and household management. The technology was an instrument for enterprise and a useful tool for daily chores. For other women, solar cookers remained an alien piece of equipment which they could not utilize to their convenience and with which they felt uncomfortable.

In short, the appropriateness of technology is very personal and individual. It will be remembered that Fatima's appreciation of the solar cookers not only reflected those of Western enthusiasts, but her comments relating to the science of the quasi-parabola were quite astounding for an illiterate uneducated woman. This almost suggests that appreciation and evaluation of technology touches a metaphysical dimension, which cuts through psychology, values, culture and history, such that the research and development conceived of a Western education can be of immediate recognition.
However, Fatima was an exceptional respondent. She had a very positive disposition to her life and home economy, being motivated towards self help. Her relationship with her husband was also noted as being one of equality and mutual sharing. At one stage during the survey, Fatima demonstrated a local aphrodisiac which she used. It may be that Fatima was one of the few women to escape female infibulation, and this might explain her better relationship with her husband, which would inevitably affect other attitudes towards her life. However, it should be emphasized that this is only speculation.

Overall however, the role of women and female subordination is fairly well documented, but this research has shown how these factors are important in women's view of themselves and their attitudes towards cooking and technology. For the most part, the Sudanese women taking part in the surveys were confined to well defined roles. In Sudanese society, women have no choice and no other expectation but to marry. Marriage is anticipated at an early age and the role of childrearer and domestic is well internalized by adolescence. Central to the female value system is a subservient sexual identity which is enhanced by the practice of female infibulation and Islamic cultural norms.

Against this male orientated background, women have little appreciation of themselves as individuals in their own right. Furthermore, if women fail to have companionship and communication in their marriages, if there is no sharing of responsibility and decision making, it is unlikely that their attitudes towards the home economy and household technology will be orientated towards change and improvement.

Sexual segregation works against social and economic advancement. However, the female identity does not stand alone but mirrors that of the wider male dominant world. It was noted that there were strong currents of fatalism and social obligation in the society as a whole, and this further shapes the attitudes of women. In view of this,
perhaps a future survey of household technology should include the attitudes and views of men rather than the female user only. At present, it is the men who generally make and sell the household equipment. It is also the men who purchase the needs of the family. In short, the man is the 'gate keeper'. A typical Sudanese stove would last about one year. It is not known which partner initiates the decision to purchase a new stove or whether the decision is the prerogative of the male. However, considering the important male role, it would seem that appropriate technologies should be surveyed among the men for their ease of construction and manufacturing as well as among the women for their appeal. Unless the real social issues are recognized, technical innovations designed to help or improve life among Third World peoples will not result in acceptance or implementation.

In summary, the consumer/technical interface was seen to be quite complex. Perceptions of economy with regard to charcoal burning was one such example. The acceptance and 'appropriateness' of technology must account for the values of the people, and it was noticed that convenience was far more readily visible than economy and efficiency. The subordination of women and the role of men were identified as affecting attitudes, values and perceptions to household technology. Several areas for further research were also identified.

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3. The Report of the Independent Commission on International Development Issues under the chairmanship of Willy Brandt; 'North - South, a Programme for Survival'


8. South, June 1982., 'The Devastating Costs of Environmental Neglect'


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APPENDIX I  The Questionnaire on Demographic Data, Fuel Use, Food and Cooking Practices.

Demographic Data

1. How many adult men (over 16 years) live in your house?

2. How many adult women (over 16 years) live in your house?

3. How many children (16 years or less) live in your house?

4. Approximately, how much is your monthly income?

5. Do you keep any animals for milk, eggs or meat?
   IF YES: What animals do you keep?

Fuel Use

1. Do you buy charcoal for cooking?
   IF YES: How much do you usually buy each month?

2. How much do you pay for it?
3. Do you buy wood for cooking your food?

IF YES: How often do you buy wood?

How much do you usually buy?

How much do you pay for it?

4. Do you collect your own wood?

IF YES: Which members of your family collect the wood?

How often do they collect wood?

How much wood do they collect each time?

How long does it take each time?

5. IF BOTH CHARCOAL & WOOD IS USED

When do you use charcoal for cooking and when do you use wood?
Food and Cooking Practices

1. How many times a day do you cook?

2. How often do you reheat food from earlier meals: do you reheat food everyday, every 2 or 3 days or less often?

At what meal do you usually reheat food?

3. When do you cook the main meal of the day?

What sort of food do you usually cook?

How many pans do you use to cook with?

Could you show me the pan(s) you use to prepare the main meal?

MEASUREMENTS:

How many stoves do you use to prepare the main meal of the day?
How long do you spend cooking the main meal of the day?

4. At what time do you cook breakfast?

What sort of food do you usually cook for breakfast?

How many pans do you use this time?

Could you show me the pan(s) you use to cook breakfast?

MEASUREMENTS:

How many stoves do you use to cook breakfast?

How long do you spend cooking breakfast?
APPENDIX II The Questionnaire on the Charcoal Stove Trials

Usage

1. How many times did you use this stove?

2. What did you cook on it?

3. Did you use the stove exactly as we showed you or did you use it differently?

   IF USED DIFFERENTLY: Could you explain how you used the stove?

Opinions

1. What is your overall opinion of the stove?

2. What did you like about this stove?

3. What did you dislike about this stove?

4. How does this stove compare to your usual stove?
5. Do you prefer this stove to your traditional charcoal stove?

Performance

1. How long did it take you to cook your food on this stove?

Was it longer than usual, about the same time, or quicker than usual?

2. How long did the charcoal fire last? Was it long enough to do all your cooking or not?

3. Did you need to add extra charcoal while cooking?

IF YES: How much did you need to add? Was it several pieces, one handful or more than this?

4. Overall, how much charcoal did you use? Was it about the same as usual or less than usual?

Handling and Design

1. How easy was the stove to operate?
2. Did you find the stove dangerous to use?

3. What do you think of the design of the stove? Have you any comments about the size or weight?

Other Comments

IF YES: Could you explain

1. Have you any other comments that you would like to make about this stove?

Have you any comments about this stove?
APPENDIX III  Questions on Charcoal Stove Preference

1. Of all the stoves that you tried, which one did you like best?
   Why did you like that one best?

2. And which stove did you least like?
   Why did you least like that one?

3. Which stove did you feel was the most economical on fuel?

4. Have you any other comments you would like to make about any of the stoves you tried?

5. Finally, which stove would you like to keep?
APPENDIX IV  Questionnaire on the Solar Cooker Trials

Usage

1. On how many days did you use the solar cooker?

IF NOT USED AT ALL:
Why did you not use the solar cooker?

2. How many times a day did you use it?

3. What time of day did you use the solar cooker?

4. What foods did you cook with this solar cooker?

5. For what foods is the solar cooker suitable for cooking?

Opinions

1. What is your overall opinion of this solar cooker?

2. What did you like about this solar cooker?
3. What did you dislike about this solar cooker?

Performance and Handling

1. How long did it take you to cook your food? Was it longer than usual or about the same time?

2. How easy was it to use the solar cooker?

3. How easy was it to reach the pot and stir the food?

4. Did you find the solar cooker dangerous to use?

5. How easy was it to clean this solar cooker?

Features of Design

1. What do you think of the general design of this solar cooker?

   Is it simple or rather complicated?
2. How do you feel about the size of this solar cooker?

Is it too big, about the right size or too small?

3. How easy was this solar cooker to move within your yard?

4. How strong or stable was this solar cooker in wind?

Other Comments

1. Have you any other comments that you would like to make about this solar cooker?

Could you explain?
APPENDIX V  Final Solar Cooker Questions

1. How do you feel about using heat from the sun to cook your food?

2. How does the use of a solar cooker compare with the use of your traditional stove?

3. How did the food taste compared with charcoal cooked food?

4. Which do you prefer, a solar cooker that remains in a permanent position or one that can be easily moved within your yard? Why do you prefer this?

5. Having tried 3 different solar cookers, which one did you like the best? Why did you like this one the best?

6. And which one did you least like? Why did you least like this one?
7. Considering the solar cooker that you liked best, if you could keep it, for what would you use it?

Would you use it for making stew?

Would you use it for reheating food?

Would you use it for boiling water for washing?

Is there anything else that you would use it for?

8. In your opinion, which of these is the most important use of a solar cooker?