Traditional fuels and cooking stoves in developing countries: a technical, social and environmental assessment

Thesis

Traditional fuels and cooking stoves in developing countries - a technical, social and environmental assessment.

A thesis submitted to the Open University in partial fulfillment for a PhD in energy research by Jasvinder Singh Gill, BSc, MSc.

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Energy Research Group/Alternative Technology Group
Faculty of Technology
The Open University
Milton Keynes
England
MK7 6AA

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Abstract

Population pressure in developing countries is believed to be the predominant cause of deforestation, due to the dual needs of food and fuel. This has led to a shortage of firewood (for cooking) and affects especially the rural poor of these countries. One intervention strategy to reduce firewood consumption has been to design, develop and disseminate "improved" (ie fuel efficient) cooking stoves for use in the rural sector. These stove programmes have failed to achieve widespread dissemination of "improved" stoves. One reason is the mismatch between the felt needs and problems of the rural poor and the assumptions of institutions and individuals designing and promoting these stoves. Moreover, traditional stoves and fireplaces are not inherently inefficient for cooking. Not all "improved" stoves have been more efficient than traditional designs in practice. Traditional modes of cooking serve a number of sociocultural and practical functions which have been neglected in stove programmes to date. Stove users in a number of developing countries appear to be more concerned about speedy cooking whilst stove programmes overemphasize fuel savings.

Villagers in Zimbabwe appear to have spontaneously transferred to stoves which consume significantly more fuel than their traditional fireplace. However, this lack of fuel economy is offset by the benefits of faster cooking, greater space heat, more stable pots and a modern "image". The higher firewood collection costs are affordable as this takes place in the agriculturally slack season.

Deforestation is a complex issue to which there are a number of contributary factors. In Zimbabwe, the processes of land degradation, deforestation, and the ensuing shortage of firewood were set in motion as early as the 1890's when the African population residing on the fertile highlands was forcibly evicted onto marginal land by European settlers. Strategies to cope with deforestation in Zimbabwe would be aided by user participation in defining needs and problems within the wider framework of land tenure, agroforestry schemes and inputs to increase the productivity of African areas.

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Chapter 1

ENERGY IN DEVELOPING COUNTRIES

1.0 Introduction

Energy supplies and costs hit the headlines when oil prices rose by a factor of four in 1973-4 (Smil and Knowland, 1980). These events have been seen as marking the transition from an era of cheap coal and oil to an age of high cost energy. By 1980 the price of oil in real terms was five times as high as in 1972 (World Bank, 1980). Although developing countries were adversely affected by the oil price rise, it was only in the mid 70's that the importance in their economies of fuels such as firewood and crop residues was given widespread attention (e.g. Eckholm, 1975; Revelle, 1976) as summarized below.

1.1 Sources of primary energy

Primary energy can be supplied by a number of fuels. Two broad terms used to categorise fuels are "commercial" and "non-commercial". "Commercial" fuels refer to traded fuels such as electricity, coal, oil and gas. The term "non-commercial fuels" is used for fuels which have traditionally been gathered at zero monetary cost in developing countries. Hence, the term "traditional fuels" is often also used (Table 1.1). "Non-commercial fuels" usually refer to fuels such as firewood, crop residues or agricultural waste (ie bagasse, rice straw, maize cobs, maize stalks), and animal manure.

There is some confusion in the literature regarding terms such as "fuelwood", "woodfuel", and "firewood" (Table 1.1). For example, whilst

Table 1.1

Definitions of fuels and energy in developing countries

Term	Source	Referring to:
(a) **wood**	Hughart (1979:8)	"firewood and charcoal"
(b) **fuelwood**	F.A.O. (1983:7)	"firewood, charcoal, crop residues"
	Hughart (1979:2)	"firewood and charcoal"
	Makhijani (1976:22)	"wood, including twigs and forest debris
	Openshaw (1978:72)	"firewood"
	Smil and Knowland (1980)	"firewood"
	U.N. (1981:802)	"firewood"
(c) **woodfuel**	Hughart (1979:1)	"firewood and charcoal"
	Openshaw (1978:72)	"fuelwood and charcoal"
(d) **biomass fuels**	Smil and Knowland (1980:6)	"fuelwood, crop residues, animal manure"
(e) **traditional fuels**	Hughart (1979:1)	"firewood, crop residues, animal manure"
	Makhijani and Poole (1975:1)	(as above)
	Smil and Knowland (1980:6)	(as above)
(f) **traditional fuel sources**	Smil and Knowland (1980:6)	"firewood, crop residues, animal dung"
(g) **traditional energy sources**	Reddy (1979:2)	"firewood, vegetable wastes, dung cakes, coal, electricity, oil, natural gas"
(h) **alternative energy sources**	Reddy (1979:2)	"alternatives to the traditional sources in vogue today"
(i) **organic fuels and non-commercial organic fuels**	Arnold (1979:232)	"woodfuel, animal dung, crop residues"
(j) **renewable biomass sources**	Smil and Knowland (1980:7)	"energy from fuelwood, crop residues, dung"
(k) **non-commercial energy**	Hughart (1979:2)	"energy from traditional fuels, draught animals, human labour, solar energy, wind, hydro plant"
	Makhijani and Poole (1975:27)	"energy from woodfuel, crop residues, dung, animal labour"
	Smil and Knowland (1980:7)	"energy from traditional fuels, draught animals, human labour"
(l) **traditional energy**	Smil and Knowland (1980:6)	see entry under "non-commercial energy"
(m) **non-conventional energy**	Hughart (1979:2)	see entry under "non-commercial energy"

some authors (e.g. Openshaw, 1978:72; Smil and Knowland, 1980:6; U.N. 1981:802) use "fuelwood" and "firewood" synonymously, Hughart (1979:1) uses "fuelwood" to mean "firewood and charcoal". Moreover a recent paper by the F.A.O. (1983:1) refers to "fuelwood and charcoal", and yet later defines "fuelwood" to include firewood, charcoal and crop residues!:

> "Fuelwood: Wood and pulp material obtained from the trunks, branches and other parts of trees and shrubs to be used as fuel for cooking, heating or generating energy through direct combustion, not only in households but also in rural industries (curing, smoking, etc.). Included in this definition are charcoal and agricultural and industrial wood and pulp residues. The large-scale use of wood fuel for industrial purposes, for example in metal-working, is not covered." (FAO, 1983:5)

"Non-commercial energy" usually refers to **energy derived from non-commercial fuels, draught animals and human labour** (e.g. Smil and Knowland, 1980), although, Hughart (1979:2) also includes "solar energy, wind and hydro power" (Table 1.1).

In this thesis, the following terms will be used as defined below:

"Firewood" refers to wood, ranging from small twigs to logs, which is utilized in direct combustion. "Fuelwood" refers to firewood and charcoal. "Crop residues" refers to agricultural residues (e.g. bagasse, rice straw, maize cobs, maize husks) which are used through direct combustion. "Traditional fuels" will be used to collectively describe firewood, charcoal, crop residues and animal manure, when they are utilized in direct combustion. "Non-commercial energy" will refer to energy obtained from draught power, human labour and the combustion of traditional fuels.

1.2 World consumption of energy

According to the Statistical Office of the United Nations (1979, 1981), in 1978, the world consumption of primary energy was just over 9,000 million tons of coal equivalent (mtce). The bulk of the total energy was supplied by commercial fuels (8755 mtce), whilst about 6% (569 mtce) was supplied by fuelwood and bagasse (Table 1.2). Moreover, world consumption of energy is dominated by the developed countries. In 1978, **developed countries** (with 18.5% of the world population) **used over half (56.6%) of the commercial energy** (Table 1.2). Within this group, the U.S.A. (with 5.8% of the population of the world) used 31.3% of the energy from commercial fuels. **Developing countries** (comprising of Africa, Latin America, the Middle and Far East including China and Viet Nam) with 73% of the world population used **20% of the energy from commercial fuels.**

According to data compiled by the United Nations (1979, 1981), over three-quarters (or nine-tenths if China is included) of the total world consumption of firewood, charcoal and bagasse took place in developing countries. (However, nearly all this energy was from firewood alone). These traditional sources provided developing countries with nearly one-third of their primary energy consumption (United Nations, 1979, 1981). However, actual consumption may be even higher owing to the nature of records of the amounts of these fuels collected and used (Smil and Knowland, 1980). For example, data on firewood consumption may underestimate actual consumption by as much as a factor of 2 (Openshaw, 1978).

Table 1.2
Energy Consumption in the World by Source

Region	Commercial energy (CE) consumption (mtce)	(% of total CE consumption)	Energy from firewood, charcoal and bagasse (NCE) (mtce)	(% of total NCE Consumption)	Percentage of World Population
Developed Countries	4953	56.6%	330	5.8%	18.5%
N. America	2736	31.3%	8	1.4%	5.8%
Centrally Planned Europe	2095	23.4%	30	5.2%	8.9%
Centrally Planned Asia[2]	772	8.8%	73	12.8%	22.8%
Developing Countries:	936	10.7%	432	75.9%	49.4%
Africa	82	0.9%	120	21.1%	9.5%
Middle East[3]	153	1.7%	12	2.1%	3.0%
Far East[4]	310	3.5%	190	33.4%	28.6%
Latin America	175	2.0%	101	17.8%	4.5%
Caribbean America	211	2.4%	11	1.9%	3.7%
Total (World)	**8755**	**100%**	**569**	**100.0%**	**100.0%**

Source: adapted data from United Nations (1979, 1981)

Key
1 m.t.c.e. - million tonne coal equivalent
2 principally China and Viet Nam.
3 excluding Israel
4 excluding Japan

The degree of dependence on traditional fuels varies between developing countries (Parikh, 1980). On the whole, Africa is the most dependent on traditional fuels, Asia less so, and Latin America the least dependent (World Bank, 1980).

Attention to this heavy dependence on traditional fuels in many of the developing countries was first drawn by studies in the mid-1970's (e.g. Eckholm, 1975; Revelle, 1976).

1.3 Developing countries: patterns of energy demand in the rural sector

Parikh (1980) estimates that in 1975, 85% of commercial energy consumption in developing countries took place in the urban areas. Traditional fuels are the principal source of energy in the rural areas of developing countries, where 70% of the population of these countries live.

Arnold and Jongma (1978) estimate that in typical villages in developing countries, between 27% and 88% of total energy consumption (including agriculture, lighting and transport) is for domestic purposes (ie for cooking and heating) (Table 1.3). In Bangladesh (Rahman and Huq, 1974), Gambia and Thailand (Openshaw, 1978) over three-quarters of total rural energy consumption is for cooking.

Table 1.3

Energy Budgets of Prototypical Composite Villages in Different[1] Regions (million kilocalories per capita per year)

	Bihar India	E. Hunan China	Tanzanian Plateau	Bolivian Andes	Northern Nigeria
Organic Fuels[2]					
wood fuel	0.25	5.0	5.50	8.33	3.75
other[3]	0.75		-	-	-
Commercial Energy	0.04	0.87	-	-	0.03
Human energy	0.75	0.75	0.75	0.83	0.71
Animal Labour	1.88	1.25	-	2.50	0.18
Total	3.67	7.87	6.25	11.66	4.67
(a) for domestic use	1.00	5.00	5.50	8.32	3.75
(b) for agriculture	1.82	2.07	0.57	1.68	0.72
(c) other[4]	0.85	0.80	0.18	1.65	0.18
Domestic energy	**27%**	**64%**	**88%**	**71%**	**78%**

Source: Arnold and Jongma (1978)
[1]all data refer to gross (input) energy
[2] see "organic fuels" defined by Arnold (1979:232) Table 1.1
[3]animal dung and crop residues
[4]transport, crop processing and so on.

Fuels such as firewood have traditionally been gathered at zero monetary cost by rural women and children (Smil and Knowland, 1980; FAO, 1983:18) - recognition of which has led to the coining of the term "energy gatherers" (Reddy, 1976) to describe the rural poor in these countries. Women in these countries are also generally responsible for cooking using these fuels (Hughart, 1979:3; IEA, 1979:16).

According to Eckholm (1975) and Revelle (1976), cooking absorbs a high proportion of total energy consumption in villages because of the very low efficiency of traditional stoves and fireplaces used in these countries.

1.4 <u>Primary Cooking Fuels: Urban and Rural Sectors</u>

A study by carried out Hughart (1979) for the World Bank, estimated that (in 1976), traditional fuels were the principal source of cooking energy for 2000 million people in developing countries (Table 1.4). The majority of these people lived in rural areas. Moreover, most of the energy supplied by these fuels came from firewood alone.

According to Hughart (1979), the use of commercial fuels for cooking is almost entirely restricted to the urban "non poor" population. For the population of developing countries as income increases there is a shift from firewood for cooking to other fuels such as paraffin and bottled gas (Openshaw, 1978).

There are important differences between the poor in urban and rural areas of developing countries regarding cooking fuels. Firstly, the urban poor generally have to purchase fuelwood (ie firewood and charcoal). Expenditure for fuelwood may represent a significant proportion of the income of the urban poor (World Bank, 1981:40). The term 'non commercial' fuels can be misleading in this situation. Secondly, a substantial proportion of cooking energy for urban users

Table 1.4

World Population by Principal Cooking Fuel
(millions)

	Total	commercial energy	fuelwood	dung and crop residues
Africa South of Sahara	340	35	215	90
Urban non-poor	30	25	5	--
Urban poor	20	--	20	--
Rural	290	10	190	90
India	610	60	290	260
Urban non-poor	60	40	20	--
Urban poor	70	--	40	30
Rural	480	20	230	230
Rest of South Asia	205	25	95	85
Urban non-poor	20	15	5	--
Urban poor	15	--	10	5
Rural	170	10	80	80
East Asia-Developing Pacific	265	95	110	60
Urban non-poor	55	40	15	--
Urban poor	30	15	15	--
Rural	180	40	80	60
Asian CPE's*	855	190	435	230
Urban	205	150	55	--
Rural	650	40	380	230
Middle East - North Africa	200	105	35	60
Urban non-poor	20	70	--	--
Urban poor	20	10	10	--
Rural	110	25	25	60
Latin America & Caribbean	325	230	85	10
Urban non-poor	145	145	--	--
Urban poor	50	25	25	--
Rural	130	60	60	10

*CPE'S - Centrally Planned Economies (ie Centrally Planned: Europe + Asia)

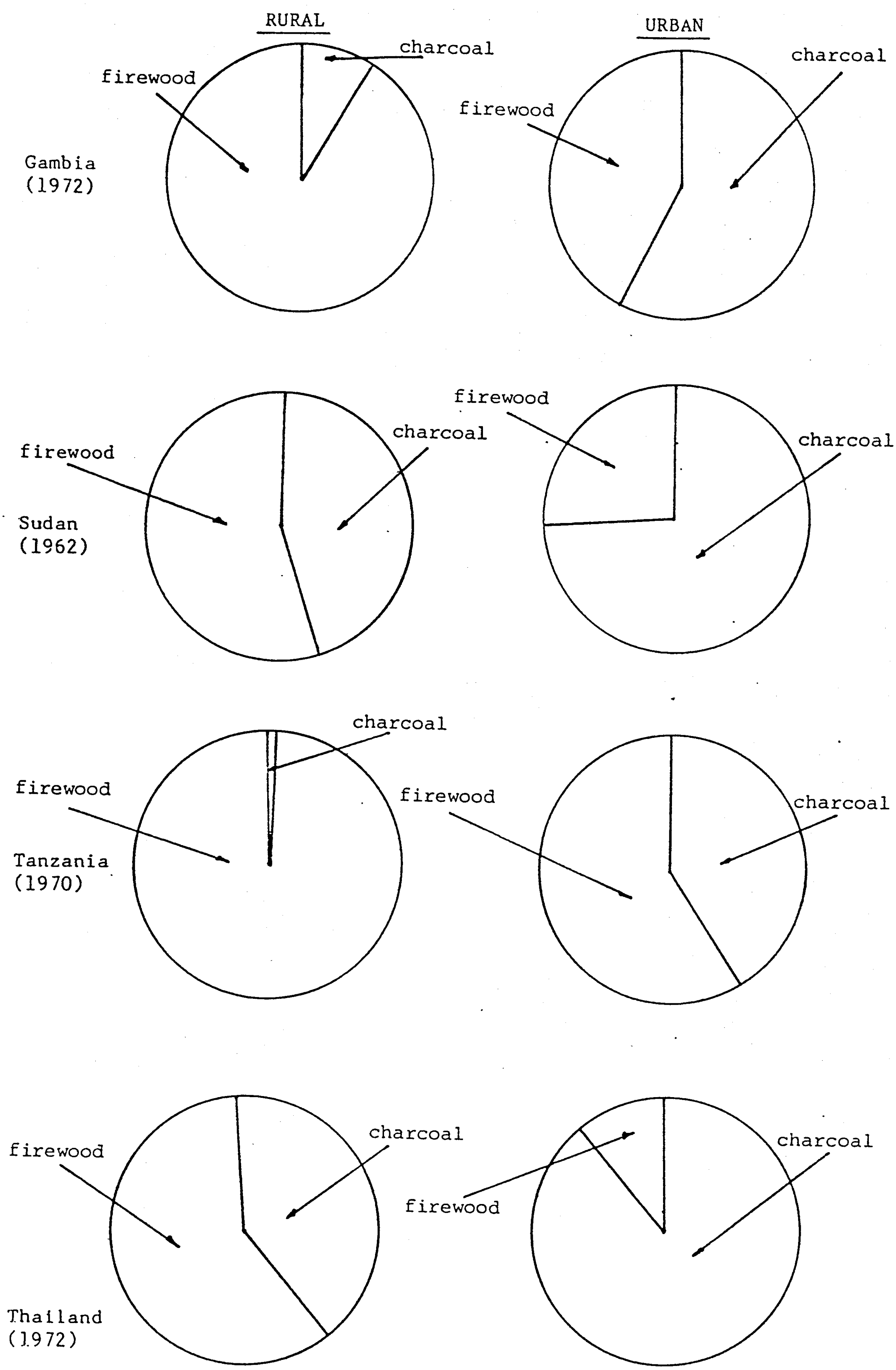
Source: adapted data from Hughart (1979) comes from charcoal, whilst for villagers energy for cooking is provided principally by firewood (Fig 1.1) (Openshaw, 1978).

1.5 Traditional fuels and deforestation

In the mid 1970's, Eckholm (1975), a researcher with the Washington based Worldwatch Institute, argued that deforestation in developing countries had led to an acute shortage of firewood in these countries, and that continued fuel gathering had led to further deforestation. By the late 70's this view was accepted by international institutions:

> "Many developing countries are...facing a second energy crisis which affects particularly the rural sectors of their economies. The magnitude of this fuel crisis is immense" (World Bank, 1980:38)

According to a number of researchers and institutions (e.g. IEA, 1979; Parikh, 1980; Smil and Knowland, 1980; VITA/ITDG, 1980; World Bank, 1980; Kennedy, 1981:33; NAS, 1981a, 1981b; Smith, 1981:31) deforestation was a result of increasing demand for firewood by the rapidly growing population of developing countries. Increases in firewood supply had not kept pace with increases in demand. In the early 1980's a report on firewood in developing countries by the Food and Agriculture Organization of the United Nations (Montalembert and Clement, 1983:119) concluded that the firewood situation in many developing countries was "deteriorating ever more rapidly". The President of the World Bank, Tom Clausen, writing in the 1981 Annual Review of the United Nations Environment Programme (UNEP) declared,



Household Consumption of Charcoal and Firewood (per capita basis)
in Urban and Rural Areas of Developing Countries
(adapted from Openshaw, 1978 in Smil and Knowland, 1980)
Fig 1.1

"Primarily because of the growing need for firewood, third world forests are being cut down ten times faster than new ones are being planted" (UNEP, 1981:171)

Concern about the rapid depletion of forests was also expressed in a report (Campbell, 1984:23), by the Institute of Terrestial Ecology, to the National Environmental Council of the United Kingdom.

According to the World Bank (1980:38), the shortage of firewood affected both the urban and rural poor:

"whereas villagers once usually could find enough firewood near their homes, many must now search for it half a day's walk or more away, and the urban poor must spend large portions of their income on fuel"

According to a number of authors (e.g. Eckholm, 1975; Hughart, 1979; Parikh, 1980; Smil and Knowland, 1980; World Bank, 1980, 1981) responses by villagers to the shortage of firewood have adversely affected food production. In addition, a number of vicious cycle effects have been set in motion, which have led to a deterioration in the supply of both food and cooking fuel:

Parikh (1980:53) reports that as supplies of firewood close to the homestead have been exhausted, the distance to sources of firewood has increased, and collection trips have become more frequent. This means that more time is spent in collecting fuel and has increased the work of rural women and children (World Bank, 1981:40; Joseph and Shanahan, 1981). In order to reduce the task of firewood collection there has been a shift to using animal manure and crop residues as cooking fuels (Kennedy, 1981:33; World Bank, 1981:41; Eckholm, 1984:26). One effect is the diversion of crop residues from animal fodder to fuel, another is the diversion of animal manure from its use as a fertiliser to use for fuel.

Earl (1975:18) reports that using cow manure as a cooking fuel is widespread in households in Bangladesh, India, Nepal, Pakistan and other countries in the Middle East. According to Eckholm (1975:9-10),

> "a visitor to almost any village in the (Indian) subcontinent is greeted by omnipresent pyramids of hand molded dung patties drying in the sun...dung is also burnt for fuel in parts of the Sahelian zone of Africa, Ethiopia, Iraq and in the nearly treeless Andean valleys and slopes of Bolivia and Peru"

Garg (1978:20) estimates that only 5-10% of the population of India used cow manure as a cooking fuel in the early 1900's. However, because of wood shortages due to the forests being cleared for agriculture and trees cut down for fuel, increasing amounts of cow manure were used, and Garg estimate that about 70% of the population used cow manure as cooking fuel by the late 1970's.

In burning animal manure and crop residues, it is argued (e.g. Gould and Joseph, 1978:4; World Bank, 1980:38), that organic fertilizer has been lost, thereby reducing crop productivity. This increases the pressure to bring more land under cultivation (World Bank, 1981:41).

Moreover, according to Dunkerley (1979:360),

> "the diversion of dung from agriculture may require the import of chemical fertilizer or even food grains; and the destruction of ground cover through deforestation may also lead to the import of extra food supplies."

Revelle (1976) reports that the food requirements of a growing population will exacerbate deforestation through the clearance of forest land for agriculture. According to Novak and Polycarbou (1969: quoted in Earl, 1975), the need for food and agricultural land by the growing populations of Asia will mean that there is little land available on which to grow firewood plantations.

According to the analysis outlined above, this shortage of firewood will become more acute. Spears (1978), in a paper prepared for the World Bank, says

> "By the turn of the century, at least a further 250 million people will be without wood fuel for their minimum cooking and heating needs and will be forced to burn dried animal dung and agricultural crop residues, thereby further decreasing food crop yields"

It is regarded as crucial (e.g. NAS, 1981a, 1981b; World Bank, 1980, 1981; FAO, 1983) to intervene in the rural energy systems of the developing countries in order to arrest the continuing ecological degradation and to reverse the deterioration in the supply of firewood.

1.6 Approaches to the cooking fuel problem in developing countries

Responses to the perceived firewood crisis are **supply** and/or **demand** orientated.

1.6.1 Supply based strategies

Supply focussed strategies are aimed at **increasing the supply of fuel.** One method is by increasing the supply on firewood, for example through forestry programmes (Revelle, 1976; World Bank, 1980; Smith, 1981:32).

Another method is **fuel substitution**, whereby commercial fuels are increasingly used to replace traditional cooking fuels. This would parallel the historical shifts from firewood to commercial fuels by developed countries. During industrialization, traditional fuels were increasingly replaced by 'modern' fuels, initially coal and subsequently by oil, gas and electricity. For example, whilst wood provided nine-tenths of the energy consumption of the United States in 1850, by 1955 this had fallen to less than 3% (Melosi, 1982).

A wide range of options regarding commercial fuels have been put forward for developing countries, depending on their energy resource endowments: programmes of growing energy crops (Hammond, 1977; Miccolis, 1977; Goldemberg, 1978), developing coal mining (Revelle, 1976; Arismunandar, 1977), drilling for oil (Rahman and Huq, 1974; Miccolis, 1977) and hydro-electric power (Adelman, 1976; Arismunandar, 1977; Revelle, 1976).

However, according to the World Bank (1980), the sharp rises in the price of oil makes the transition to commercial fuels for villagers in developing countries very difficult. Villagers are likely to be too poor to be able to afford any other but traditional fuels (Arnold and Jongma, 1978). Moreover, if present rates of rural electrification continue, then only 25% of the world's villagers are likely to have access to electricity by the year 2000 (World Bank, 1975). It seems likely that the future fuel supply for the vast majority of the populations of developing countries will continue to be traditional fuels even by the year 2000 (Wood et al, 1980; Venkatasubramanian and Bowonder, 1980).

1.6.2 Demand focussed strategies

Demand based strategies aim to **decrease the demand for firewood** and reduce pressure on forests. Two ways in which this can be done are:

(a) Introduction of "improved" stoves

One method is the **introduction of "improved" (ie fuel efficient) cooking stoves** (Revelle, 1976; NAS, 1981a:viii; World Bank, 1980) to replace traditional types of stove and fireplace. In addition, traditional stoves and fireplaces are said to produce substantial amounts of smoke in kitchens which is damaging to health (e.g. Chrenko, 1967-8; Evans and Wharton, 1977; Goldemberg and Brown, 1978; VITA/ITDG, 1980), hence, the emphasis has been on designing improved stoves which are also smokeless (Raju, 1957; Evans, 1978; French, 1984).

(b) New technologies

In the second category are interventions concerned with the **introduction of new technologies**, principally biogas plants (Brown and Howe, 1978;

Kashkari, 1977), and solar cookers (e.g. Hoda, 1978). Biogas plants produce a gas which is mainly a mixture of methane and carbon dioxide and can be used as a cooking fuel. In addition a fertilizer rich slurry is left which can be used to increase crop yields.

1.7 Expected effects of technical fix interventions

According to a number of authors (e.g. Eckholm, 1975; World Bank, 1980, 1981; FAO, 1983) the rural energy crisis can be contained through a combination of technical strategies such as reforestation and the introduction of 'improved' (ie fuel efficient) stoves.

The widespread dissemination of "improved" stoves is believed to have the following effects: (i) An immediate impact on deforestation (e.g. Goldemberg and Brown, 1978; Attwood, 1980; CSE, 1982). (ii) A reduction in the health risk to rural women working in smokey kitchens (e.g. Raju, 1957; Acott et al, 1980). (iii) A Substantial reduction in firewood consumption in cooking (e.g. Evans, 1978; Bogach, 1981; Ma, 1982). As a result of reduced fuel consumption, the firewood collection burden on rural women and children will be reduced (e.g. NAS, 1981a; Norman, 1981; Prasad, 1982; Howes et al, 1983). Women may then be released to carry out other activities which could raise their income (e.g. Kallupatti, 1957; Soedjarwo, 1982), and hence, increase their economic status, whilst decreasing their dependence on men (Arnold, 1980a). It would also be possible for children to attend school, without depriving rural families of essential labour (e.g. Prasad, 1982). This is in accord with the development objective of increasing the degree of control individuals have over their own lives.

These 'technical fix' strategies make the following assumptions:

(1) there is a shortage of traditional cooking fuel in rural areas of developing countries;

(2) deforestation is caused by the rural populations' use of fuelwood for cooking and other domestic purposes, and exacerbated by population growth;

(3) traditional stoves and fireplaces developing countries are inefficient as modes of cooking;

(4) traditional stoves and fireplaces used in developing countries contribute to the ill health of women because of smoke production;

(5) the low thermal efficiency of traditional cooking stoves aggravates the burden of fuel collection on rural women and children;

(6) It is possible to solve the cooking fuel problem purely by technical fixes.

1.8 Summary

Energy demands in rural areas of developing countries are met primarily by traditional fuels such as firewood, crop residues and animal manure. These fuels have usually been gathered by rural women and children at zero monetary cost, and used for cooking (a task generally performed by women). It has been estimated up to 88% of all energy used in Third World villages is for cooking in the household (the remainder being used for agriculture, lighting, transport, and so on). One reputed reason for such a high consumption of cooking fuel is the very low efficiency of traditional stoves and fireplaces used in these countries. More than 2000 million people in developing countries are estimated to rely mainly on traditional fuels for cooking.

However, increasing demand for firewood and agricultural land by the growing population of these countries has led to increasing pressure on forests, which is widely believed to be leading to deforestation. In addition, the dual pressure for food and fuel has set into motion vicious cycle effects. As nearby firewood supplies become exhausted the work of rural women and children has increased. This has necessitated firewood trips further afield and with greater frequency. In order to reduce the task of firewood collection, there has been an increasing shift to animal manure and crop residues as cooking fuels. Organic fertilizer has thus been lost, thereby reducing potential crop productivity and further increasing the pressure for clearance of forest land. Hence, it is argued that this energy shortage will become more acute.

A number of "technical fix" strategies have been put forward to alleviate the perceived shortage of cooking fuels in developing countries. These strategies aim to reduce demand for firewood (e.g. through the introduction of "improved stoves") or increase the supply of traditional fuels (e.g. by forestry programmes).

1.9 Objectives of the research

The following chapters will critically examine the six propositions outlined earlier (see p17).

1.10 Methodology

This thesis is primarily concerned with interventions to solve the rural energy problem. Domestic energy in the rural sector is supplied primarily by firewood, crop residues and animal manure, consequently, charcoal burning stoves or the problem of cooking fuel in the urban sector will not be considered.

Data to test all the above propositions was gathered by conducting a literature search. Additional information was obtained through a 3 month research visit to a developing country (Zimbabwe) - the detailed methodology adopted is given in Chapter 6. Laboratory tests were conducted to assess the efficiency of two traditional stoves used in developing countries, and a stove which had displaced the traditional fireplace in Zimbabwe - the detailed methodology used is given in Chapter 5.

Chapter 2 assesses the evidence that the rural areas of developing countries are suffering from a shortage of firewood.

Chapter 3 details the strategy of introducing "improved" stoves into developing countries.

Chapter 4 examines the basis of the belief that traditional modes of cooking have very low efficiencies.

Chapter 5 details the results of laboratory tests of thermal efficiency of three cooking 'stoves'.

Chapter 6 presents the results of a pre-feasibility study on the need and the design of "improved" stoves for Zimbabwe.

Chapter 7 draws together the themes that have been running through this thesis, and outlines further work which needs to be done.

Chapter 2

FUEL STRESS AND DEFORESTATION IN DEVELOPING COUNTRIES

2.0 Introduction

The previous chapter has shown that according to organizations such as the F.A.O. (1978:13) and the World Bank (1980:38), the growth in the population of developing countries has lead to deforestation. As a result of deforestation, developing countries suffer from an acute shortage of firewood, especially in the rural sector. This chapter examines the evidence of fuel stress in the rural sector of developing countries and whether the demand for firewood by the rural population is the major cause of deforestation.

2.1 Evidence of firewood shortage

It is widely believed (see Chapter 1) that the rural poor in developing countries are experiencing a shortage of firewood for the following reasons: increases in the time spent in firewood collection, a shift in the type of food crops grown, changes in cooking practices, a shift to "inferior" cooking fuels and deforestation. The following will examine the evidence for each of these.

2.1.1 Increased time spent in collecting firewood

Estimates of the time spent per family in firewood collection vary between 50 and 300 days per year in India (Makhijani, 1977:1459) and between 200 and 300 days per year in Tanzania (per family of five) (Workshop on Energy for Rural Communities in Tanzania, 1980). Another estimate has put the time spent in collecting firewood in India at between 200 and 300 days (Vita/ITDG, 1980:1). The basis of these estimates is not given.

Village level studies have been carried out in which the time spent in gathering firewood has been measured: on average 16 hours were spent per family per week in firewood collection in Ungra village (in south India) (Reddy, 1979). In Kwenzitu, (NE Tanzania), the time spent per family per week in firewood gathering was found to be between 4 and 12 hours (Fleuret and Fleuret, 1978); these values did not take time spent by children into account. Similar values of between 4 and 10 hours per week per family were obtained for Nyakusa village (Brush, 1977) in Tanzania. Assuming 52 weeks per year and 8 hours per working day, means that on average 104 days are spent collecting firewood per year per family in Ungra village. The minimum time spent in both Tanzanian villages per family per year is 26 days and a maximum of 65 and 78 days for Nyakusa and Kwenzitu respectively.

It is not possible though, to determine how the firewood collection "burden" has changed without data on time spent in gathering firewood in the past.

Some authors have pointed to a dramatic rise in the time spent in firewood collection in the space of one generation:

> "deep in the once heavily forested Himaylayan foothills of Nepal, journeying out to gather fuelwood and fodder is now an entire day's task. Just one generation ago the same expedition required no more than an hour or so" (Bishop and Bishop, 1971)

It has not been possible to obtain the data upon which this statement was made. The extent to which this change is representative of other parts of Nepal or other developing countries is not known.

In any case it has been assumed that firewood collection is always a burden. The following will show that this issue is not so clear cut: perceptions of the task of gathering fuels such as firewood are not coherent. On the one hand, fuel collection has variously been described as "an odious task" (Goldschmidt, 1951:412), "a lowly and endless process" (Kroeber, 1951:156), and "a distasteful chore" (Holmberg, 1950:41) (all cited in Heizer, 1963:189).

It was reported, at a workshop held in Tanzania in 1974 for extension workers, that two of the tasks regarded as being most burdensome were cooking with traditional equipment and fires, and collecting wood (UN Economic Commission for Africa, 1975:22, cited in Martin, 1979:62). **This information is not reliable unless reported by the villagers themselves.** However, it is not known whether this was reported by villagers or not.

In some instances, firewood collection is said to be an enjoyable activity. For instance, an anthropologist working with Mayan Indians in Mexico, commented how she,

> "had never really understood why the women did not seem to mind going to the woods; the immense loads of firewood they brought back looked painful to carry on their tump lines (ie rope used to tie the bundle of firewood) their foreheads straining against the rope. The little children also seemed to love going to the

> woods ... The trip was a mixture of work and play ... (and she was later told that) ... when women go to 'lenar' (ie get wood) it is an outing - a group experience. 'The women love it ... They are free in the woods'" (Elmendorf, 1976:28-29).

Similar observations were made in an earlier study of Mayan Indians in a Tzeltal village, in Mexico. The study helps shed more light on this, since it seems that once a women is married,

> "she is expected to keep her social life within the boundaries of her husband's circuit ... except for gathering firewood, a woman has few chances to go out of the compound" (Hunt, 1962:143-144).

Hence, it may not be the task of collecting firewood in itself which is enjoyed but rather that

> "going to gather wood is a very nice break in the routine and women usually go in the company of other women with whom they chat, exchanging news and gossip" (Hunt, 1962:144).

It has also been argued that there is no point in reducing labour time spent in firewood collection, since there is no alternative work to be done by the rural poor (Desai, c.1978). In addition, the task of firewood collection may be done in conjunction with other activities. For example in Uchucmarca village in the Peruvian Andes, women's gathering trips are combined with tending food crops in daily trips to cultivated fields (Brush, 1977:77). Hence, any measure to reduce firewood consumption would not necessarily lead to a reduction in time spent in firewood collection. In areas of high fuel stress the savings in firewood, brought about by more efficient cooking methods may result in increased profligacy of firewood consumption as people may consider other benefits such as increased space heating or returning to the original diet which had had to be abandoned owing to firewood scarcity.

It also has to be borne in mind that firewood collection is not the only contribution to the burden of rural women (this is examined in more detail for Zimbabwe in Chapter 6), nor is it only women who collect firewood; men and children can also be involved (Wood et al, 1980).

2.1.2 A shift in the types of food crops grown

According to the FAO (1978:15), the major problem in introducing more nutritive crops in some areas of Haiti is that they would require more cooking. In the uplands of Nepal, farmers are said to be only growing vegetables which can be eaten raw (FAO, 1978:15). In addition,

> "the cost and scarcity of firewood have forced Nepalese women to include more raw grains, vegetables and nuts in their diet ... the women of Sahel are switching from millet to rice **since rice takes less time to cook**" (Srinivasan, 1980:17) (emphasis added)

However, this shift to rice from millet may have been to save time rather than simply to save firewood: a number of programmes to disseminate "fuel efficient" stoves have found that women prefer to have stoves which will allow them to cook more quickly (Gern et al, 1981; Howes et al, 1983; Joseph, 1983) - in some cases even at the cost of greater fuel consumption (see Chapter 6).

2.1.3 Change in cooking practices

A similar shift in diet has also been reported to occur in in West Africa and meals are being cooked for less time (Hoskins, 1980 cited as pers comm in Novick, 1980). According to the FAO (1978:15) in areas of West Africa suffering from "serious shortages of firewood" villagers have only one cooked meal each day instead of two. The reduction in cooking time and number of meals will affect nutrition. It is not known whether the change in diet is for better or worse.

2.1.4 A shift to "inferior" fuels

It has been argued that as nearby supplies of firewood become exhausted villagers begin to turn to "inferior" fuels such as crop residues and animal manure. The following will show that the situation is much more complicated and that use of crop residues does not necessarily mean that villagers are under fuel stress. Crop residues may simply be used in seasons when they are available. In addition, some villagers perceive certain advantages to using crop residues.

Seasonal variations occur in the type fuel used for cooking, have been reported for a number of developing countries: Bangladesh (Islam, 1980), Burkina Faso (formerly Upper Volta) (Ernst, 1978), Peru (Skar, 1982), Sri Lanka (Howes et al, 1983; Stewart, 1983), Zimbabwe, (Gill, 1982), Brazil, Mexico and Tanzania (Wood et al, 1980:32-33).

In Bangladesh, firewood is the principal cooking fuel during the rainy season, and collected by the men, whilst crop stalks are used as the main fuel source during the dry season. Firewood is collected over a period of fifteen days and stored, while the collection of crop stalks is carried out by the women and children, and is a daily task (Islam, 1981: pers comm). Similarly, in Burkina Faso (formerly Upper Volta) millet stalks are used from November (at the end of harvest) through to May. Wood is used from around late April or early May. Collection of wood occurs once or twice a day in order to stock up for the rainy season (Ernst, 1978).

Seasonal variation in the type of fuel appears to be linked to agriculture, as well as increased accessibility of areas of sources of firewood (Wood _et al_, 1980). Labour requirements for agriculture in developing countries show a marked variation over the year. Ploughing, weeding and harvesting all have a high labour requirement. At these times, little spare labour may be available for activities such as firewood collection. Villagers can overcome these problems by strategies such as storing fuels collected during the slack season and/or using alternative fuels such as crop residues which are readily available after harvesting.

Variation in agricultural labour demand may be important in the patterns of collection and use of traditional cooking fuels, or in the acceptability of alternative fuels. In recognition of this, biogas plants in Haryana State in India were installed during the agricultural slack season (in this case November to March) - a time when both the farmers and departmental officials were relatively free (Moulik _et al_, 1978:75).

Villagers attitudes to using different cooking fuels vary: on the one hand, in north-east Ghana, women do not like using millet stalks, because they burn faster than wood, and require a lot of attention.

According to the women the firewood was either "too expensive", "in short" supply or simply "too far" away (Martin, 1979:42).

Additionally,

> "nearly three fourths of the women who cook with firewood or with stalks said they would prefer using another fuel, at least to prepare foods such as soup, stew, or tea" (Martin, 1979:29)

However, in Burkina Faso (formerly Upper Volta) villagers prefer millet stalks to firewood because

> "the stalks weigh no more than wood, and they are found in fields next to the women. There is no need for stocking unlike wood, and the millet stalks can be collected either several times a day, for each meal, or as needed" (Ernst, 1978:3).

Village women said it took less time to collect millet stalks compared with wood, and the stalks could be much more easily broken up than wood, as well as be collected by children. This gives the women more time to undertake other activities, such as spinning. Whilst millet stalks burn much faster than wood, it is not regarded as a problem, as the rate of burning can be slowed down by wetting the stalks (Ernst, 1978:4).

2.2 Deforestation

Trivially, deforestation can be defined to occur when the rate of depletion of forests is greater than their rate of regrowth. However, forests must be seen as the terminal stage of plant communities, from grassland through scrub, secondary and then primary forests. Deforestation occurs when this succession is reversed, for example, when firewood collection causes the succession to reverse and create an environment dominated by scrub, grasslands or crops. Productivity is usually greatest at the early stages of succession (Odum, 1969). This is shown in European practices of pollarding and coppicing.

Firewood collection by the rural poor has been cited as a major cause of deforestation. It is not within the scope of this thesis to consider deforestation in developing countries in any depth. The following will show that the situation is very complicated and that there are a number of contributions to deforestation and related issues (e.g. soil erosion, falling crop productivity, the increased incidence of flooding and so on).

It has been argued that,

> "as a rule, the poor do not cut whole trees for fuel much less entire areas. Most fuelwood consists of twigs and small branches. Moreover, a great deal of this does not come from the forests, but rather from trees planted near people's homes, on field bunds, willage common lands and roadsides" (Makhijani, 1979:24).

There is evidence to support this view: in Central Java between two-fifths and four-fifths of fuelwood came from trees and shrubs in home gardens and between one-fifth and two-fifths from dry-land farming areas. This left only between one-twelfth and one-fifth from forests, roadside trees and so on (Wiersum, 1976, quoted in Arnold and Jongma, 1978).

In addition, Makhijani goes on to say that

> "population growth also seems to be a relatively minor factor. The increase in deforestation has been sudden and faster than population growth. Moreover, people usually do not clear entire areas of forests because of fuelwood needs. The devastation of forests in many regions, where forests have been entirely or largely wiped out, clearly point to other causes...large scale commercial clear-cutting for timber and fuelwood by governments and private contractors is one of the major causes." (Makhijani, 1979:24).

Supporting this view, is that in India,

> "there is some evidence that timber contractors are permitted to engage in overcutting, especially in tribal areas" (Adams and Tyner, 1977:79).

Deforestation in Central America has been linked to cattle ranching to produce cheap hamburgers for the North American market (Myers, 1981); commercialization of the forests in West Bengal has led to their disappearance (Raman, 1982); extreme forest damage has been incurred in Indonesia as a result of logging operations (Kartawinata <u>et</u> <u>al</u>, 1981); in the case of the Sahel environmental degradation appears to be a consequence of the peanut production system (Franke and Chasin, 1981).

Other contributions to stress on forest resources include tree felling for export (Sardar, 1981; Francois, 1977), road construction (Zerbe et al, 1980), shifting cultivation practices (often now ecologically disastrous owing to a perversion of traditional practices whereby rotation cycles have been compressed) (Ashish, 1979, 1980; Digernes, 1978), charcoal production (Martin, 1979) which is used mainly by urban dwellers (Steckle, 1972; Martin, 1979).

In Bangkok, charcoal consumption in 1972 was equivalent to 3 million cubic metres of wood (Arnold and Jongma, 1978:233). According to Arnold and Jongma (1978:233) tobacco production in Malawi accounts for one million cubic metres of firewood, representing 17% of the total annual energy consumption. The energy demand for tobacco curing in Malawi was rising much faster than household demand for firewood.

Moreover, when looking at any country or region in detail it becomes increasingly obvious that the situation is very complicated. A case in point is that of Zimbabwe, (this is examined in more detail in Chapter 6), where deforestation in the rural areas appears to be a consequence of extension of land for agriculture not firewood gathering activities. However, this pressure on land is embedded in the political economy, whereby a growing African population was forcibly evicted in the 1890's from the fertile highlands and artificially constrained to "reserves" - this led to increased man/land ratios and to both soil erosion and environmental degradation leading to vicious cycle effects (Ndlela, 1981). Bunker (1981) similarly links the political economy of Brazil to the destruction of Amazonia.

2.3 Conclusions

Whilst there may be shortages of firewood in certain countries or areas it is not a universal phenomenon. Issues related to the collection and consumption of traditional fuels are more complicated than has been assumed. For example, firewood collection is not always regarded as a burden, and the causes of deforestation are manifold requiring detailed study.

The next chapter looks in detail at the strategy of reducing firewood consumption through the introduction of "improved" cooking stoves.

Chapter 3

"IMPROVED STOVES": PROBLEMS AND PROMISES

3.0 Introduction

The previous chapter has shown that there are a number of contributory factors in deforestation, and that the issue of traditional fuels in developing countries is more complicated than assumed by many observers.

Traditional stoves and fireplaces commonly used in developing countries are believed to have both low cooking efficiencies and contribute to poor health because of smoke produced in the kitchen (Raju, 1957; Eckholm, 1975; Knowland and Ulinski, 1979; Baron, 1980; Siwatibau, 1981). In order to eliminate smoke from traditional kitchens - for reasons of health - and reduce consumption of firewood, much effort has been devoted to designing and disseminating stoves which are both smokeless and more efficient than traditional designs. These are generally referred to as "improved" stoves. It was believed that if these "improved" stoves could be adopted on a widespread scale, then firewood consumption would fall, thereby reducing the pressure on forests (e.g. Makhijani, 1976: 24-26; Salariya, 1983:4). This would increase the chances of success of solutions concerned with increasing the supply of firewood, e.g. reforestation, agroforestry, silviculture.

Other aims of stove programmes have been to improve women's health through their working in a smoke-free kitchen and a reduction in time spent in cooking and collecting fuel (Acott et al, 1980; Soedjarwo, 1982; UNICEF, 1982). Women could spend the time saved in economically productive activities (Arnold, 1980a). In order to have a significant effect (on health and firewood consumption), the dissemination of "improved" stoves must occur on a large scale.

This chapter identifies the various "improved" stoves that have been promoted for the rural sector of developing countries and the reasons why these stoves have not been able to displace traditional designs to any extent. This chapter is concerned principally with the proposition that "improved" stoves save firewood (compared with traditional stoves) and for that reason will be desirable to the rural poor.

This chapter is divided into several parts: first the various types of traditional stoves and fireplaces used in developing countries are considered; section 3.2 introduces efficiency concepts in the context of cooking stoves; section 3.3 details methods to determine the efficiency of cooking stoves and measurement of of firewood consumption in the field; section 3.4 examines reasons for disseminating "improved" stoves; section 3.5 looks at the various types of "improved" stoves; section 3.6 examines reasons for the general failure of "improved" mud stoves to achieve widespread dissemination; section 3.7 examines the response of improved stove promoters in both Sri Lanka and Indonesia to the problems of dissemination and their early experience in promoting "improved" ceramic (or "pottery liner") stoves.

3.1 <u>Different Types of Traditional Stoves and Fireplaces Used in Developing Countries</u>

In this thesis, 'traditional' stoves and fireplaces will be used to mean open fires (and variations), and mud/clay stoves which are widely used in developing countries today, (most of which have been in use for many centuries). "Improved" stoves are those which have specifically been promoted in developing countries, on the basis of being smokeless and a reputedly high cooking efficiency e.g. HERL chulha, Lorena stove, Magan chula.

Stoves may be classified in a variety of ways, for example stove types may be categorized in terms of stove material, and/or the number of pot holders. In the following classification stoves and fireplaces will be divided into three categories: open fires (usually with the addition of rocks or stones); mud/clay stoves; below ground/pit stoves. The list presented here is neither exhaustive nor exhausted. Details of many stoves not included here are given in the other literature on stoves (e.g. Joseph et al, 1980; De Lepeleire et al, 1981; TERI, 1982; Foley and Moss, 1983).

3.1.1 Open fire with the addition of rocks or stones

(a) open fire + three legged pot

One of the simplest arrangements is a fire under a three legged pot (Fig 3.1). This method of cooking was observed (Best, 1979a:32) in three villages in South Africa (Natal and the Eastern Cape) and Lesotho.

(b) 'three-stone' fireplace

Open fires with rocks or stones which act as a support for the cooking utensils are very widespread. The most common arrangement involving an open fire in conjunction with supporting rocks or stones is the 'three stone' fireplace (Fig 3.2). This has been observed in parts of Latin America, Bangladesh, and much of Africa (Table 3.1)

Table 3.1
Traditional Cooking Stoves and Fireplaces

'Stove'	Where Observed	Source
Open fire and variations		
(a) 3-Stone fireplace	Ghana	(Martin, 1979:63-64)
	Nigeria	(Ay, 1978:27)
	Tanzania	(Mnzava, 1980:99)
	Zimbabwe	(Ascough, 1981)
		(Gill, 1982, 1983)
	sub-Saharan Africa	(FRIDA, 1980:44)
	Upper Volta	(Ki-Zerbo, undated)
	Dori	" "
	Niger	" "
	Sahel	" "
		(Norman, 1981:3)
	West Africa	(Asare, 1976:23)
	Guatemala	(Evans, 1978)
	Ecuador	(Moran, 1981)
	Indonesia	(Singer, 1961:24-28)
	Bangladesh	(Islam, 1980:III-4)
(b) 'Two Stone' fireplace		
	Fiji	(Weir and Richolson, 1980; Siwatibau, 1981)
	Malaysia	(Ohlsson and Purvis, 1972)
(c) two bricks + iron bars as supports	Ecuador	(Moran, 1981)
Clay/Mud Stoves		
(a) 'U' Chulha	India	(Rao, 1962)
		(Salariya, 1978)
		(Jajodia, 1980)
	Sri Lanka	(Stewart, 1983)
(b) Mud wall + iron bars	Mexico	(GATE, 1980)
(c) two/three hole stoves	Indonesia	(Singer, 1961:24-28)
	Java	(" " ")
	India	(Geller, 1980; 1982)
Below Ground/Pit Stoves		
(a) earth oven	Oceania	(Gould and Joseph, 1978)
	Pacific	(Kuper, 1977:212)
	Mexico	(Elmendorf, 1976:31)
(b) Bangladeshi pit chulha	Bangladesh	(Islam, 1980:III-4)

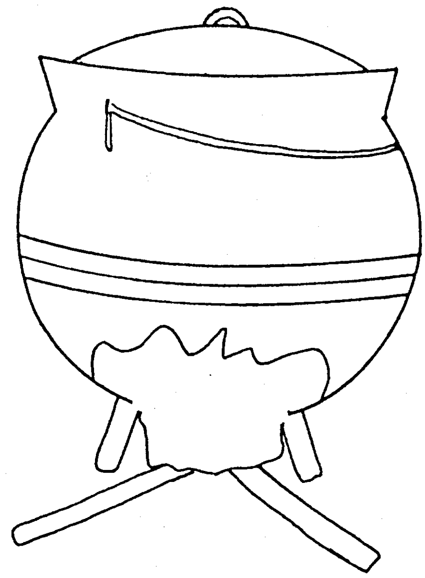


Fig 3.1   Fire under 3-legged pot
(Best, 1979a)

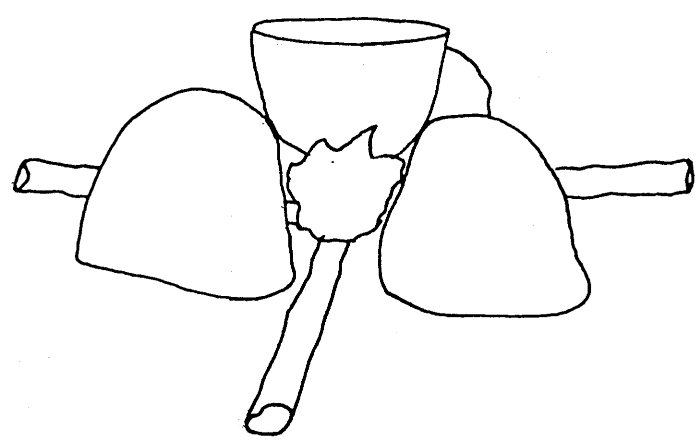


Fig 3.2   3-stone fireplace

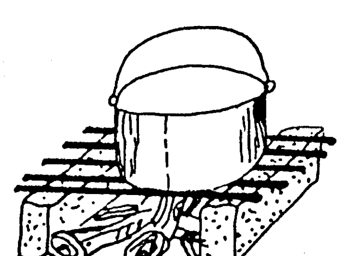


Fig 3.3   Ecuadoran 2-stone method
(Moran, 1981)

During the cooking process the firewood is continuously fed into the fire. The power output (burning rate) can be controlled by moving the fuel in or out of the burning fire. In villages around Ibadan in Nigeria the size of these sticks is commonly a metre or more in length (Ay, 1978:27).

The size of the supporting rocks vary depending on the size of the cooking utensil: small stones being used for small pots and large stones for large pots; in Zimbabwe small pots may be placed directly on the burning firewood rather than the stones (see Chapter 6). Sometimes mud is placed between the supporting rocks to act as a wind shield (Martin, 1979:64).

Cooking may require more than one utensil to be heated at the same time. This can be achieved in a variety of ways. The three-stone fireplace may with the addition of a two more rocks, (at zero cost), become the "five stone" fireplace. This enables two pots to be heated at the same time. This arrangement is frequently observed in sub-Saharan Africa (FRIDA, 1980).

In rural areas of Guatemala the most common traditional method of cooking is the 3-stone fireplace, though cooking is sometimes done over a "primitive iron grill" (Evans, 1978:3). According to Evans (1978) the "rising middle class" either buy a propane stove or build a "poyo" - a brick cooking platform with a cast iron plate and chimney. Evans (1978) reports that the fireplace is usually on the floor and sometimes on a raised platform. However, the opposite was found in a survey of 1000 households conducted in Guatemala by Bogach (1981:2.19): only one-fifth of the families used an open fire on the floor whilst nearly two thirds cooked on an open fire on a raised platform.

(c) Fijian Traditional "Open Fire"

A traditional arrangement in Fiji (Siwatibau, 1978, 1981; Weir and Richolson, 1980:9) involves placing iron bars across two large stones. Moran (1981) reports a similar method for supporting the cooking pot in Ecuador (Fig 3.3).

3.1.2 Mud Stoves

(a) One-Pot Stoves

Indian 'U' Chulha

The Hindi word for stove or fireplace is "chulha" (also spelt chula, chulah and choola), and has been absorbed in the literature on stoves throughout the world. In this thesis the words "chulha" (and derivatives) and "stove" will be used interchangeably. A variety of chulha's are used in India. The simplest is a small horseshoe-shaped structure (Fig 3.4) made out of brick or mud (NCAER, 1959; Salariya, 1978, 1983). This can be regarded as a simple wind shield.

'Madura' and 'Keren' Stoves

Two simple one-pot stoves observed in East Java (Singer, 1961) are the 'Madura' (Fig 3.5) and 'Keren' (Fig 3.6) stoves.

Portable Bangladeshi Chulah

A portable chulha has been reported to be used in Bangladesh (Fig 3.7) (Vita/ITDG, 1980), and Indonesia (Singer, 1961).

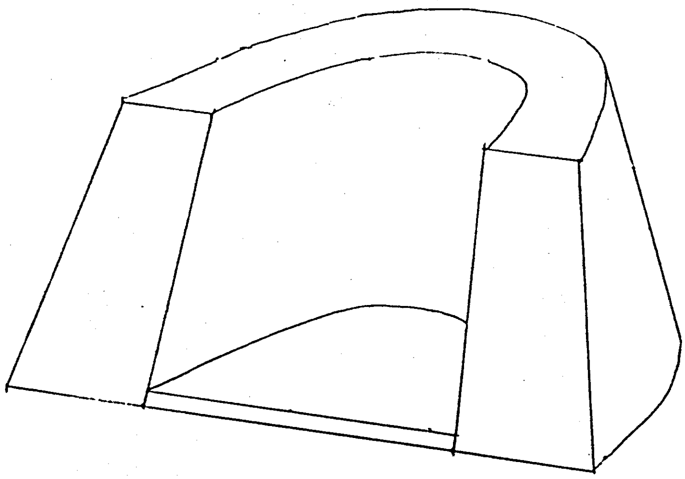


Fig 3.4 Indian 'U' chulha

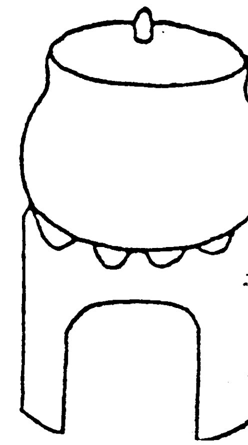
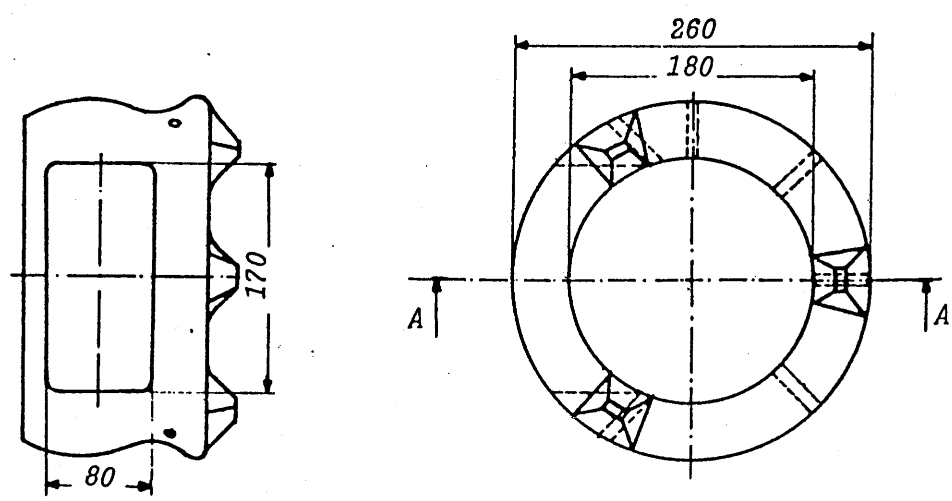


Fig 3.5 Madura stove
(Singer, 1961)



(all dimensions in cm)

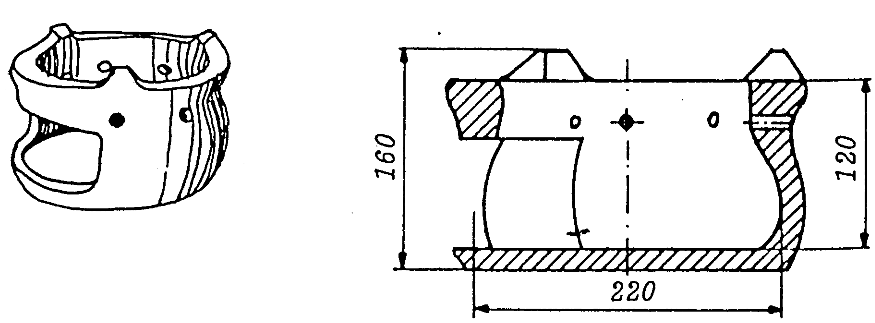


Fig 3.6 Keren stove
(De Lepeleire <u>et al</u>, 1981)

section A-A

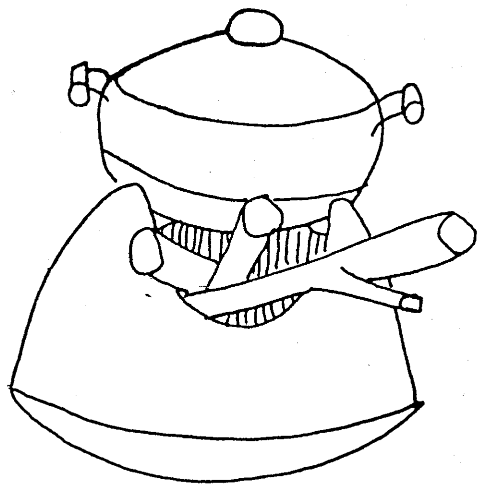


Fig 3.7 Portable chulha
(VITA/ITDG, 1980)

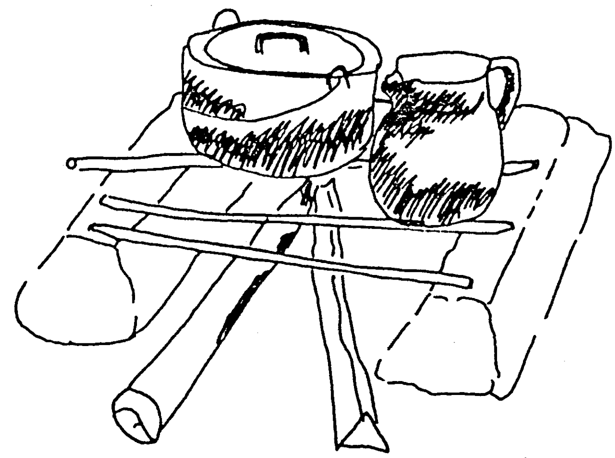


Fig 3.8 Mexican mud wall
(GATE, 1980)

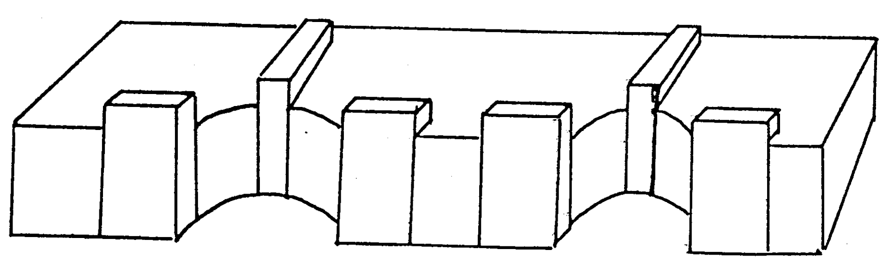


Fig 3.9 Twin 'U' Sri Lankan chulha
(Howes et al, 1983)

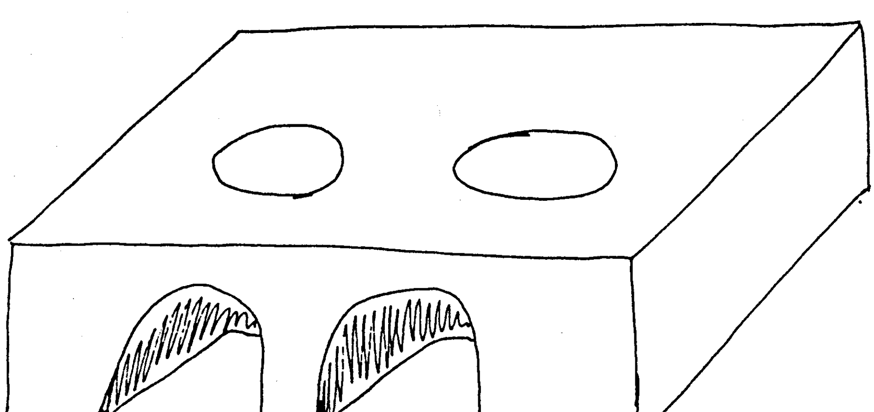


Fig 3.10 Twin fireplace chulha
(TERI, 1982)

(b) Multi-Pot Stoves

There are a variety of mud stoves on which several (usually two or three) cooking utensils can be heated simultaneously. These types of stove are reported in the literature predominantly for Asia (see below).

A design similar to the 'U' chulah has been reported for Mexico, and will support several cooking utensils. This design utilizes a low 'U' shaped mud wall and metal bars (Fig 3.8) (GATE, 1980:23). A twin 'U' chulha is traditionally used in Sri Lanka (Fig 3.9) (Howes et al, 1983; Stewart, 1983)

A stove with two openings the "Twin fireplace Chulah" (Fig 3.10) has been observed in some rural parts of India (Jajodia, 1980). Other traditional two-hole stoves are used in West Java (Fig 3.11) (Singer, 1961) and India, (Fig 3.12) (Dutt, 1978, in De Lepeleire et al, 1981:139).

Another two pot stove is the Tungku Muntilan (Fig 3.13). The second pot seat of this stove acts as a chimney. This stove is built by artisans in central Java and Indonesia and used in domestic cooking as well as in restaurants and for processing food (Joseph et al, 1980). The size of these stoves vary in size from 30 x 15 x 15cm to 120 x 50 x 70cm. A stove 65 x 33 x 22cm weighs about 20kg. The lifetime of this stove is estimated to be up to 10 years.

Traditional three-hole stoves have been observed in India (Fig 3.14) (Dutt, 1978, in De Lepeleire et al, 1981:139), Indonesia (Fig 3.15) (Singer, 1961) and Egypt (Fig 3.16) (Theodorovic, 1954).

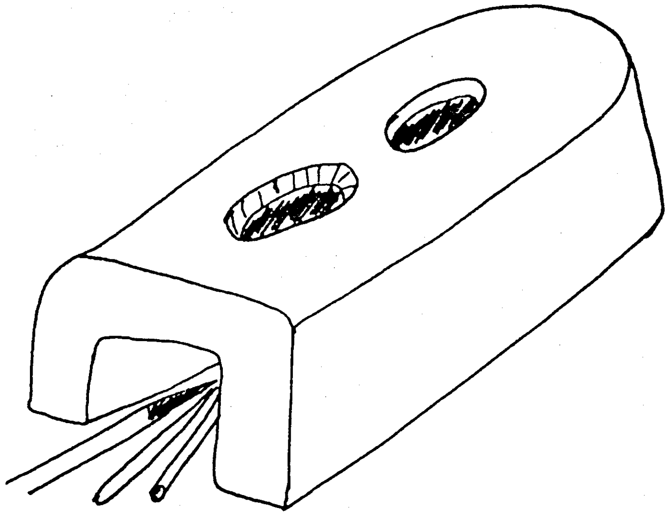


Fig 3.11 West Jave 2-pot stove (Singer, 1961)

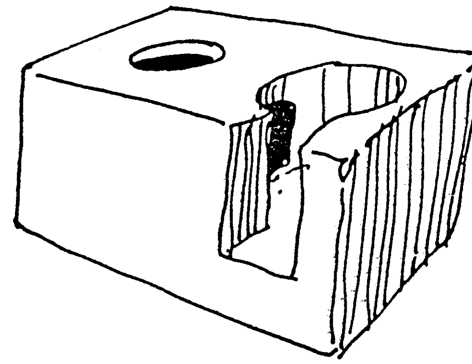
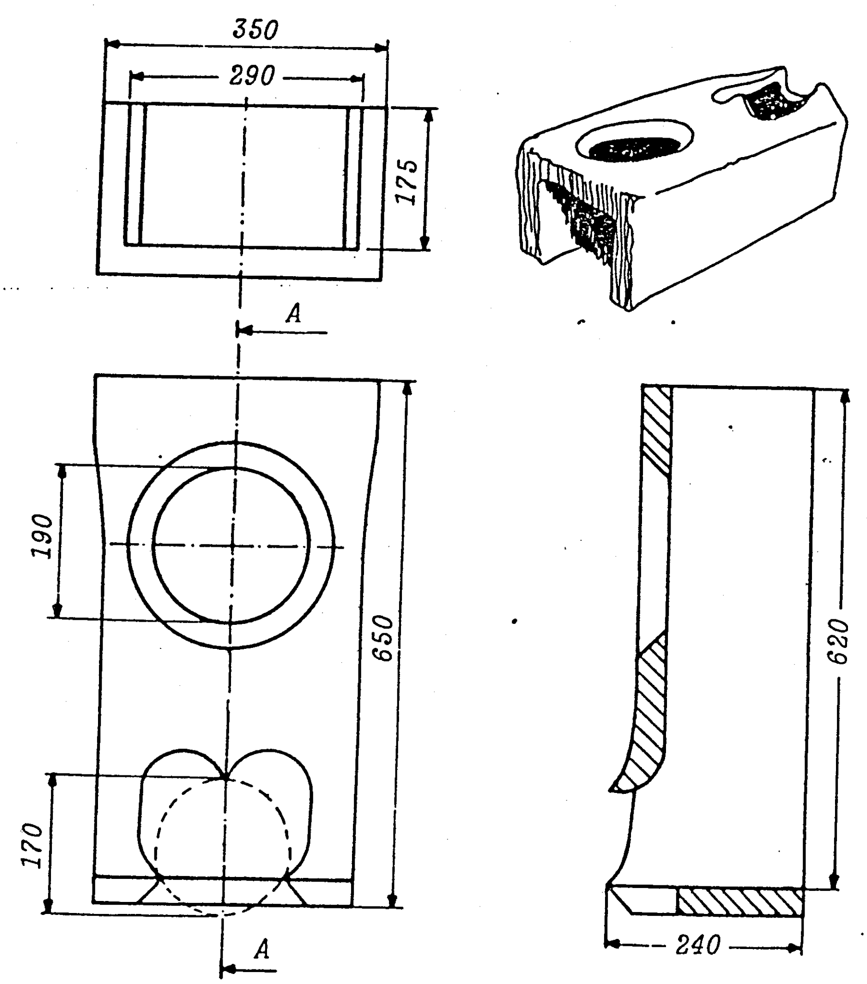


Fig 3.12 Indian 2-pot stove (De Lepeleire et al, 1981)



(all dimensions in cm)

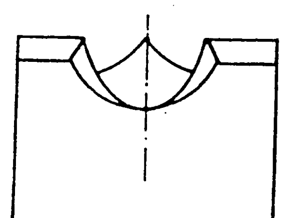


Fig 3.13 Tungku Muntilan (De Lepeleire et al, 1981)

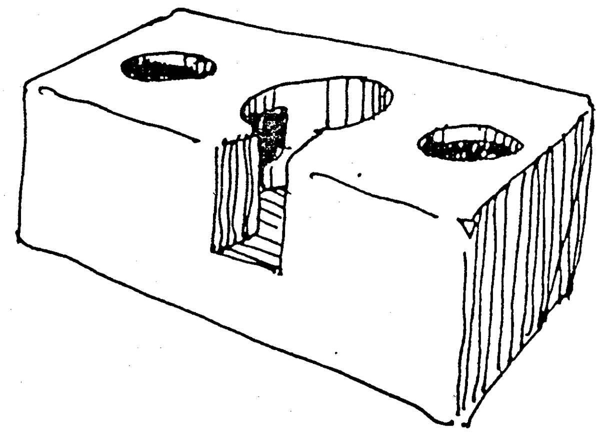


Fig 3.14 Indian 3-pot stove
(De Lepeleire et al, 1981)

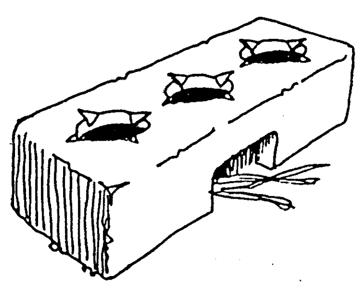


Fig 3.15 Indonesian 3-pot stove
(Singer, 1961)

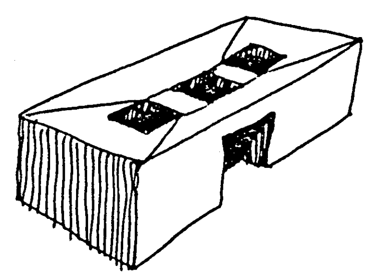


Fig 3.16 Egyptian 3-hole stove
(De Lepeleire et al, 1981)

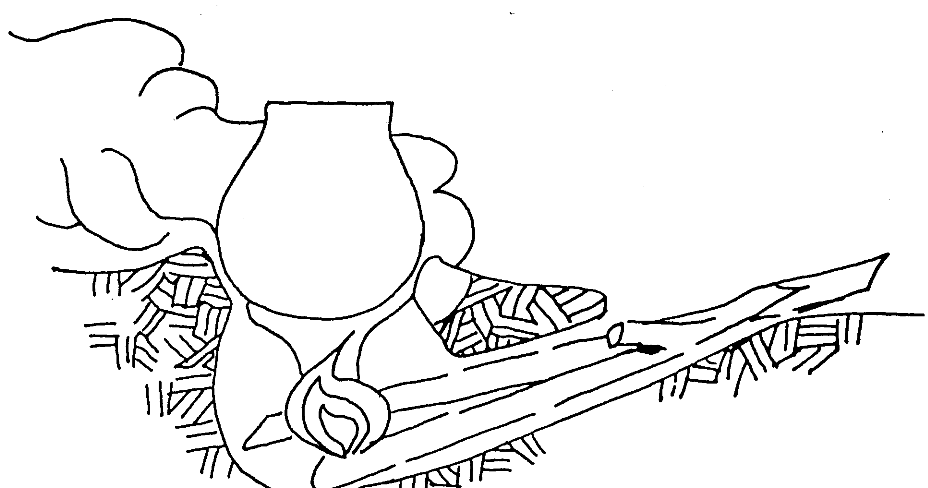


Fig 3.17 Bangladeshi pit chulha
(VITA/ITDG, 1980)

3.2.3 below-ground/pit "stoves"

(a) Earth Oven

The earth oven is reported to be common throughout Oceania (Gould and Joseph, 1978) and the Pacific (Kuper, 1977:212). Elmendorf (1976:31) has observed the Mayan Indians in Mexico also using the earth oven.

According to Gould and Joseph (1978:6) the following cooking procedure is used in Oceania: a shallow hole is dug in the ground, in which pieces of wood are placed and set alight. Once glowing coals have formed, volcanic rocks are placed on them. After all the wood has burnt, the ashes and rocks are removed. The bottom of the hole is then covered with leaves. Parcels of food (wrapped in leaves) are placed in the hole, along with the hot rocks, and covered with leaves. The heat from the rocks slowly cooks the food. Food can be steamed by sprinkling water on the hot rocks. About ten pounds of food can be cooked in four hours - and if needed for social occasions - 300 pounds in about twelve hours. This method is time consuming, and is now only used for special occasions. People in Oceania now tend to cook either over open fires or use kerosene stoves.

(b) Bangladeshi Chulha

The Bangladeshi chulah is similar to a mud stove, but constructed below the ground (Fig 3.17) and uses the thermal insulating properties of the earth (VITA/ITDG, 1980). This stove consists of a spherical hole - the combustion chamber - above which the cooking utensil rests, and a side vent through which fuel is introduced. These stoves can have one or two 'mouths', on which the cooking pot(s) rest (Islam, 1980:III-4).

3.2 Efficiency Concepts

Cooking consists of maintaining food at an elevated temperature for a given length of time. The length of time required depends both on physical factors (e.g. quantity of food, type of food, ambient temperature, wind speed), and subjective factors (e.g. taste and cultural preferences). The elevated temperature is provided by water (when boiling or simmering), by oil (when frying) or simply by air (when using an oven).

During the process of cooking, heat flows from the burning fuel to the food. The cooking pots and stove (or fireplace) act as channelling agents for this flow of heat. In order to minimize fuel consumption in **cooking**, the proportion of heat energy which goes to the food must be maximized. Cooking on a traditional stove involves losses of heat in a number of ways. For example, through hot or unburnt gases which escape, radiation and convection of heat from the hot stove as well as food and cooking pot(s) and so on).

The efficiency of an energy conversion device is usually defined as the amount of **useful** energy or work provided by the device, divided by the energy input.

It is useful to define partial efficiencies associated with the transfer of heat (liberated from the combustion of the fuel) to the food (Equations 3.1 - 3.5) (De Lepeleire, 1982).

These partial efficiencies can be combined to obtain an overall stove efficiency, (ie Equation 3.5) (De Lepeleire, 1982:46).

Partial Efficiency Equations

combustion efficiency n_c:

$$n_c = \frac{\text{heat generated by combustion}}{\text{consumed heat energy in firewood}} \qquad \text{Equation (3.1)}$$

transfer efficiency n_t:

$$n_t = \frac{\text{gross heat input into the pan}}{\text{generated heat}} \qquad \text{Equation (3.2)}$$

efficiency n_p:

$$n_p = \frac{\text{net heat input into the pan}}{\text{gross heat input}} \qquad \text{Equation (3.3)}$$

efficiency nr:

$$n_r = \frac{\text{heat absorbed by food}}{\text{net heat input in the pan}} \qquad \text{Equation (3.4)}$$

overall cooking efficiency

$$n = \frac{\text{heat absorbed in the food mix}}{\text{heat consumed by firewood}} = n_c \cdot n_t \cdot n_p \cdot n_r \qquad \text{Equation (3.5)}$$

Definitions of efficiency have tended to focus on the provision of heat for cooking (see section 3.3). However, in developing countries stoves are used for a variety of purposes, such as the provision of space heat and drying food, and not just for cooking. Hence, not all heat which does not go to the food is necessarily a "loss". Traditional cooking stoves in developing can also have socio-cultural functions (e.g. provide a social focus or reflect the status of the user). Moreover, stove users may also be concerned about other practical aspects of a stove, (e..g long lifetime, low maintenance requirement, cash and labour cost, and so on (Dutt, 1981). Invariably these would involve trade-offs, since a number of features considered desirable may conflict, e.g. low cost and long lifetime. In recognition of multiple practical functions of stoves, Joseph and Shanahan (1980a)use the term "Percentage Heat Utilization" (PHU) in place of "efficiency".

A single value of efficiency is often quoted for traditional stoves and fireplaces (see Chapter 4). However, cooking stoves will have a variety of cooking "efficiencies" depending on the definition of "efficiency" chosen as well as operating conditions. Hence, a family of curves will be produced rather than a single value.

3.3 Methods for Determining Fuel Consumption of Different Stoves

Efforts have been made to obtain information on the fuel consumption of traditional stoves. Various tests have been used to provide information on energy flows. These data can be used to design new stoves, or to modify existing ones by optimizing the heat energy which is delivered to the food.

One aim of stove testing has been to provide information on the performance of cooking stoves and fireplaces (Bialy, 1981:1). An analysis of the literature relating to test data and the results of programmes to disseminate "improved" stoves show that this task has proven to be more difficult than initially envisaged. One technical reason is that the concepts of efficiency rely on being able to achieve a steady state situation, but the dynamics of combustion of wood and other traditional fuels are not a simple affair (see Browne, 1958; Shelton _et al_, 1978).

There are several ways of obtaining data on consumption of traditional fuels in cooking. Experimental tests in the laboratory or field can be carried out to provide fuel consumption data under defined conditions. These tests are either carried out using food which involves cooking **standard meals** or heating water (instead of food) and are known as **Water Boiling Tests.** Water Boiling Tests are the most common type of testing method.

At the field level, fuel consumption can also be determined by asking the households to estimate their fuel consumption (the **direct recall method**) or by **direct measurement.** Field tests have also been designed to determine the **relative fuel consumption** of different stoves (the **Kaya test**) as well as optimizing stove design (the **Bamako test**).

These various methods are described below.

3.3.1 Water Boiling Tests

Water Boiling Tests (WBT's) involve heating water instead of food to simulate the cooking process: the energy absorbed by the water can easily be calculated if the specific heat capacities and the temperature rise of the water and cooking pots are known.

Joseph and Shanahan (1980a) use the term PHU to denote the proportion of heat energy absorbed by the water from the fuel. Two PHU's (PHU1 and PHU2) are defined in bringing the temperature of the water from ambient to boiling point. PHU1 treats evaporated water as an energy loss, whilst PHU2 does not. PHU's involving simmering do not treat energy associated with evaporated water as an energy loss.

$$\text{PHU1} = \frac{\text{temperature rise of water x specific heat x mass of water}}{\text{heat energy of consumed wood}} \qquad \text{(eqn 3.6)}$$

$$\text{PHU2} = \frac{\text{(temperature rise of water x specific heat x mass of water)} + \text{mass of water evaporated x latent heat of evaporation of water)}}{\text{heat energy of consumed wood}} \qquad \text{(eqn 3.7)}$$

In the nomenclature used by Joseph and Shanahan (1980a) the term **BP1** refers to the time taken for the water, in a one-pot stove, to reach boiling point from ambient temperature. If the stove has two pot holders, than BP2 refers to the time at which the water in the second pot has reached boiling point. This terminology is similarly extended to stoves which can heat more than two pots simultaneously (ie BP3, BP4 and so on).

Measurements of the PHU after 't' minutes of simmering, for a one pot stove, are referred to as BP1St. For example, BP1S30 means measurements taken 30 minutes after the water in the first pot reached boiling point.

Most experimental work on cooking stoves has been carried out using firewood as the fuel. The following details the calculations of heat liberated when using firewood (the same principles would apply to other fuels such as crop residues or animal manure).

The **calorific value of virtually all oven dry woods,** whether from tropical or temperate regions is **20 MJ/kg** to within 5 per cent (Bialy, 1979). The calorific value of **moisture-free wood** is referred to as the **gross calorific value** (or **high heat value**). The presence of moisture in wood lowers the amount of heat energy that is available, as this water absorbs heat in being converted to steam. The calorific value of **wood containing moisture** is referred to as the **net calorific value** (or **low heat value**).

Using standard enthalpy reactions associated with the combustion of wood, and the assumption that the hydrogen content of virtually all woods is around 6%, Bialy (1979) calculates that the variation of net calorific value (E(m)) with moisture content, is approximately given by the equation:

$$E(m) = \frac{2.4\ (780 - m)}{(100 + m)} \qquad \text{Equation (3.8)}$$

where m is the moisture content (dry basis) - a more detailed account of moisture content and calorific values is given in Appendices A and B.

The heat energy released by the firewood is calculated by subtracting the heat energy available in the fuel residue, from the heat energy in initial quantity of firewood; the latter is simply the product of its mass and calorific value (corrected for moisture content).

The heat energy of the fuel residue can be determined in a variety of ways. The simplest is by separating any unburned charcoal from any unburned wood in the fuel residue. Each of these is then weighed. Since the approximate calorific value of charcoal and wood are known, the total heat content of the residue can be calculated. For charcoal, Shafizadeh (1981) (quoted in Emmons and Atreya, 1983) gives calorific values in the range 24-31 MJ/kg, with an average of 28 MJ/kg. Joseph and Shanahan (1980a) use a value of 29 MJ/kg.

A number of WBT's have been reported in the literature (Ahuja, undated; Bhatt, 1983) each of which, according to Joseph and Shanahan (1980a) gives a different result. Five methods are described below - the final two methods have been the least reported in the literature. A more detailed account of some of these WBT's is given in Bhatt (1983).

(a) Cooking Simulation Test

A fixed amount of water is brought to the boil, and the quantity of wood used, and mass of water evaporated, recorded. The water is then allowed to simmer for a defined length of time, at the end of which the remaining wood, charcoal, and water are weighed.

This appears to have been the most widely used test. A detailed description of which is given in Joseph and Shanahan (1980a) who adopted it because of its similarity to cooking which involves simmering. Weir and Richolson (1980) extended this methodology to include thermal losses from the cooking pots.

This WBT has been critisized since cooking food which involves simmering initially requires a high power output to quickly bring the water to boiling point. Once the water has boiled, the heat input is reduced to just maintain simmering. Hence, a stove which gives a high PHU with such a WBT's may not do so when cooking food. Thus, Agarwal (1980) refers to a report (Government of India, 1964) in which an "improved South Junagadh Stove" had a higher PHU than the traditional design in WBT's. However, in practice, the "improved" version used more fuel than the traditional design! In recognition of this criticism there has been a shift to WBT's which are carried out at high and low powers.

(b) High power/low power tests

This WBT, described in Vita (1982), is a simple modification of the previous test: a known mass of water is brought to boil at the maximum power output of the stove, and allowed to simmer for 15 minutes, at this power output. The mass of residual firewood, charcoal and water is weighed and PHU's calculated at BP1S15. A known amount of firewood is then put in the stove and lit. The procedure outlined above is then repeated. However, after simmering for 15 minutes, the power output of the stove is reduced to the minimum to maintain simmering, for one hour. The PHU's obtained at the low and high power outputs are compared. The ratio of the maximum and minimum power output (averaged over each part of the test) are also calculated. This is referred to as the "turn down" ratio of the stove.

(c) Water Evaporation Method I

A known mass of water is heated and a given mass of fuel completely burnt. The PHU is calculated from the temperature rise in the mass of water and the amount of water evaporated.

This test is used by the Woodburning Stove Group at Eindhoven University in the Netherlands (Visser and Verhaart, 1980; Prasad, 1981). In their tests, small pieces of wood were fed into the fire in "charges" (e.g. 50g, 100g). This procedure had the advantage of performing the test under quasi-steady state conditions. The end point was defined when the temperature of the water in the cooking vessel fell below a set value.

(d) Water Evaporation Method II

The mass of fuel required to evaporate a fixed quantity of water is measured at a variety of burning rates (ie power outputs).

High PHU's are obtained for stoves capable of a high power output, however, this test is not particularly useful since the parameter of interest is the quantity of fuel to cook a meal, not the steam generating efficiency.

(f) Constant Power Output Method

This test is recommended by Khanna (1965) (quoted in Bhatt, 1983). In this test, a known mass of wood is burnt. The number of times a fixed quantity of water can be brought to (or close to the) boiling point is recorded. As the water in the final cooking vessel heated may not reach boiling point, the highest temperature reached is recorded. The PHU is calculated from the temperature rise of the total mass of water heated in the test. One advantage of this test is that there is very little time lag between one cooking vessel being removed from the stove and another being heated. It is not known whether evaporated water is included in the calculation of the PHU, but as the water is not allowed to simmer for any length of time, it is likely that the energy associated with steam will be very small.

This test has been recommended by Micuta (1985) to give villagers a visual indication of the relative fuel consumption of two stoves.

3.3.2 Fuel Consumption in Cooking "Standard" Meals

In WBT's, calculations of PHU after the water has reached boiling point generally include the energy carried away by steam. However, this energy has not performed any useful function. The parameter of interest is the fuel consumption to carry out any cooking task, not the efficiency with which steam can be produced. Consequently, PHU's should only be given in bringing the water to boil. Measurements involving simmering should give the total fuel consumed. In order to allow comparison with PHU data of other authors, the WBT data in Chapter 5 gives values of PHU after the water has reached boiling point.

WBT's are also open to the criticism that measuring the fuel consumption in bringing water to the boiling, or in allowing it to simmer, is not the same as cooking a meal. In order to overcome this criticism as well as to determine the fuel consumption in cooking, "standard" meals are defined and cooked on different types of stove. (Another response has been to measure cooking fuel consumption in the field, see section 3.3.4). As variations are expected in cooking practices between as well as within countries, standard meals have to be site specific. Meals which are most often cooked, or cooking procedures which are most common, are used as a basis for designing these standard meals.

Fuel consumption is calculated by measuring the amount of fuel at the beginning and end of the test. An appropriate correction has to be made for differences in calorific value between the unburned fuel and fuel residue. For example, if firewood is the cooking fuel, the fuel residue will consist of firewood and charcoal, each of which have different calorific values. The remaining charcoal has to be expressed in terms of the mass of firewood which will have the same available heat energy. This can be done by multiplying the mass of charcoal by the ratio of the calorific values of charcoal and the firewood. Micuta (1985) suggests using a value of 1.5 for this ratio. The firewood consumption can simply be calculated by subtracting the 'firewood' remaining at the end of the test from the initial quantity of firewood.

Data from standard meals is sometimes expressed in terms of the amount of fuel to cook one kilogramme of food (e.g. De Lepeleire, 1982, in VITA, 1982: Micuta, 1985). This is referred to as **specific fuel consumption.**

Cooking standard meals can give information on fuel consumption, and ease of operation of each type of cooking stove or fireplace. Such tests can also be used to identify and relate the physical characteristics, (e.g. number of pot holders, controllability of heat output), to the existing cooking patterns. This information would be useful in designing 'improved' stoves.

3.3.3 Field Measurements of Fuel consumption

Methods used to determine fuel consumption depend upon the situation in the field. For fuels such as firewood, animal manure and crop residues two basic methods - direct recall and direct measurement - are commonly used. Procedures to determine the relative level of fuel consumption of different cooking stoves are based on the direct measurement method.

(a) Direct Recall Method

In this method, each household is asked to recall the amount of fuel it has used over a particular period of time (ranging from one day to a year). The longer the time period the larger the errors that will creep in. However, short periods may be subject to daily variation. As a result, there is need to ask about fuel consumption over several short periods. It has to be borne in mind that information on consumption may only be available in units of measurement with which the respondents are familiar e.g. per headload or cartload.

An extension of this method is to ask the householder to place in a pile the amount of each fuel used over a short period of time, e.g. the previous day or week. These quantities can than be weighed or measured (for example to obtain the volume of firewood) by the researcher.

(b) Direct Measurement

The second method relies on physically measuring the fuel consumption over a defined period (e.g. per day, per week or per month) for defined activities e.g. cooking and space heating. A common way of doing this is by asking selected households each to make a pile of the fuel (e.g.

firewood) used. Only fuel from this pile should be used by the household. The researcher by weighing each pile of fuel periodically, and replenishing as needed, can estimate the fuel used for the defined activities. Errors can arise from various factors, for example if fuel not from the experimental pile is used, or if another householder uses this fuel.

Another source of error is that the very act of measuring fuel consumption may affect the actual consumption, since monitoring consumption of fuel would draw attention of the households to their fuel use. Wood (1981, 1982) reports the results of a fuel survey in Burkina Faso (formerly Upper Volta): the average level of firewood consumption was 6% lower in the second week of the survey (following a one week gap in measurement) with families using the same traditional stove. However, the overall change for these families ranged from an increase of 11% to a decrease of 24%. Whilst, Wood ascribes this variation to the act of observing consumption, this variation may simply have been due to different types or quantities of food being cooked over these weeks (see Chapter 6, for a discussion of the variation in consumption reported in the Zimbabwean villages visited). Unfortunately, Wood did not gather data on the type and amount of food cooked.

3.3.4 Relative Fuel Consumption of Stoves/Optimization of Stove Design

Field tests based on direct measurement of fuel consumption have been described which can be used to compare the efficiency of different stoves (the **'Kaya' test**), which can be followed by the **'Bamako' test** to optimize the stove design (Dutt, 1981).

(a) Kaya Test

This test is named after Kaya, Burkina Faso (formerly Upper Volta) where the test was first carried out. The Kaya test is used to compare the performance of two stoves or a stove operating under two different operating conditions (Geller and Dutt, 1982). For the former objective, each participating household is given the two stoves to be compared. Households are instructed to alternate their cooking between these two stoves. Measurements of fuel consumption are then taken after each meal or at the end of each day. It is recommended that at least five households are chosen and tests conducted over six consecutive days to permit statistical analysis. It is important to design the cooking schedule such that the same meal is not repeatedly cooked on one stove and not on the other. A worked example based on field data, along with detailed statistical analysis is given in Geller and Dutt (1982).

(b) Bamako Test

This test is named after Bamako, Mali where this test was first carried out. The Bamako test enables optimization in stove design parameters or cooking practices (i.e. stove use) and is based on the Kaya test outlined above. A detailed account is given by Dutt (1981). In the test, two stoves (a **reference stove,** and **test stove**) are given to a selected household. These two stoves may now be compared using the Kaya test procedure. After about one week the relative fuel consumption will have been determined. The effect of changes in the design parameters of the test stove, for example chimney height, shape of combustion chamber, or the introduction of a grate, can be observed in continuation of the test over subsequent weeks. One parameter is altered at a time.

Simultaneously, tests may be carried out in another household where a different parameter is altered at one week intervals. Similarly, changes in fuel consumption due to alterations in cooking practices can also be obtained. In this latter case the original cooking practices must be retained when using the reference stove.

Dutt (1981) points out some of the weaknesses of the Bamako test procedure. Firstly, the optimal values of each parameter only relate to the stoves of a particular dimension. Hence, in practice optimization of every parameter would have to be done for stoves of varying sizes - this would be a tedious process. However, Dutt points out that once each parameter has been individually optimized then it is likely that the overall optimal values will be close to these values.

Another problem is that the actual energy consumed will not be known since the fuel consumption figures in this procedure do not take into to account variations in the calorific value of different firewood species and moisture content. However, alternate use of the stoves will tend to reduce errors due to these variations.

An approximate value of the total heat energy consumption can be determined if the calorific value and moisture content of the fuels is known. If these values are not known, or can not be measured, then 'typical' calorific and moisture content values of these fuel types may be used. An assumption made here is that the fuel(s) used are homogeneous in terms of parameters which affect the heat content. Variations in these parameters may be taken into account by sampling the fuels.

Finally, the optimization of a single parameter at a time ignores interaction effects. Dutt argues that further optimization can be undertaken on stoves which have been initially optimized using this method. Moreover, there are factorially designed experiments which can be used to examine interaction effects (Fisher, 1942) and have been applied stove testing (Bialy, 1981). (The application of factorial design to testing an Indian 'U' chulha is given in Chapter 5.)

Measurements of fuel consumption and households chosen must be statistically representative. In addition, since seasonal and regional variations are expected, generalization or extrapolation from these results may not be possible.

The major disadvantages of these types of field tests is the degree of disruption of cooking patterns of the families under observation, as well as the effect of monitoring on the observed fuel consumption.

3.4 Reasons for Introducing "Improved" Stoves

The most important reasons put forward for replacing traditional cooking stoves by "improved" ones are to increase the efficiency of cooking with firewood, thereby reducing firewood consumption (e.g. Raju, 1957; Makhijani, 1976:24; World Bank, 1980:39; Kennedy, 1981:33; Smith, 1981:15; TERI, 1982:3; Salariya, 1983:4) and to provide a smoke-free cooking environment for women in the kitchen (e.g. Kallupatti, 1957; Chrenko, 1967-8; Siwatibau, 1981:77). The evidence to support these beliefs are examined below.

(a) The "Efficiency" of Traditional Stoves/Fireplaces

There is a widespread belief that traditional stoves and fireplaces are very inefficient (see Chapter 4). The basis of this belief is examined in detail in Chapter 4.

(b) Cooking Fires and Smoke-Related Diseases

Using traditional stoves and fireplaces in confined spaces means that cooking is done in a smokey atmosphere: a lot of smoke can be produced during cooking particularly during the early stages of the fire, owing to incomplete combustion of the volatile gases released.

Cooking out of doors can reduce the deleterious effects of the smoke. However, this may not always be possible, owing to adverse weather conditions, or because of religious, social or cultural reasons. In Nepal for instance, villagers are uncomfortable about cooking in public (Yoder, 1981). One way around this has been to vent the smoke from the kitchen by means of a chimney; this is the principle behind most of the "improved" stoves that are "smokeless".

The ill-effects of smoke in cooking huts (e.g. Kallupatti, 1957; Chrenko, 1967-8) is the major rationale given for promoting smokeless stoves. Siwatibau (1981:77) argues that smokeless stoves should be introduced on grounds of improving health alone, **even if this means an increase in firewood consumption.** The evidence relating cooking with traditional stoves and smoke induced diseases, as well rural womens perceptions of smoke in the kitchen are considered below.

Clifford and Beecher (1964:25) report that 85 cases of primary malignancy of the nasopharynx were admitted to hospital from all over Kenya in 4 years (1959-1961). In this study, more men were treated at hospital for nasopharyngeal cancer than women - this may have arisen because women were less likely to go to hospital than men. To explain the spatial distribution of cases of "nasopharyngeal carcinoma", two possible aetiological (ie causal) factors - environmental and hormonal - were suggested:

(i) In terms of environmental factors,

> "the disease occurs in areas above 2000 feet in altitude, with an annual rainfall of over 20 inches ... these are also areas of greatest population. The African population in these areas live in small **ill-ventilated huts** constructed of mud and wattle with a grass thatched roof **without a chimney.** The disease is not evident in the Coast and Northern Province which are dry and warm and cooking is generally done outside, in contrast to the colder and higher areas (where the disease occurs) where there is a cooking fire in the hut most of the day" (Clifford and Beecher, 1964:40).

Hoffmann and Wynder (1972) reach similar conclusions regarding the different environmental conditions of villagers living in the mountains and coastal regions of Kenya,

> "the mountain tribes live in a cold rainy climate and remain in their **very poorly ventilated dwellings** during large parts of the day. The huts have only one small door and **no windows.** They are constantly heated by an open wood and cowdung fire. The analysis of indoor air for (two carcinogens) BaP (benzo[a]pyrene), and BaA (benzo[a]anthracene) and the

irritating phenols and volatile acids revealed the highest air pollution density so far recorded." (Hoffmann and Wynder, 1972:11-12).

It was noted that the disease occurred especially in areas of Kenya where "exotic trees (eucalyptus and wattle) and the indigeneous acacias, which belong to the same Mimosa family as wattle are used to provide firewood" (Clifford and Beecher, 1964).

(ii) Comparing the sex and racial incidence with other studies additionally suggested a hormonal link (Clifford and Beecher, 1964:42).

Results (reported by Siwatibau (1981:71)) from a survey of one town by the Fijian Medical department showed that Fijians had a higher incidence of trachoma (ie inflamed granulation of the eyes) than Indians: 30% of all Fijians surveyed had trachoma, compared with 16% of all Indians surveyed. Siwatibau (1981:71) comments that this may be a result of Fijians sleeping in the room where cooking is done.

A number of negative comments have been made about smoke from traditional stoves by women doing the cooking. Martin (1979) reports that women in Ghana complain that smoke flavours the soup they are cooking. In Fiji, more than three-quarters of the women interviewed in a rural energy survey complained about eye irritation due to smoke (Siwatibau, 1981: 71). One reason given by rural women in Zimbabwe for changing from their traditional fireplace, was that the new stove produced much less smoke (see Chapter 6, Gill, 1983).

However, smoke from stoves is not universally regarded as a problem for a number of reasons. Villagers surveyed in Sri Lanka (Howes et al,

1983) were not particularly concerned about smoke, since this escaped through the roof. In Guatemala, not all the villagers were worried about smoke as it was traditionally used to cure meat (Evans, 1978) and served to eliminate parasites from the ears of corn hung from the roof (Shaller and Shaller, 1979).

Smoke also acts as an insect repellent. In Fiji, fires are kept burning in areas with a high incidence of mosquitoes (Siwatibau, 1981:71). Moreover, the roofs of houses in rural areas are made using materials such as grass, leaves and crop residues. The smoke from the burning fuel tends to deter insects from the dwelling. In Gambia, the introduction of smokeless stoves led to the roofs of the buildings collapsing (Joseph, 1980: pers comm). Since there was little smoke, the insect population in these dwellings multiplied rapidly, ate the roofing material, and caused the roofs to collapse. Foster (1962:80-82) reports similar experiences with the introduction of smokeless stoves in both Iran and India.

According to Joseph (1983: pers comm), users of smokeless stoves in Gambia, came up with an ingenious solution to this problem. During the initial stages of the cooking process, the covers of the pot holders on the stove were removed, causing smoke to fill the dwelling, and thus repelling insects.

The evidence to support the view that women in developing countries would be healthier by working in a smoke-free environment is patchy. Moreover, smoke that is produced is not always regarded as a problem, as it may serve a useful purpose, for example, curing food and deterring insects.

3.5 Types of Improved Stoves

A number of "improved" stove designs have been promoted in developing countries. These stoves have been made out a number of materials: mud stoves, ceramic stoves and cement (or brick) stoves, metal stoves and hybrid stoves (e.g. mud + metal) - this chapter deals in detail with mud and ceramic based stoves. Most interest has centred on the design, development, and dissemination of **"improved" mud stoves.** Interest in the early 1980's shifted to **"improved" ceramic stoves.** These two stove types are considered below.

The following will show that attempts to achieve widespread adoption of "improved" mud designs have not been successful for a number of reasons. In many cases, "improved" mud stoves in the field, used more fuel than the traditional design. In some cases, this was a result of poor construction. Moreover, "improved" mud stoves which saved fuel initially, were reported to have rapidly deteriorated in performance over the following 6 to 9 months. In addition, improved mud stoves were characterized by a high labour cost, a low lifetime (due for example to the cracking of the stove body, erosion of the combustion chamber and connecting channels), and poor construction (sometimes even by trained stove builders). Moreover, the large mass version of these stoves gave out very little space heat. Other reasons put forward to explain the failure of "improved" stove programmes are given in section 3.6.

3.5.1 "Improved" Mud Stoves

The earliest reported "improved" mud design was developed in India in 1953 at the Hyderabad Engineering Research Laboratories (HERL) - in the southern Indian state of Andhra Pradesh - by S.P. Raju (1957); this stove is known as the HERL chulha. A number of other mud based designs appeared from 50's onwards: the 'improved' Egyptian Stove (Theodorovic, 1954), the Singer Stove in Indonesia (Singer, 1961), PRAI chulha in India (Joseph et al, 1980), Lorena Stove first introduced into Guatemala (Evans, 1978), the "new Nepali Chulho" (R.E.C.A.S.T., 1979a; 1979b), and the Tungku Lowon introduced into both Indonesia and Sri Lanka in the early 1980's (Soedjarwo, 1982).

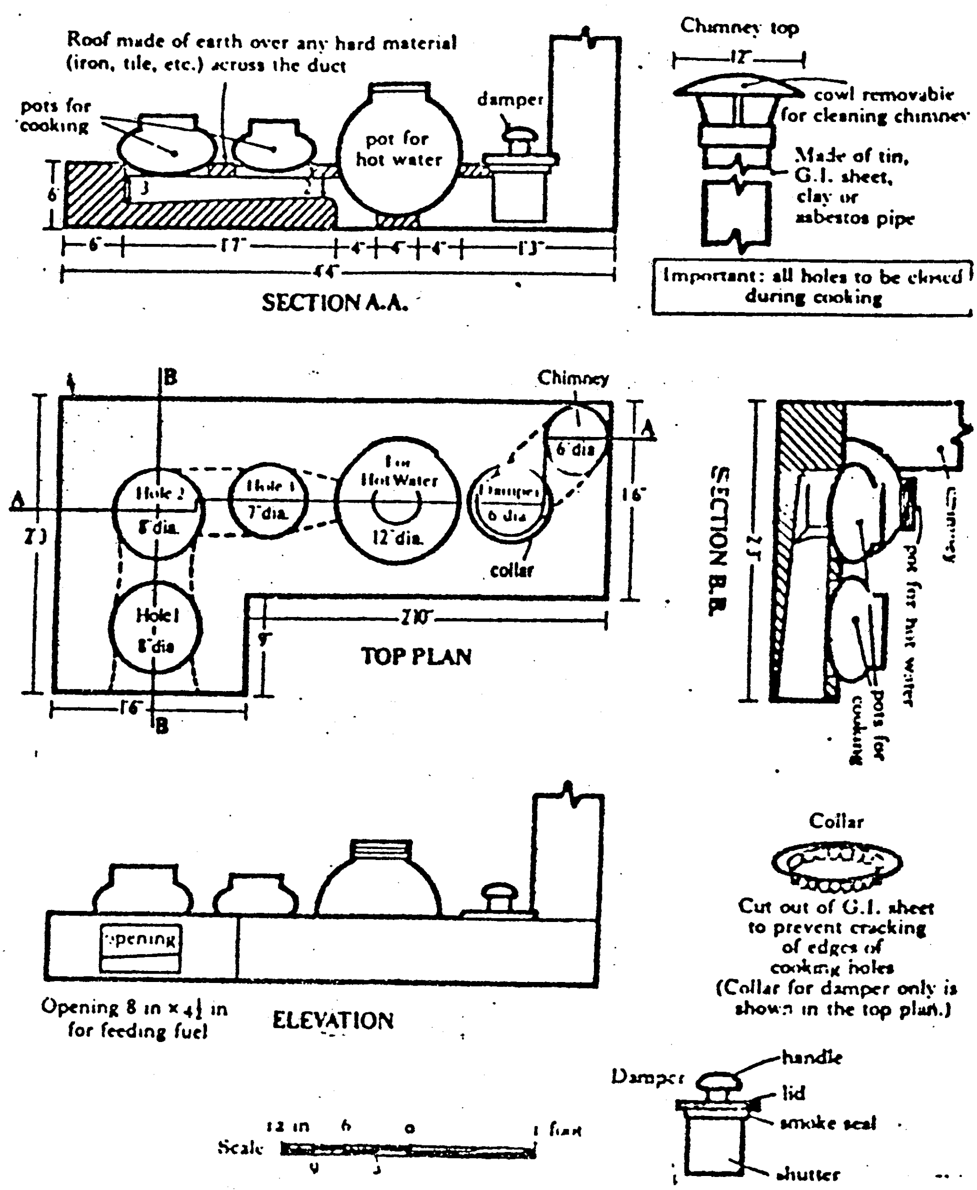
(a) The HERL Smokeless Chulha

Raju (1957) stressed the importance of using local resources (in terms of skills and materials) and traditional cooking practices in the design of the HERL chulha:

> "the basic materials of the chulha should be earth and earth products that can be fabricated by village craftsmen or built by village women themselves ..... the general shape, method of feeding firewood and operation should be as little different as possible from what is already familiar to them" (Raju, 1957: 5).

A number of versions of the HERL chulha - having up to four pot holders - were designed (Fig 3.18); each design had one pot hole reserved for heating water. Women using the HERL chulha were reported to have saved between 20% and 40% of their previous fuel consumption (Raju, 1957:3) - though no data is given to substantiate these claims.

According to Raju (1957) this basic design had been taken up in Pakistan, Burma, Sri Lanka, Africa, Lebanon, Iraq and the West Indies.



(dimensions in feet and inches)

Fig 3.18 HERL chulha
(TERI, 1982)

However, to date, very little has come of these attempts (Joseph et al, 1980).

Ohlsson and Purvis (1972:1) report that women extension workers, in the state of Perak (in Malaysia), experimented with "Indian type" smokeless stoves. It was found that these stoves were too heavy to be installed on the wooden floor of Malaysian village homes.

Raju (1953) claimed that the HERL chulha used considerably less fuel than the traditional Indian design. Geller (1981) reports on WBT's and SFC (specific fuel consumption) tests conducted on the HERL chulha and the traditional 3-pot Indian chulha (used in Ungra region). For both types of test, **the traditional design was more efficient:** the PHU for the HERL chulha was slightly lower than the traditional design; the HERL chulha also used nearly one-fifth more firewood than the traditional chulha for the same cooking task.

According to Siwatibau (1981), an Indian chulha (HERL chulha design) is well known in Fiji: a trial introduction in a whole village by the Ministry for Rural Development showed that the average lifetime was around 3 years. Stove users reported (Bale, 1978) that the Indian chulha developed cracks which were difficult to repair. Consequently, villagers "reverted to previous devices". The reason given by Siwatibau (1981: 76) is that the villagers could not replace the Indian chulha's "easily", though she also comments that the Indian chulha continues to spread.

Siwatibau (1981) reports on cooking tests on the two-stone fireplace (see section 3.1.1), the Indian HERL chulha, and Ghanain smokeless stove (Fig 3.19); Siwatibau refers to the two-stone fireplace as an "open

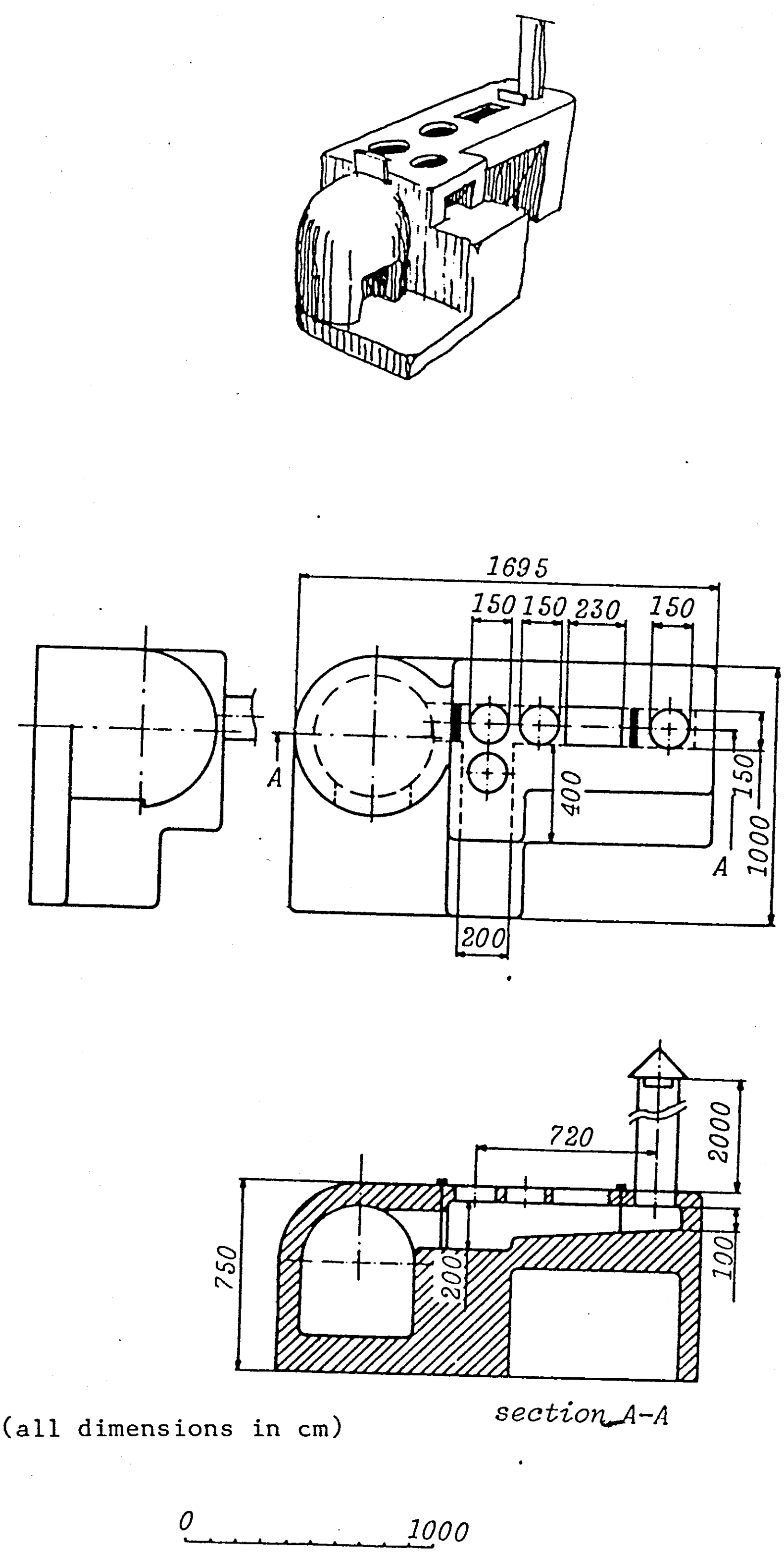


Fig 3.19 Ghanain smokeless stove
(De Lepeleire *et al*, 1981)

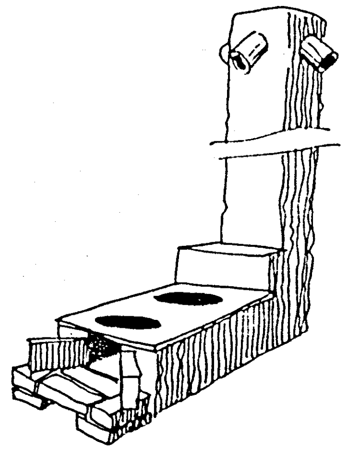
fireplace". Five different type of meals were cooked: two types of Chinese meal, two types of Indian meal, and one Fijian meal. The time taken and the firewood consumption were recorded. It was found that the traditional **two-stone fireplace used about half the firewood required with the Indian chulha** in four types of meal. There was no difference in firewood consumption for the remaining meal type. Cooking with the two-stone fireplace was much faster for all the meals.

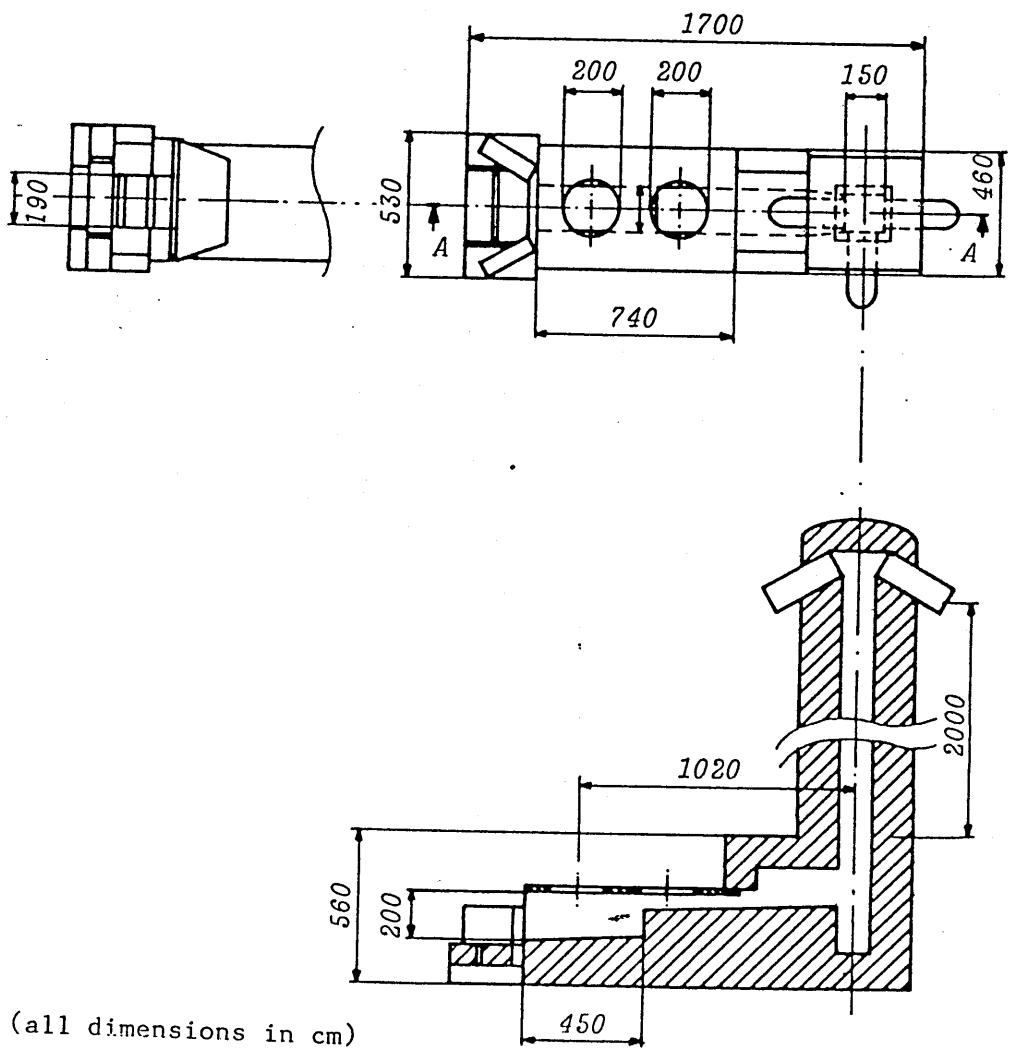
Data on firewood consumption gathered in the field was at variance with these findings: a four year old Indian HERL chulah used in one the villages surveyed by Siwatibau (1981: 76) was badly cracked, - the owner complained that the stove used "too much fuel". Yet, it used less firewood than two-stone fireplaces used by the other villagers: the mean mass of firewood (oven dry equivalent) used per person per day was 1.28kg and 1.57kg for the Indian chulha and two-stone fireplace respectively.

Siwatibau (1981: 76) attributes these divergent results, (between the HERL chulah tested in the field and laboratory), to differences in the dimensions of the firebox and smoke channel. This is supported by the work of Joseph and Loose (1982) who found that the shape and dimensions of the combustion chamber critically affected the PHU of a 2-hole "improved" ceramic stove (see Tungku Lowon below).

(b) The "Improved" Egyptian Stove

In the early 1950's, Theodorovic (1954) adapted the improved stove design by Raju (1953) to design a two pot smokeless version (Fig 3.20) for use in Egypt.





(all dimensions in cm)

3.20 Improved Egyptian stove
(De Lepeleire et al, 1981)

Theodorovic (1954) carried out a total of 10 WBT's using **corn stalks and husks** as a fuel. These involved heating 1 litre of water in each of two pots (made of tinned brass).

In the first five WBT's the **test was terminated when water in the pot directly above the combustion chamber reached boiling point.** At this point the temperature in the second pot was recorded. The time taken to bring the water in the first pot to boiling point in the traditional and 'improved' versions was 8.4 and 11.7 minutes, respectively. The PHU's (excluding evaporated water) were 4.4% for the traditional stove and 5% for the "improved" version.

In the next five WBT's, the **test was continued until the water in both pots had reached boiling point.** With the traditional design, the average time taken for the water in the first and second pot to reach boiling point was 6 and 9 minutes respectively, and 1.290kg of crop residues were used. Using the 'improved' design, the average time for the water in the first and second pot to reach boiling point was 8.5 and 11 minutes respectively. In the process 0.930 kg of crop residues were consumed.

On the basis of these results, Theodorovic concluded that the **only disadvantage of the 'improved' stove was that it took longer to heat water,** but had several advantages, principally a lower fuel consumption and a smoke-free environment. As will be shown later **villagers** in a number of developing countries **regard the ability to cook quickly as being important (and in some cases more important than fuel economy).**

No further information has been found on the 'improved' Egyptian stove, and the degree of dissemination of this stove is not known.

(c) Singer Stove

Work on "improved stoves" was carried out in the late 50's by Hans Singer, at the Regional Housing Centre, Bandung, in Indonesia (Foley and Moss, 1983:104). Singer (1961) proposed three models of "improved" mud stoves (often referred to as "Singer stoves"). Two of the models had 3 pot holes, however, the pot holes in one were aligned along a straight flue (Fig 3.21), whilst the other had an "L" shaped flue (Fig 3.22). All the models vented the smoke through a chimney. The third model was designed for smaller families and had two pot holes. All the stoves could be built as either "high" or "low" versions. The height of the "low" and "high" versions was about 30cm and 70cm respectively. Singer (1961) gives the results of WBT's on these "improved" stoves: PHU's between 20% and 30% were reported. To date however, no other work has been able to confirm these data, nor the extent to which these stoves have been disseminated in Indonesia.

(d) Ghanaian Smokeless Stove

In Ghana, smokeless stoves made from locally available material (Fig 3.19) claiming to use only half the fuel of traditional stoves were introduced in the late '60's. According to Hoskins (1979:33), the stove design was taken from an F.A.O. report, and recommended by the Canadian Hunger Foundation and the Brace Research Institute. The programme was abandoned in the mid '70's when it was found that women were no longer using many of the stoves (Hoskins, 1979:33). It was discovered that when the covers were not on the unused pot holders **the stove consumed even more fuel than the traditional stoves** (Martin, 1979). People soon switched back to the stoves they had used before. Other reasons given for the rejection of the 'improved' stoves were that the pots did not

(all dimensions in cm)

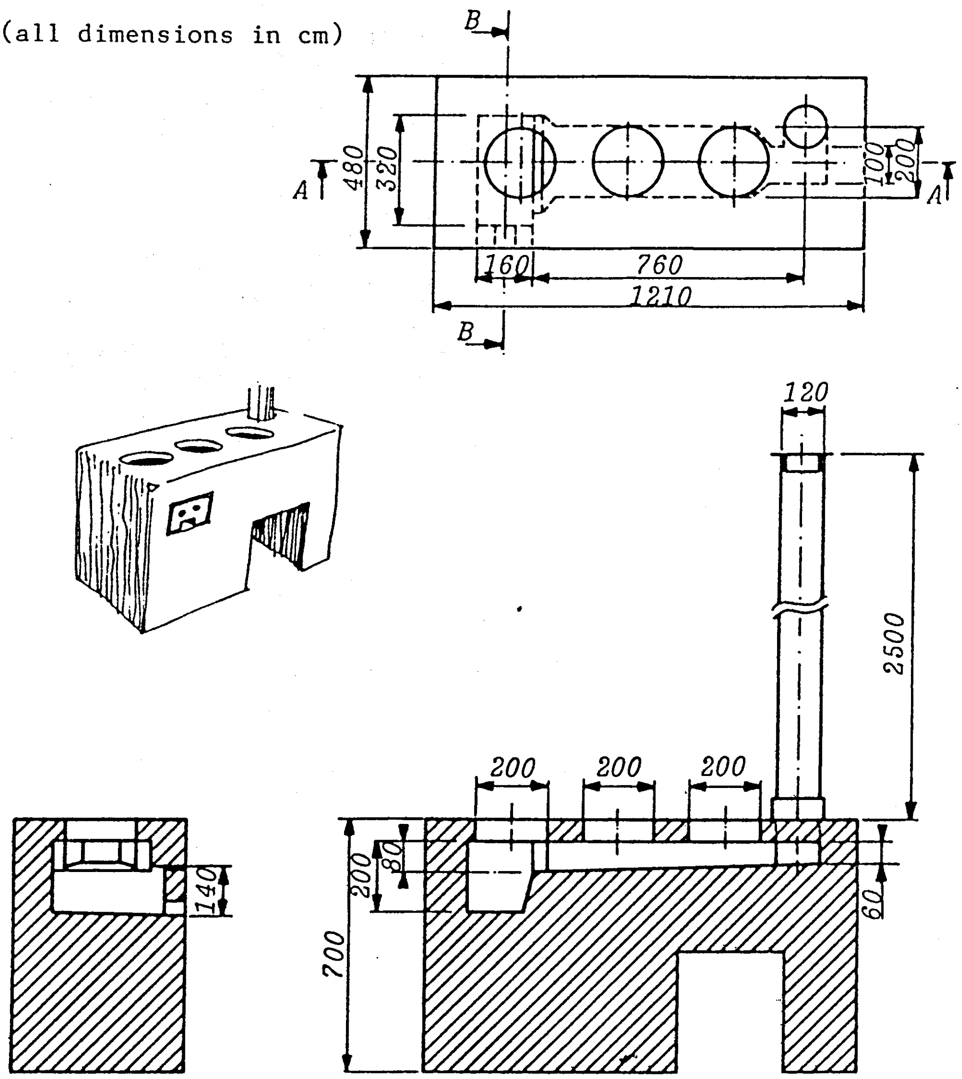


Fig 3.21 Singer stove (straight flue)
(De Lepeleire et al, 1981)

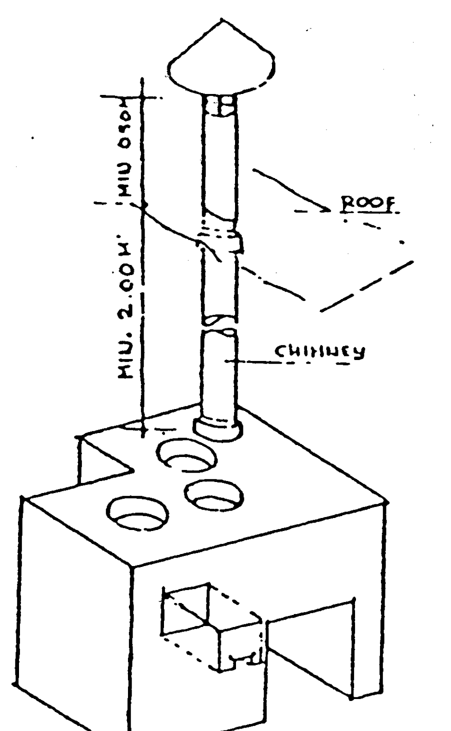


Fig 3.22 Singer stove (L shaped flue)
(De Lepeleire et al, 1981)

fit the cookers, larger pieces of wood were needed for the stove than could be found locally, and the surface of the stove was too high for stirring the large pots for their traditional dish (Hoskins, 1979:34). These latter problems might have been avoided if the recipients of the technology had been involved in the design process (Martin, 1979:77).

(e) Lorena Stove

Probably the best known "improved" mud stove is the Lorena stove. This stove was developed in Guatemala in the mid 1970's. A number of variations of the basic design are given in literature on "improved" stoves (e.g. Joseph et al, 1980; De Lepeleire et al, 1981; T.E.R.I., 1982).

The Lorena stove - "Lorena" comes the spanish, "lodo" (mud) and "arena" (sand) - is made out of adobe, (a mixture of sand and clay), and does not need firing. To construct the stove, a large base of adobe is used, upon which the wet sand/clay mixture is heaped, and evened out to form a cylindrical shape, lying on one face. When this cylinder is dry enough, the pot holders, combustion chamber, and interconnecting channels are carved out.

The Lorena stove originated in Latin America: a firewood shortage had arisen in Guatemela in 1976, owing to the subsequent timber requirements for rebuilding the houses following a major earthquake. The Lorena stove (Fig 3.23) was developed by the Choqui Experimental Station in Guatemala in response to this firewood shortage. By 1984, between 5,000 and 7,000 Lorena stoves were estimated to be in use in Guatemala (Erlbeck, 1984:6). Its designers claimed that it was smokeless and reduced firewood consumption by half (Evans and Wharton, 1977:8). How-

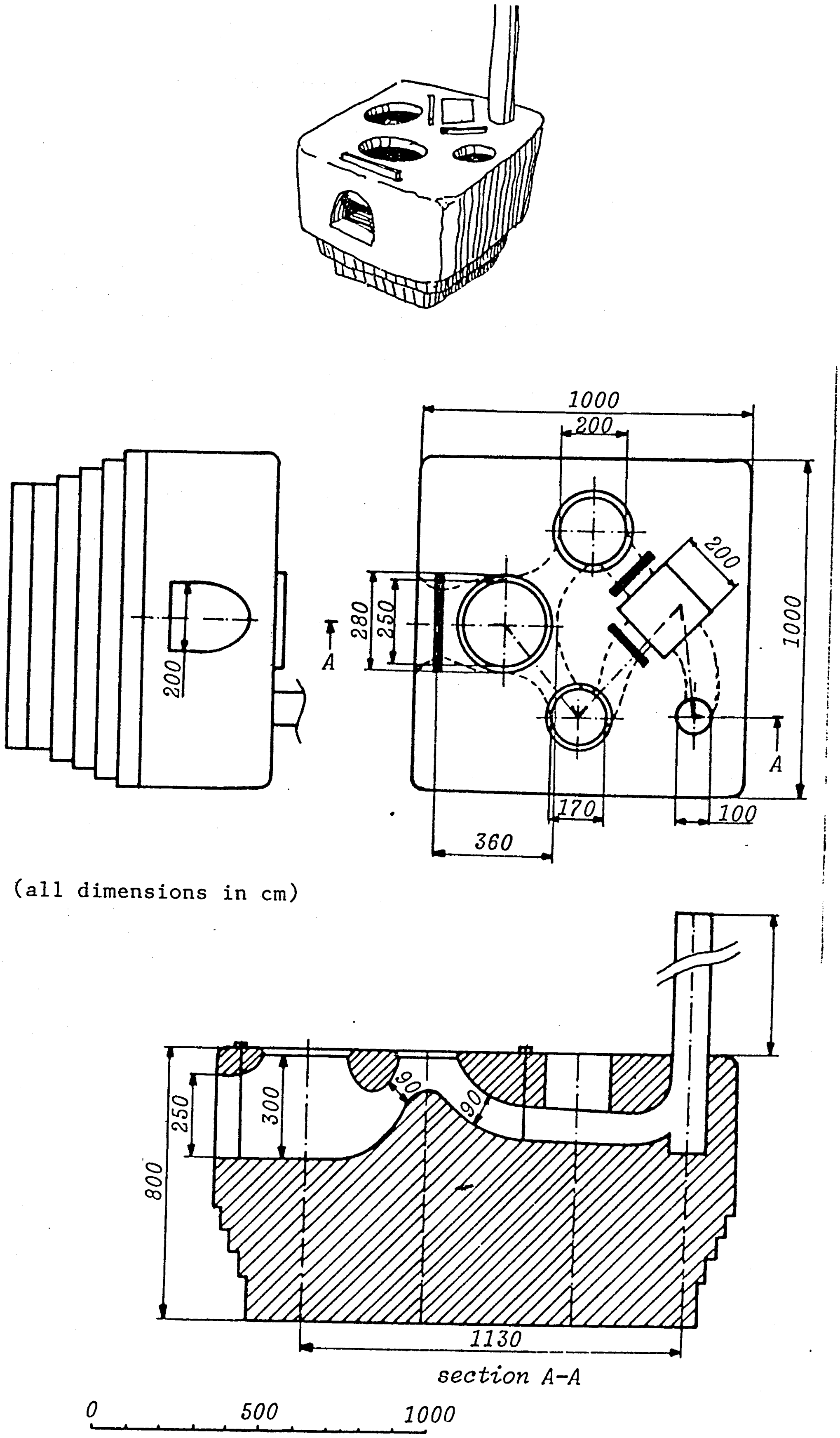


Fig 3.23 Lorena stove
(De Lepeleire et al, 1981)

ever, no evidence is given to support the latter claim.

Although villagers in Guatemala liked the height, and cleanliness of the Lorena stove (Shaller and Shaller, 1979) there were problems in dissemination. These are outlined in section 3.6.

Erlbeck (1984:6) comments that whilst the Lorena stove was generally acceptable in the highlands, cases of rejection were more widespread in the coastal regions of Guatemala. No reason is given. Caceres (1983: cited in Foley and Moss, 1983), estimates that by 1983, around 6000 Lorena stoves had been built in Guatemala.

In Guatemala, very few people using the Lorena stove realized the savings in firewood that had been claimed by the designers (Shaller and Shaller, 1979) and in some cases, there was no change in firewood consumption.

Over 800 Lorena type stoves were built in Indonesia over a 4 year period (1978-1981). This stove programme was halted when it was discovered that the majority of these stoves were no more efficient than the traditional local stove (Soedjarwo, 1982:4). Lorena type stoves introduced into Malawi were similarly found to have a high level of firewood consumption (French, 1984) and their dissemination was discontinued in 1981.

Attempts to disseminate the Lorena stove into a number of other countries - Ecuador (Erlbeck, 1984:6), Sri Lanka (Howes et al, 1983) and Zimbabwe (McGarry, 1981: pers comm) - have met with little success.

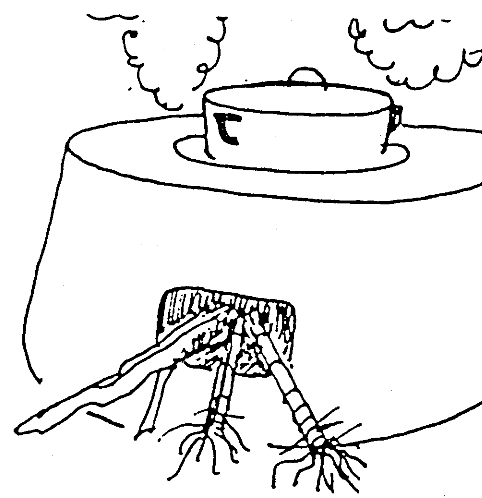
In August 1983, the Government of Guatemala set up the Ministry of

Energy and Mines with a department responsible for renewable energy, and which in association with about 20 Non-Governmental Organizations (NGO's) was planning to distribute 300,000 "fuel saving stoves" (Erlbeck, 1984:7). The stove type or the target population is not known.

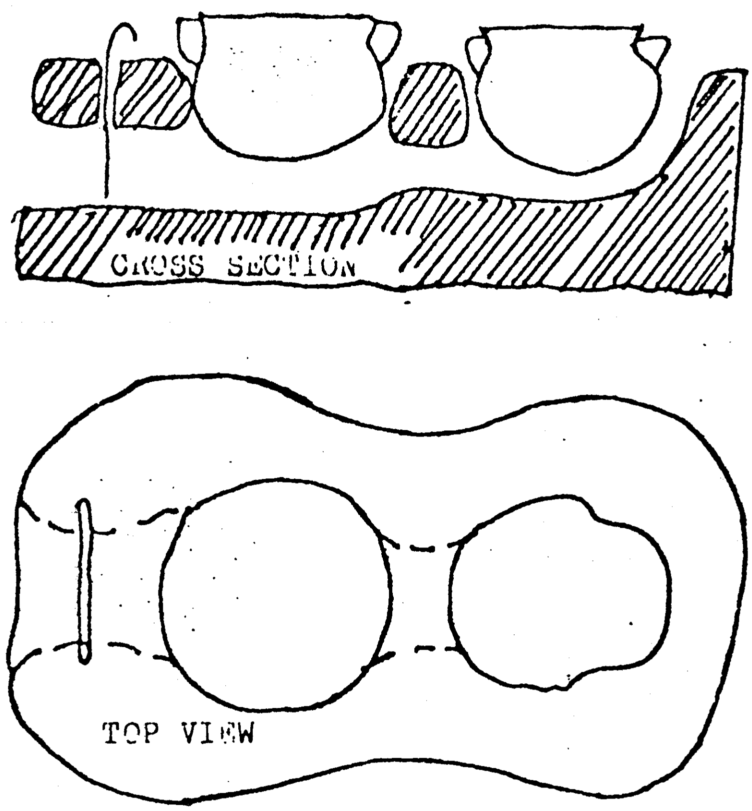
(f) Ban-ak-Suuf Cookstoves

Lorena stove building techniques were used in the Senegelese "Ban-ak-Suuf" stove programme, which was initiated in 1980. Ban ak Suuf means clay and sand in Wolof (Senegalese). The national stove programme was carried out by the Centre for Study and Research on Renewable Energy (CERER) at the University of Dakar. Initially large Lorena stoves were designed but these proved to be unsuitable. Smaller models, designed with the help of local people were made (Foley and Moss, 1983:109). The most popular type of stove was small chimneyless design known as the "Louga" (Fig 3.24). According to Foley and Moss (1983:109) Louga stoves are mainly designed and constructed by women. Though, Gern et al (1981:34) had earlier commented that whilst women were considered to be the best extension agents in the stove programme, there was "little deliberate attention in involving women.

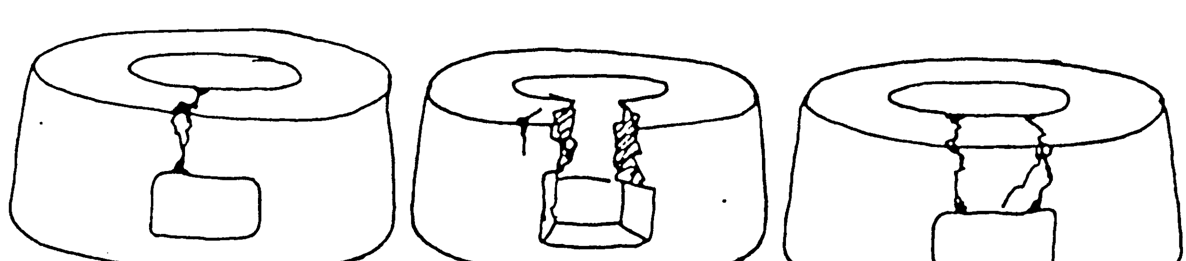
The two main problems reported with the Ban ak Suuf construction material have been crumbling (especially on getting wet) and cracking. After a year or so, many stoves had "almost crumbled away" (Foley and Moss, 1983:109). In a survey carried out by Gern et al (1981:44) it was found that cracks (due to thermal expansion) had developed in almost all Louga stoves in use. The cracks usually developed on the firebox bridge, though sometimes in the connecting bridge (Fig 3.24). However, users continued to use the stoves (Gern et al, 1981:44).



(a) One-pot Louga stove
(Gern, 1981)



(b) 2 pot Louga stove
(TERI, 1982)



(c) Cracks in one-pot Louga stove
(Gern, 1981)

Fig 3.24

By 1982, 5000 stoves had been built, of which one-third had chimneys. Whilst 65% of the stoves were found to in regular use, one-fifth of these stoves were considered by a (CERER and Peace Corps) survey team to be in a very poor condition (Foley and Moss, 1983:111).

(g) The "Economical" 'U' Chulha's

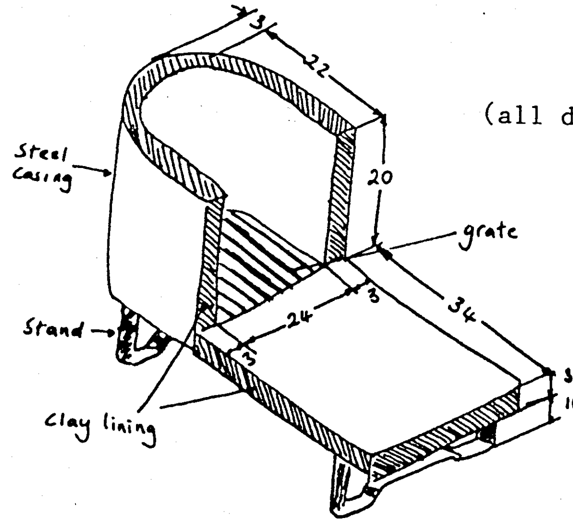
Salariya (1978, 1983) gives the results of WBT's on three types of "economical" 'U' chulha's (Fig 3.25), all of which are modifications of the traditional Indian 'U' chulha. One is a traditional 'U' chulha with the addition of a grate, another design has a water jacket around the mud walls of the traditional design, and the third design incorporates both a water jacket and a grate. These are reported to have PHU's (based on WBT's) of 15.8%, 18.9% and 23.2% respectively. There is little information available on the tests conducted or dissemination results.

(h) New Nepali Chulho

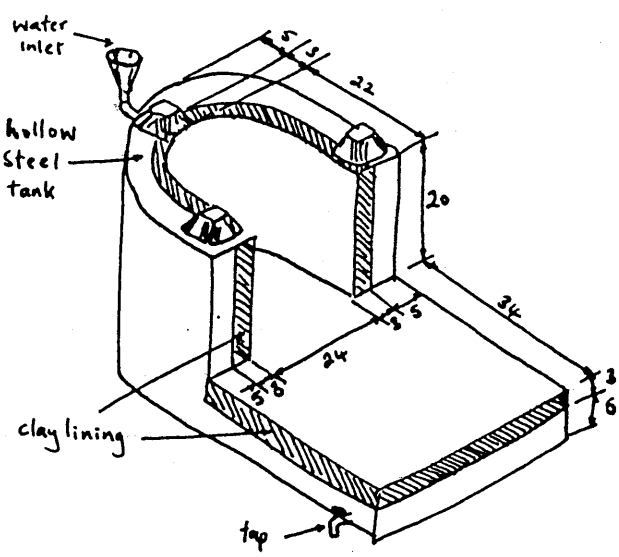
In response to both the smokiness and (perceived) "low efficiency" of traditional cooking methods used in Nepal, (e.g. 3-stone fireplace, iron tripod, or mud stove), the Research Centre for Applied Science and Technology (RECAST) designed the new Nepali Chulho. This stove was based on the HERL chulha and the Lorena stove (RECAST, 1979a). It was claimed that Chulho used less than half the fuel of traditional Nepalese stoves (RECAST, 1979a). However, no evidence is given to substantiate this claim.

Two versions (with differing pot hole configurations and masses) (Fig 3.26 and 3.27) of the Chulho were designed (RECAST, 1979b): a low mass

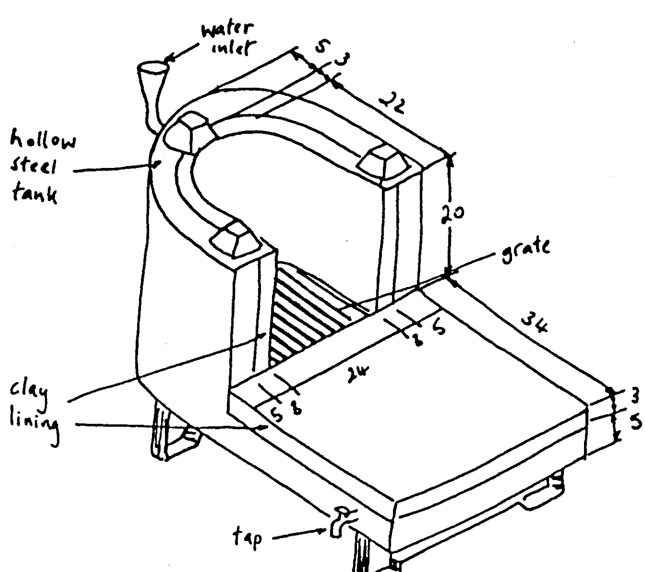
(all dimensions in cm)



(a) Chulha with grate



(b) Chulha with water jacket



(c) Chulha with grate and water jacket

Fig 3.25 "Economical" chulhas (Salariya, 1978)

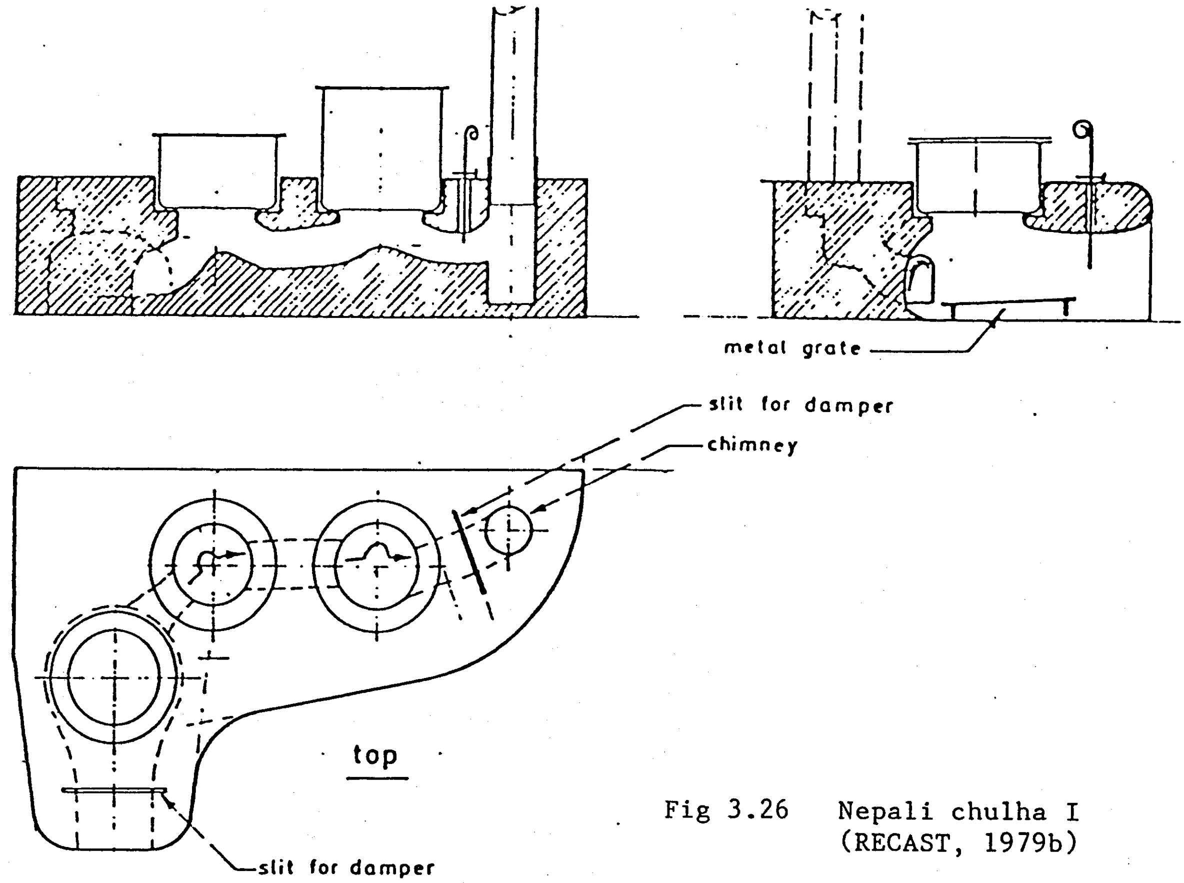


Fig 3.26 Nepali chulha I
(RECAST, 1979b)

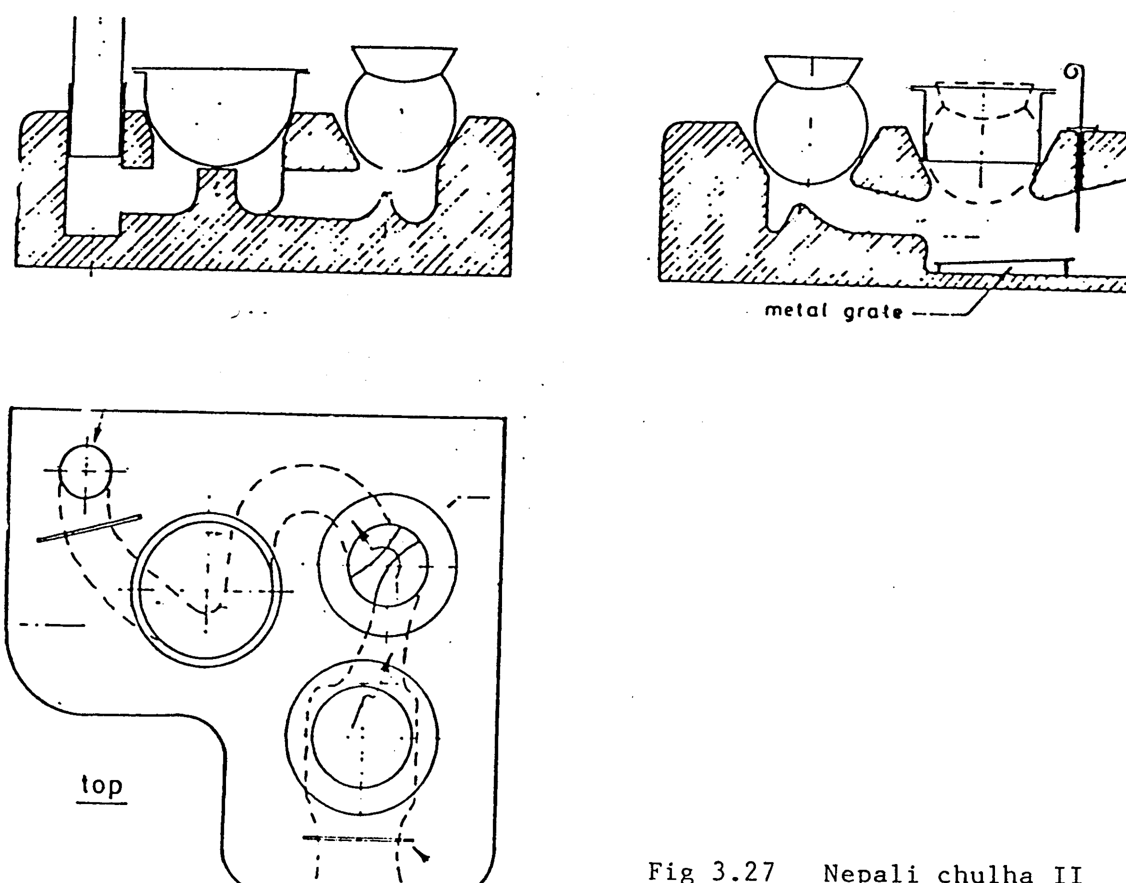


Fig 3.27 Nepali chulha II
(RECAST, 1979b)

and high mass version. The higher mass stove is recommended for "cold climates" where space heat was required, and the lower mass stove for "moderate climates" (RECAST, 1979b).

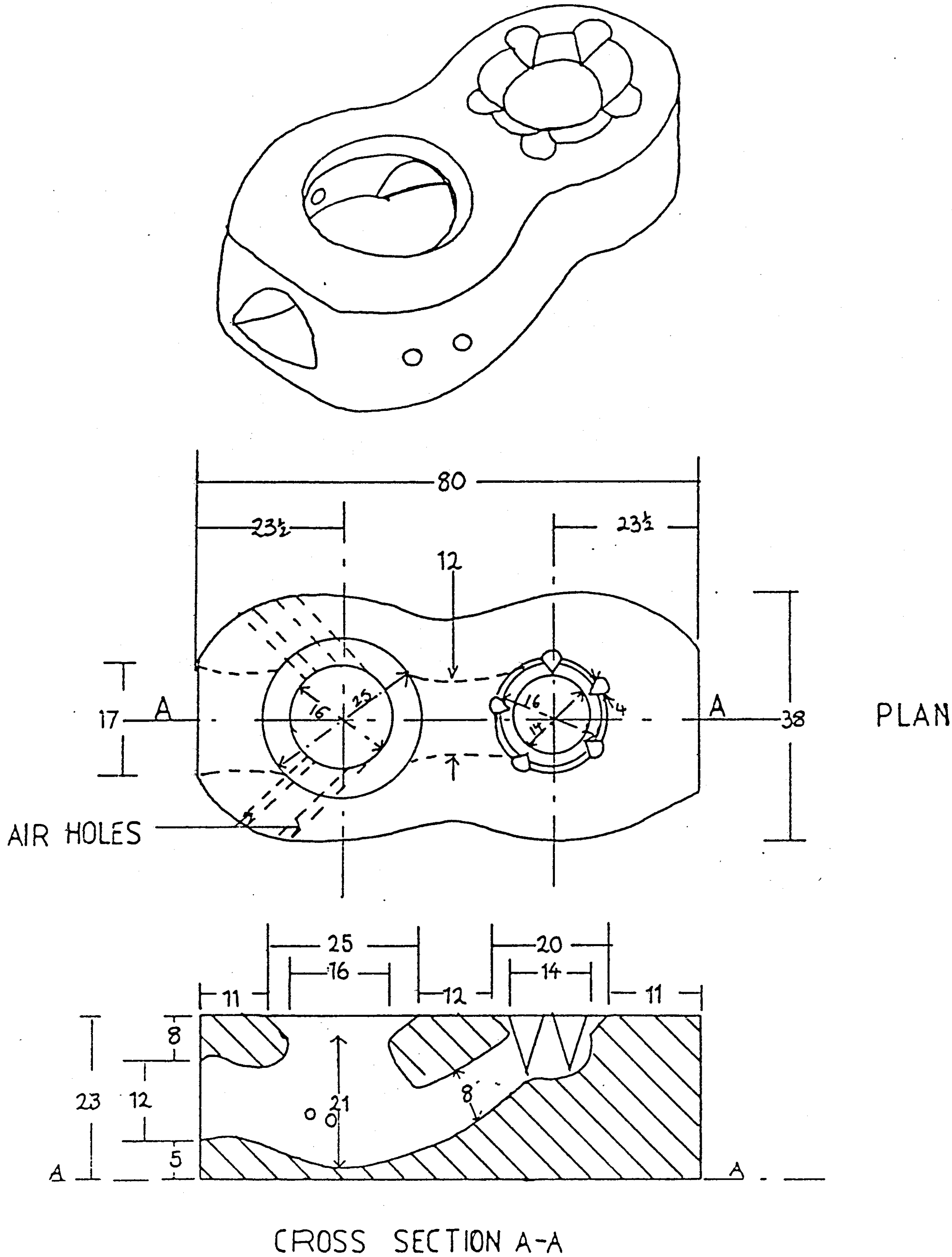
In the initial field trials 7 Chulho's were installed in schools "where formerly there were no traditional stoves at all" - each school catering for between 80 and 120 pupils (RECAST, 1979b). The results of these trials are not given.

No additional information has been obtained from RECAST in Nepal.

(i) **"Tungku Lowon" stove**

The Tungku Lowon stove was designed in Indonesia by Dian Desa when the shortcomings of the Lorena type stoves (promoted between 1978 and 1981) were realized. This stove is a two-pot chimneyless design based on a traditional Indonesian stove and has been introduced into both Indonesia and Sri Lanka in 1981 (Howes et al, 1983). Hot gases generated in the combustion chamber heat the pot on the first pot holder, and are channelled to where the second pot sits, by a sloping channel (Fig 3.28). The second pot is slightly higher than the first pot.

WBT's (for cooking times of BP1, BP2 and BP2S30) using 2 aluminium pots each containing 2 litres of water have been carried out by Dian Desa in Indonesia. ITDG carried out additional tests on a modified version of this stove. WBT's and "cooking tests" were carried out on both a traditional Sri Lankan stove and the Tungku Lowon at the Panwila Test Centre in Sri Lanka; the cooking tests involved village women cooking breakfast, lunch and heating "1 pot of water" each day for a period of 4 days. The results for all the above tests are reported in Joseph and



(all dimensions in cm)

Fig 3.28 Tungku Lowon
(Joseph et al, 1980)

Loose (1982), and are summarized below.

A lot of smoke was produced on lighting the stove. ITDG found that the internal dimensions of the stove had a major effect on both the amount of smoke produced and the firewood consumption. Increasing the slope of the channel connecting the first and second pot holders (Fig 3.28) decreased both the amount of smoke and the time to boil but increased the amount of firewood required. The time taken to boil the water in the first pot, varied between 12 and 32 minutes. PHU2 was 20% at BP1 and 22% at BP2; evaporative losses were between 1-2% at BP1 and 4% at BP2.

In the WBT's carried out by Dian Desa, PHU's around 23% were obtained at BP1 and 22% at BP2. BP1 was 15 minutes, whilst an additional 9 minutes were taken for the water in the second pot to reach boiling point.

In Sri Lanka, 10 WBT's were carried out on the Tunkgu Lowon and a further 8 tests on the traditional Sri Lankan 'U' shaped stove. The results for for these tests are as follows: for the traditional stove the "effective" mass of wood (ie energy in the charcoal left at the end of test not neglected), used was between 0.84 kg and 1.35kg, the time to boil varied between 19 and 40 minutes, and PHU2 between 10% and 17%; the mean value of PHU2 and time to boil was 13.7% (s.d. 1.8%) and 31 minutes respectively.

For the Tunkgu Lowon, the range of firewood used was much smaller: 0.69kg to 0.90kg, and the values of PHU2 (16% - 22%) were higher than for the traditional Sri Lankan stove. Joseph and Loose (1982:20) conclude that skills to use the stove efficiently are not so crucial with the Tungku Lowon compared with the traditional Sri Lankan design.

Two series of cooking tests were also carried out. In the first series of tests, the Tungku Lowon used around 30% less firewood (statistical significance $p<0.05$) than the traditional design. However, the firebox of the Tungku Lowon (firebox) had deteriorated by the second series of tests. This was caused by the "differential heating and cooling" and mechanical erosion of the "door" through which the firewood was inserted (Joseph and Loose, 1982:19). As a result there was no significant difference in fuel consumption between the traditional stove and the Tungku Lowon (Joseph and Loose, 1982:21).

Approximately 800 Tungku Lowon type stoves had been built in Sri Lanka over a period of 8 months, however, about two-fifths of these had been built inaccurately, and were not properly maintained or repaired (Joseph, 1983:15). In addition, the performance of these stoves decreased after about 6 and 9 months. As a result, production shifted to the ceramic based stoves (see section 3.5.2).

(j) <u>"Improved" Malawi Mud Stoves</u>

The Energy Studies Unit (E.S.U.) in Malawi became involved in the design and testing of mudstoves for use in rural areas towards the end of 1981. The findings reported below are taken from French (1984). The E.S.U. in association with the Farm Home Assistants (F.H.A.) of the Natural Resources College, considered three "improved" designs (Fig 3.29) for dissemination. Laboratory tests were carried out to measure firewood consumption and time to cook 'standard' Malawian meals (Table 3.2).

In March 1983, a total of 18 of these 3 types of stove were installed in 3 villages (ie 6 stoves in each village). Two months later women were asked to comment on the fuel consumption and speed of cooking of the

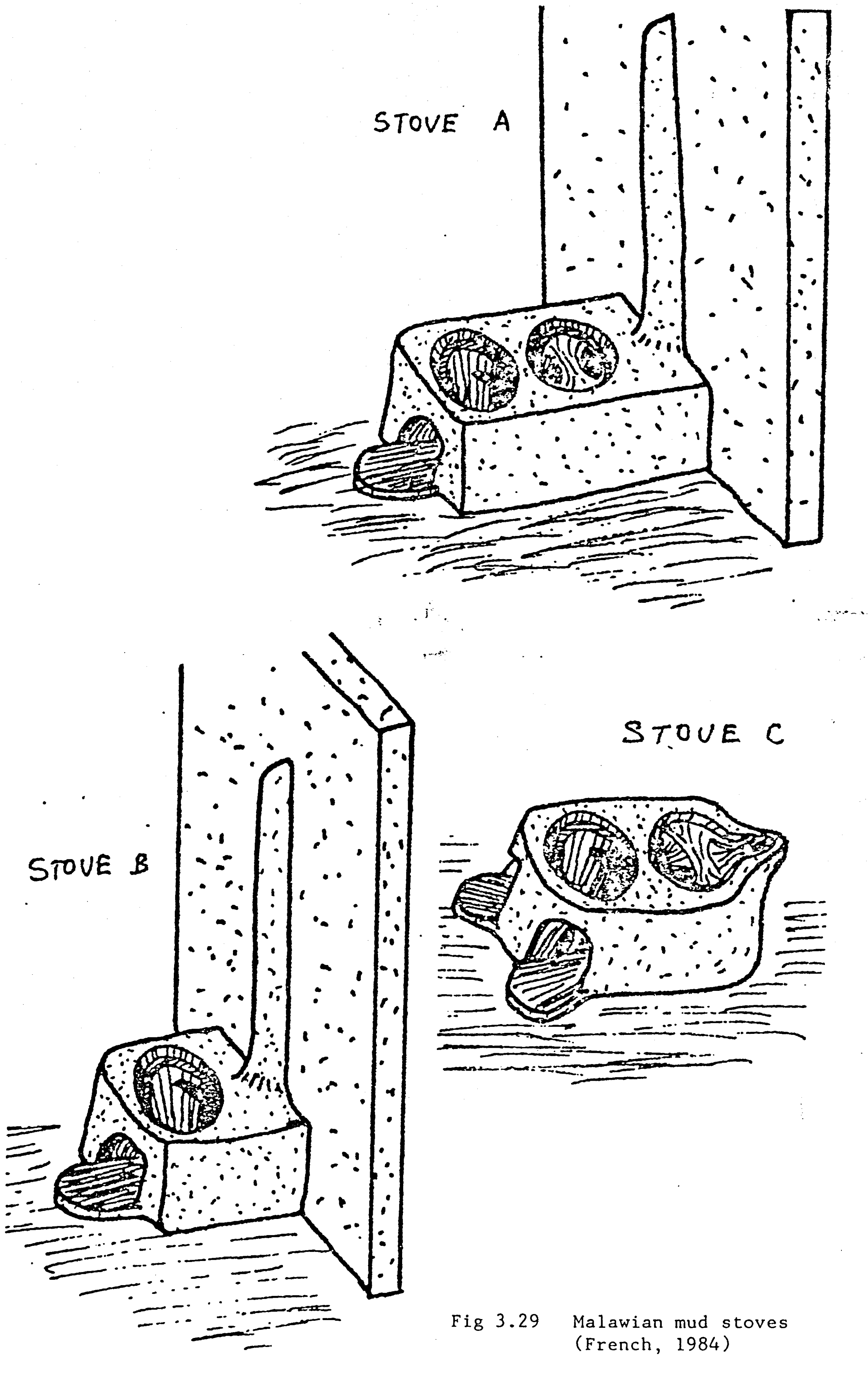


Fig 3.29 Malawian mud stoves (French, 1984)

Table 3.2

Laboratory tests on Malawian "improved" stoves and 3-stone fireplace
(French, 1984)

Meal	Stove Type			
	Stove A	Stove B	Stove C	3-Stones
nsima + relish				
- firewood used (kg)	0.40	0.41	0.51	0.84
- cooking time (mins)	32	46	31	50
consumption relative to 3-Stones (%)	48	49	61	100
Beans				
- firewood used (kg)	1.69	1.75	2.02	3.33
- cooking time (mins)	165	183	168	164
Consumption relative to 3-Stones (%)	51	53	61	100

Table 3.3

Cooking Tests on "improved" stoves in Malawi in the Field
(French, 1984)

Meal	Stove Type			
	Stove A	3-Stones (outside)	Stove B	3-Stones (inside)
nsima + relish				
- firewood used (kg)	1.06	2.18	1.37	1.52
- cooking time (mins)	56	54	81	69
consumption relative to 3-Stones (%)	49	100	90	100
Beans				
- firewood used (kg)	2.84	5.24	2.70	3.24
- cooking time (mins)	148	147	150	145
Consumption relative to 3-Stones (%)	54	100	83	100

"improved" stoves and their traditional 3-stones. All the women reported firewood consumption had been halved and cooking could be done more quickly.

The survey team found that women using stove type A had moved their 3-stones outside, as there was insufficient room for both in the cooking hut. Tests on standard meals carried out in the field showed that mudstove type A (inside the cooking hut) used about half the firewood of the 3-stones outside the cooking hut (Table 3.3). These data were comparable to the laboratory tests conducted earlier. However, the cooking time was the same for both types of cooking stove. In earlier tests mudstove A cooked nsima and relish more quickly (32 minutes) than the 3-stones (50 minutes).

Firewood savings with mudstove B relative to **3-stones inside the cooking hut** were much less (10% and 17% savings to cook nsima and relish, and beans respectively). French (1984) attributes the lower efficiencies of the 3-stones outside the cooking hut (see above) to the effect of breezes.

Although more efficient in earlier laboratory tests, in the field tests, mudstove type C used more fuel than the 3-stone fireplace .

In November of the same year, the villages were visited again, and it was found that 6 of the 18 stoves were no longer in use. Moreover, cooking was not being done on the remaining stoves in the most efficient way. For example, in some cases, stones had been placed on top of the stove to support the pot.

French (1984) concludes that savings with "improved stoves" are much smaller in the field than in the laboratory, that the women's perception of the relative speed and firewood consumption of the "improved" mud stoves and the 3-stone fireplace were inaccurate.

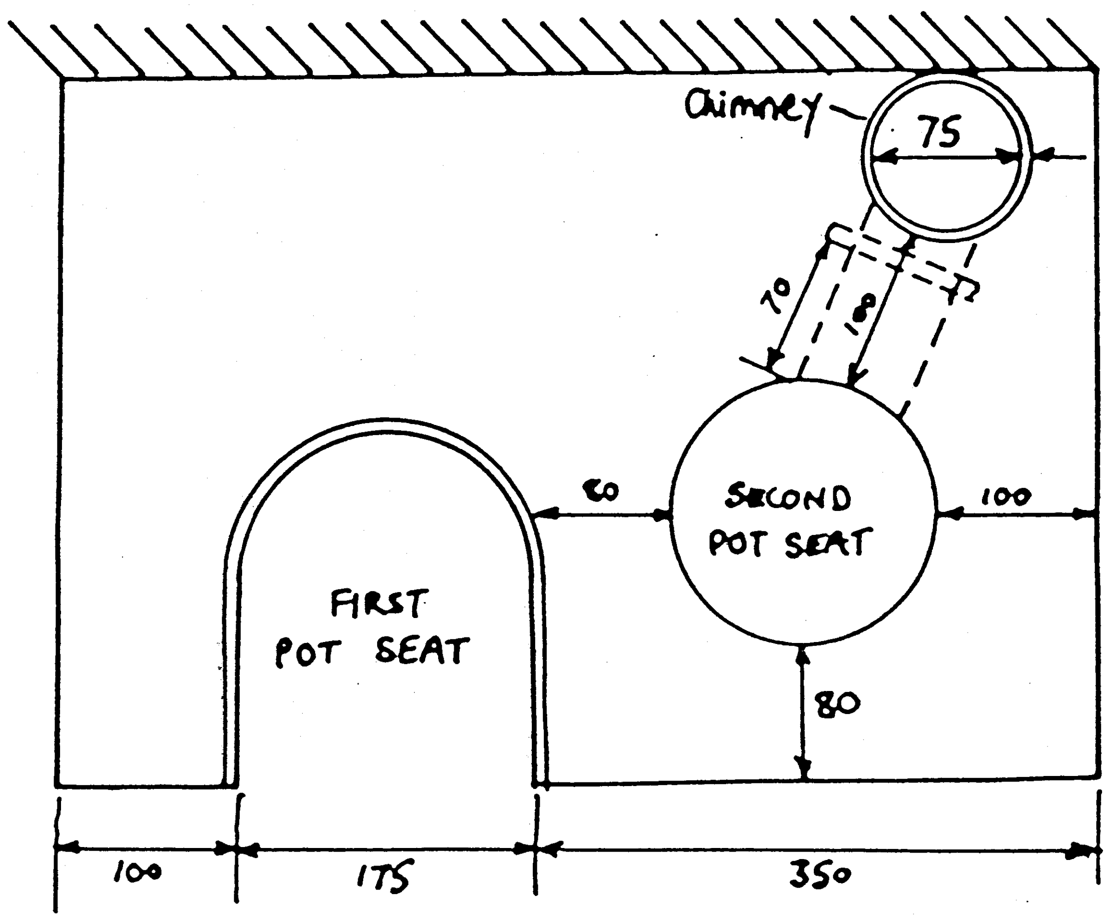
(k) GS Chulha

The GS chulha (Fig 3.30) is named after Gyan Sagar (1980) and based on the HERL chulha.

Wood (1981) conducted WBT's on a modified version of the GS chulha: 2 pots each containing 3 litres of water were heated. When the water in the pot above the firebox reached boiling point, a record was made of the temperature of the water, and the weight of both the pots and wood; the mass of the charcoal was estimated at this stage. The pots were returned to the stove and heating continued for another 30 minutes, after which the measurements were repeated. PHU's were calculated at BP1 and BP1S30.

Field tests using the Kaya test (see section 3.3.4) were carried out for "low income" squatter settlements on the outskirts of Ougadougou, Burkina Faso (formerly Upper Volta). A control group of 10 families used the traditional 3-stone fireplace throughout the survey period. This group was found used 6% less firewood (on average) in the second week of the survey. Data from 7 families using the modified GS Stove used (on average) 55% less firewood in the second week of the survey compared to the first week when they were using the traditional open fire.

However, as fuel savings with other "improved" mud stoves have been observed to fall significantly over time, e.g. 6 - 9 months (see



(all dimensions in cm)

Fig 3.30 GS chulha
(Sagar, 1980)

"Improved" Malawi Mud Stoves, and "Tungku Lowon"), it is likely that these levels of fuel saving would persist only over the short term.

3.5.2 "Improved" Ceramic Stoves

At temperatures above 450°C, clay loses it chemically combined water and becomes similar to a moderately hard stone (Scott, 1955). Ceramic is a term used to describe clay that has undergone this heat treatment (or firing). Although the earliest ceramic stove was the Indian Magan Chulha, designed in the early 1950's, ceramic based stoves appear to have been neglected till the late 1970's. Recent designs are the "Tandoor Stove", "TERI/ITDG stove", "Tungwu Sae stove", and the "new Keren stove". These stoves are also known as "ceramic insert" or "pottery liner" stoves.

(a) Magan Chulha

The earliest ceramic based stove design is the Magan Chulha, designed in India by the Khadi Village Industries Association (K.V.I.C.) in the early 1950's. This design was modified by Kallipatti (1957) to produce a portable (Fig 3.31) and fixed (Fig 3.32) versions. The fixed version simply had pottery liners which were surrounded by mud, to act as a thermal insulator. These designs were planned to replace the traditional one-pot and 2-pot stoves. The primary objective of the Magan chulha was to remove smoke from the kitchen, though it was claimed that this chulha also reduced firewood consumption by about 30% and cooking could be done more quickly. However, no test data was given. An additional positive feature was that building the chulha would provide employment for rural potters.

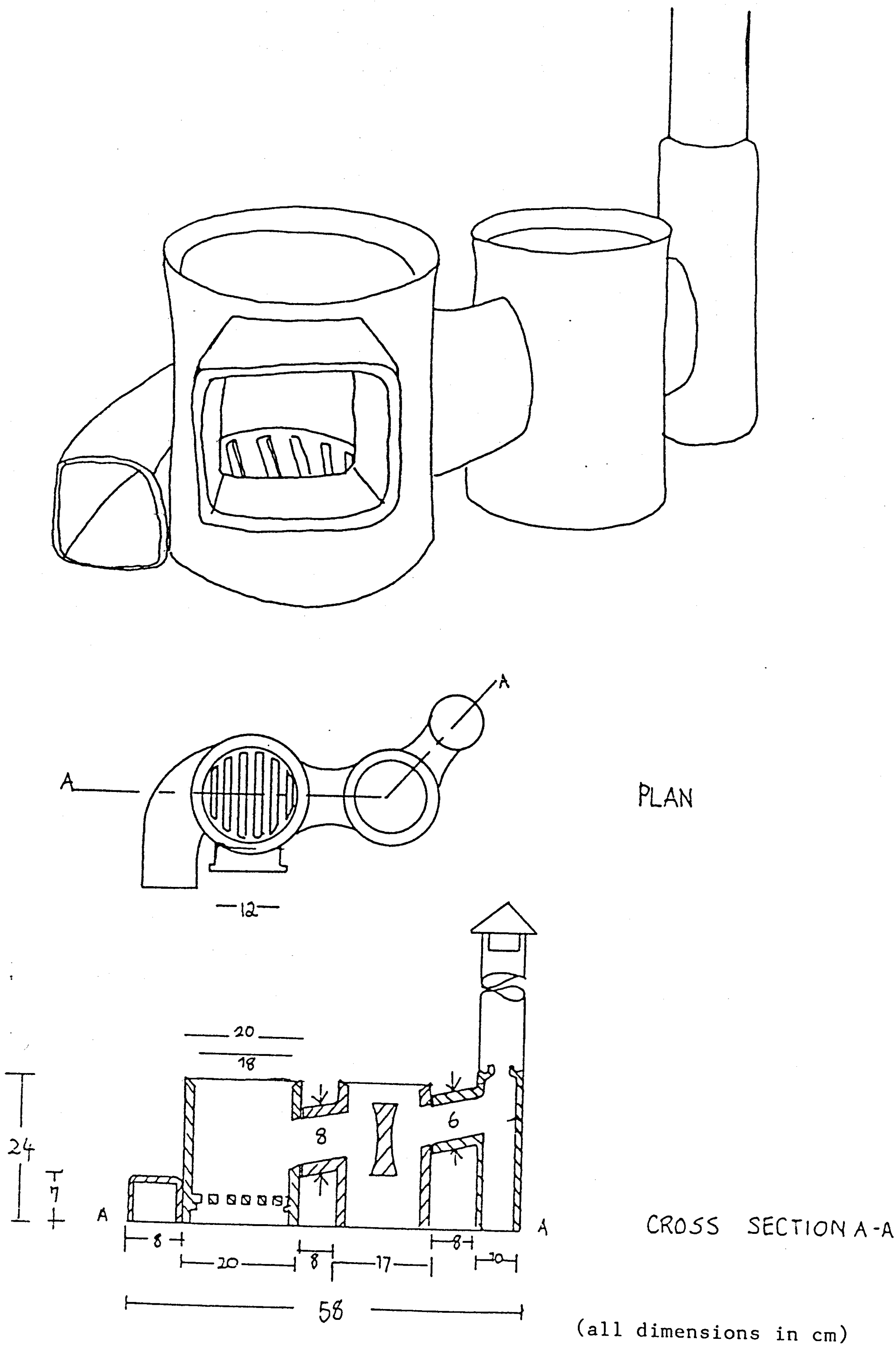


Fig 3.31 Portable Magan chulha
(Joseph *et al*, 1980)

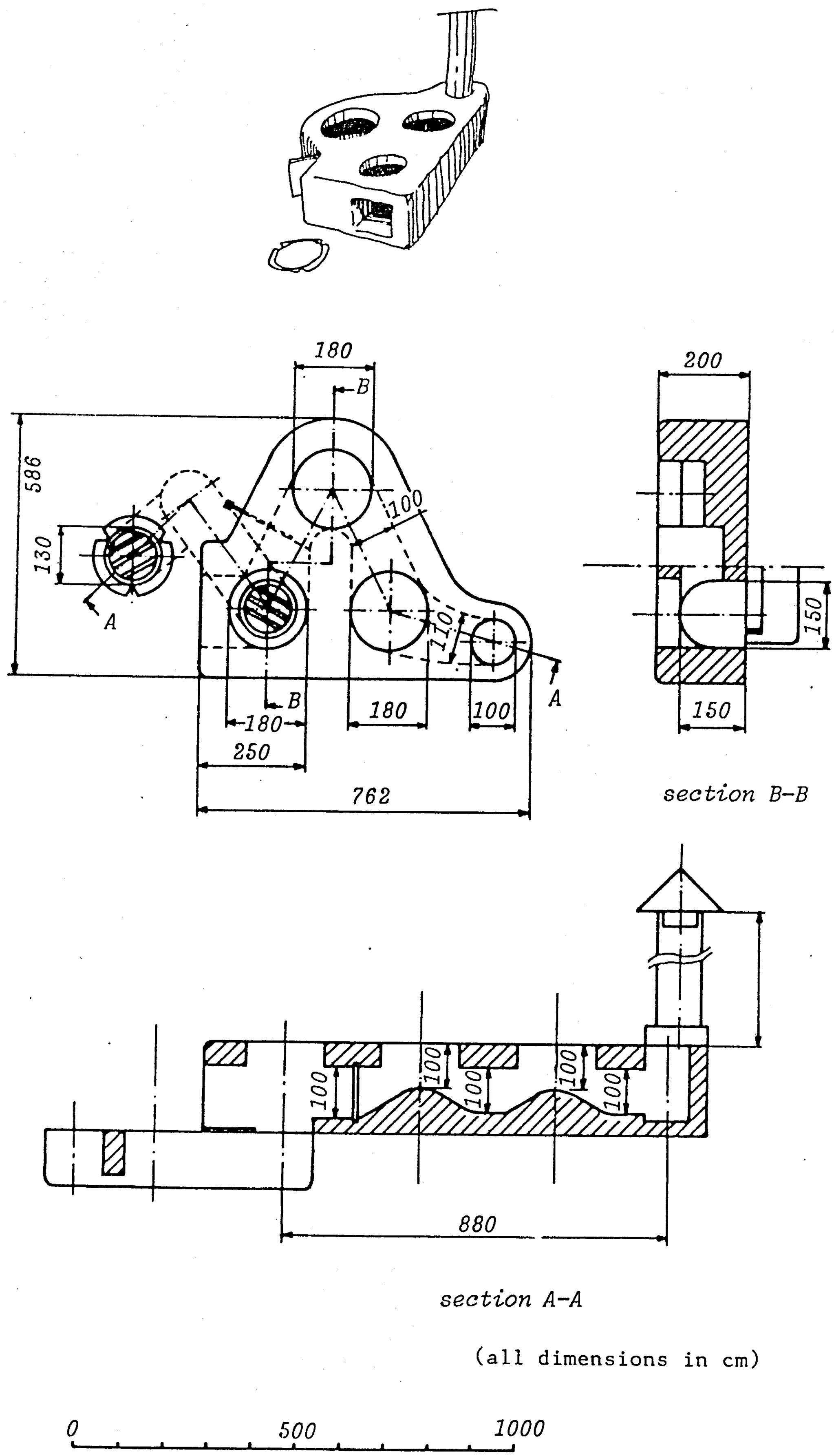


Fig 3.32 'Fixed' Magan chulha
(De Lepeleire et al, 1981)

PHU's around 7% were obtained in WBT's on a portable 2-pot version of the Magan chulha, conducted by ITDG (Shanahan, 1980). PHU's of 12% have been reported in subsequent tests (Joseph and Shanahan, 1980b). It was later found that the Magan chulha had not been correctly set up, and PHU's between 16% and 22% have been obtained (Joseph and Loose, 1982).

(b) Tandoor Stove

The Tandoor stove (Fig 3.33) was designed by ITDG in 1978 (Joseph et al, 1980), and modified in accordance with feedback from M. Garg (ATDA) to ensure that the stove was suitable for cooking pratices in northern India. WBT's were conducted using 2 aluminium pots (each containing 2 litres of water). PHU's ranged between 14 - 18%; the water in the second pot reached a maximum of 80°C. The lifetime of the Tandoor stove is estimated to be more than 2 years.

(c) TERI/ITDG

The TERI/ITDG stove (Fig 3.34) is a modification of a stove designed by the Tata Energy Research Station in 1980 (Joseph et al, 1980). WBT's by ITDG consisted of heating 2 litres of water in each of two aluminium pots (Joseph et al, 1980:38). A combined PHU of 20% was obtained in bringing the water in the first pot to boiling point and raising the temperature of the water in the second pot to 66°C,. The lifetime of the stove is estimated to be 2 years.

(d) Tungku Sae

The Tungku Sae (Fig 3.35) was developed by Dian Desa in 1980, based on the traditional Indonesian stove and the Tandoor stove (Joseph et al,

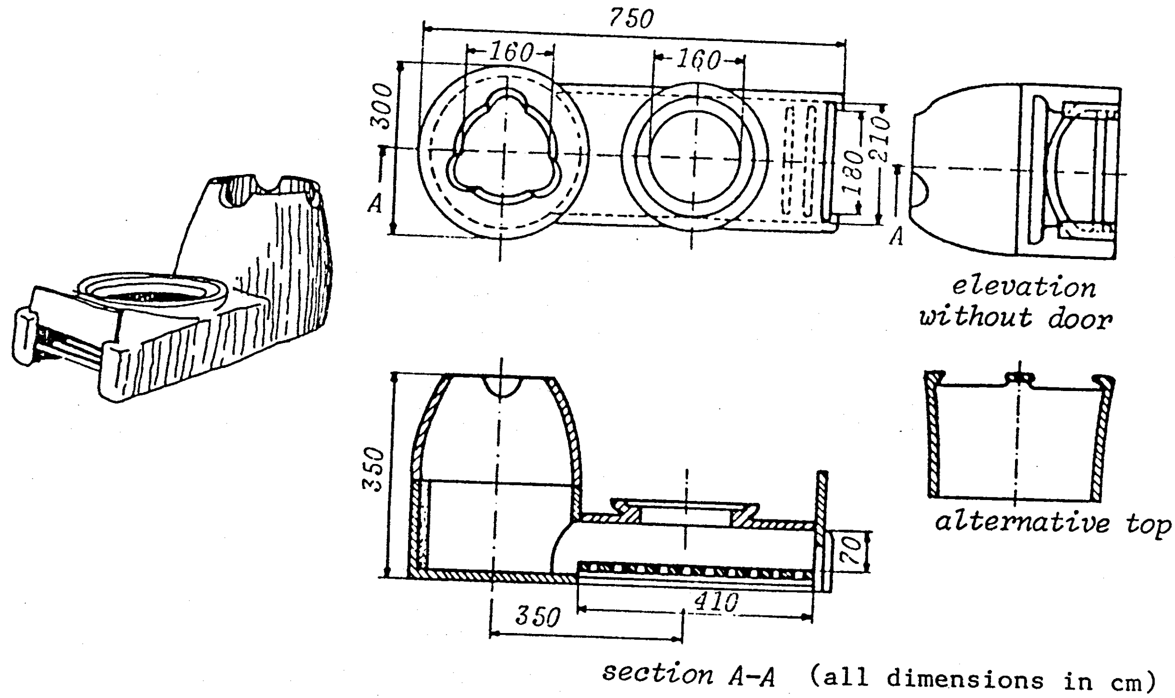


Fig 3.33 Tandoor stove
(De Lepeleire et al, 1981)

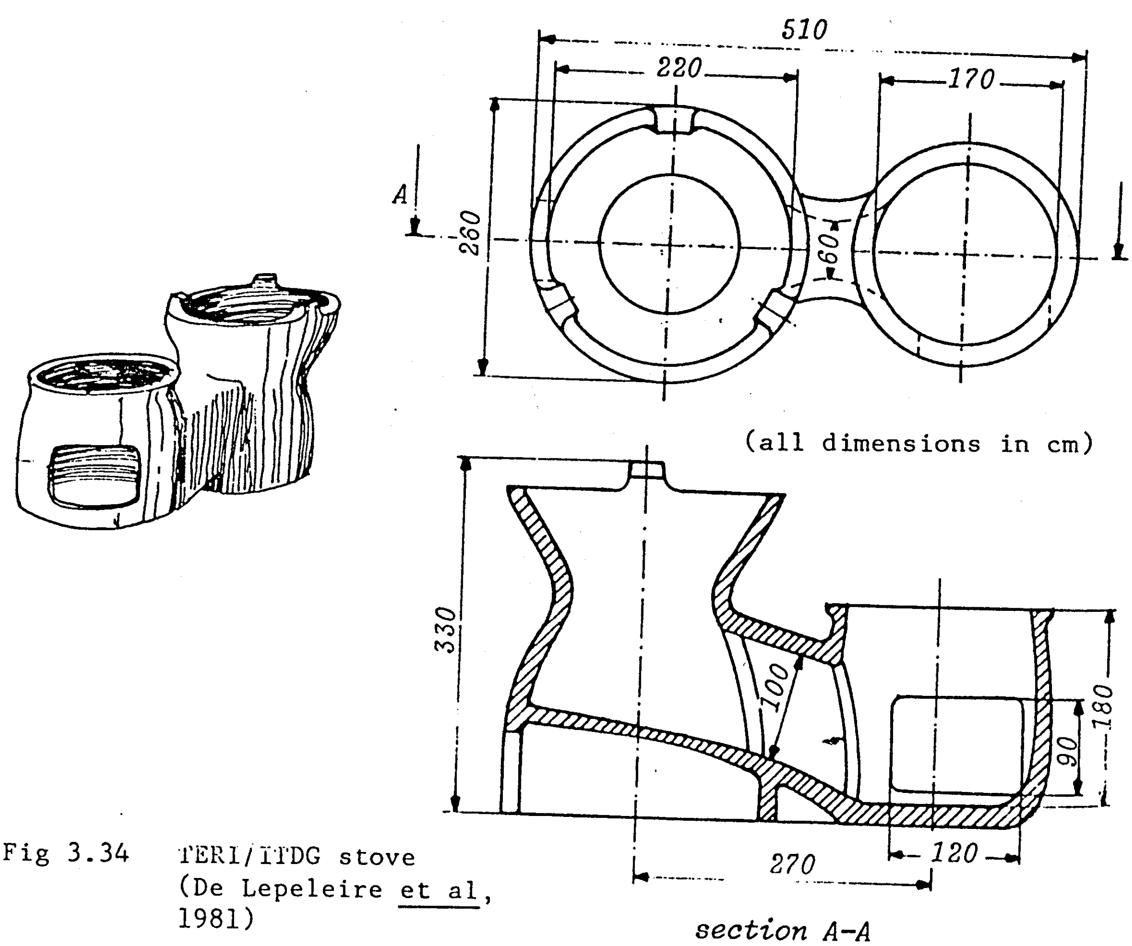


Fig 3.34 TERI/ITDG stove
(De Lepeleire et al, 1981)

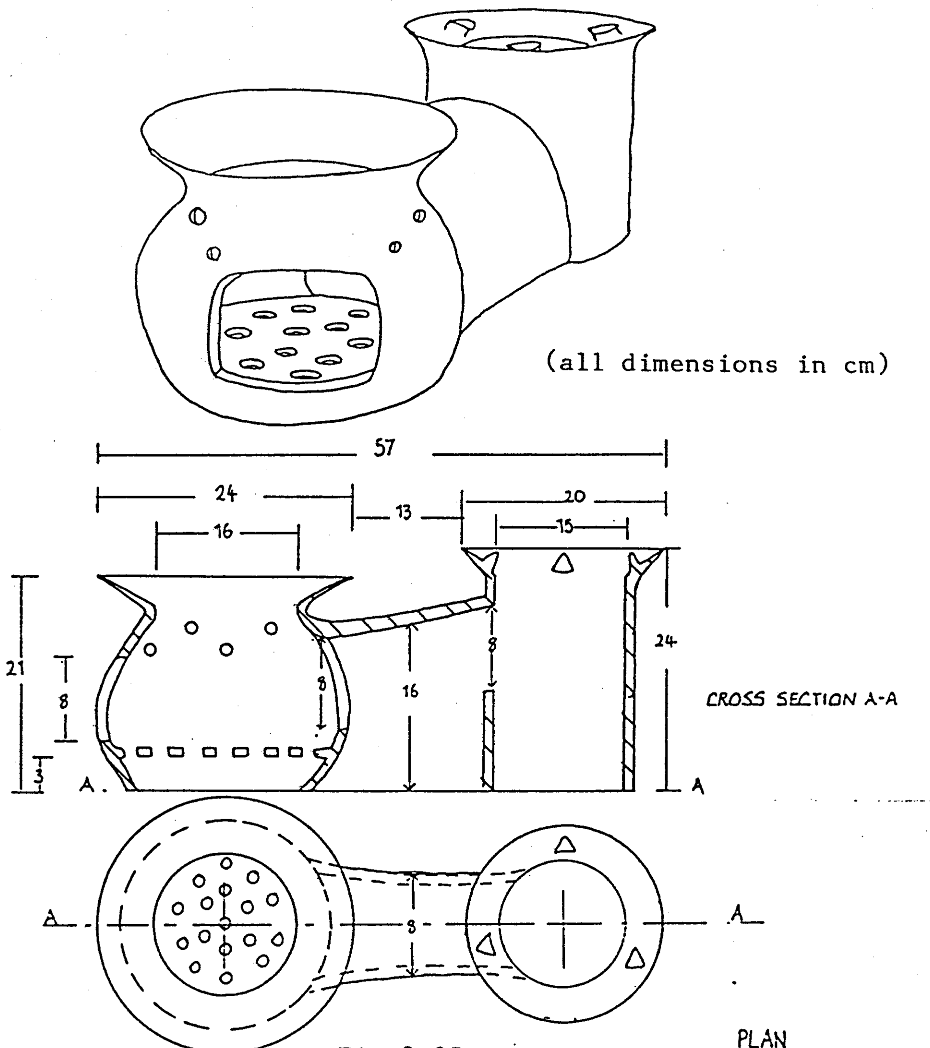


Fig 3.35 Tungku Sae
(Joseph et al, 1980)

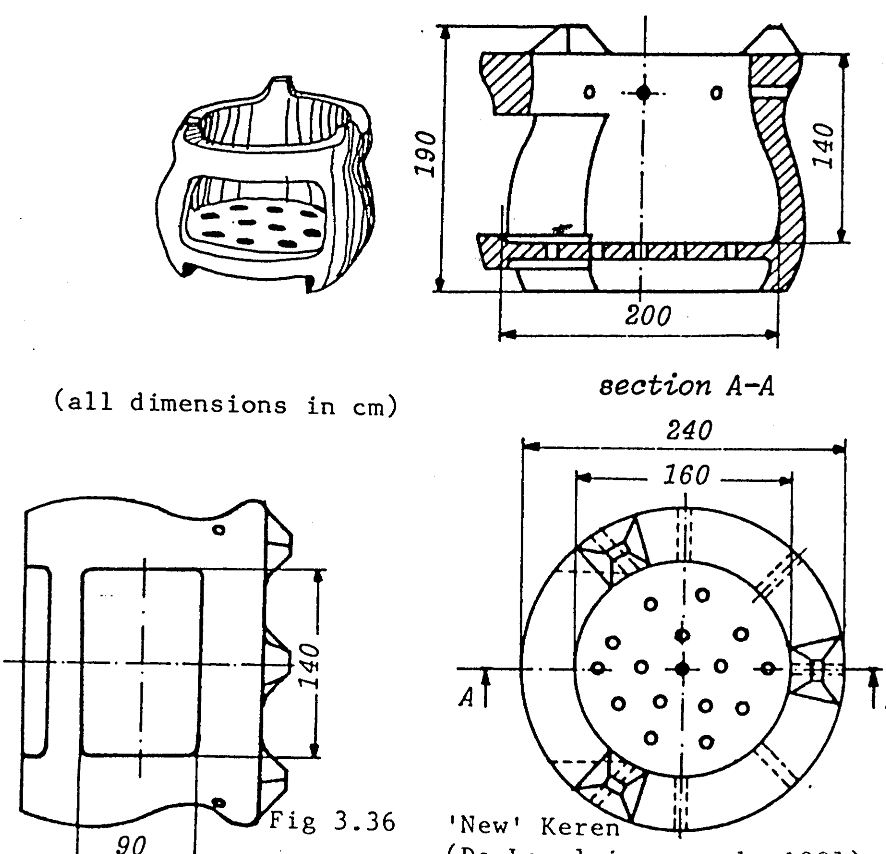


Fig 3.36 'New' Keren
(De Lepeleire et al, 1981)

1980: 20-22). Five WBT's carried out at Dian Desa in which 2 litres of water in each of two aluminium pots, were heated. PHU's in the range 16-19% were obtained in bringing the water in the first pot to boiling point.

(e) <u>the 'new' Keren stove</u>

The Keren stove (Fig 3.36) is widely used for fast cooking (usually for boiling water or frying) in central Java. WBT's conducted by ITDG (Joseph <u>et al</u>, 1980) gave PHU's which were not significantly different compared to the traditional design. The estimated lifetime of the improved version is 2 years.

3.5.3 <u>Improved stoves: an assessment</u>

Fuel efficient cooking stoves require the following: all the fuel to undergo combustion, a maximisation of the heat transfer to the cooking vessel, minimisation of the thermal losses from the cooking pot, and controllability of the heat output of the burning fuel (de Lepeleire <u>et al</u>, 1981; Dunn, 1985).

Improved stoves can conveniently be grouped into 2 categories: 1-pot and multi-pot designs (Dunn, 1985). In 1-pot designs a cooking vessel is placed directly over the burning fuel - the hot gases liberated from the fuel flow past the bottom and sides of the cooking vessel and subsequently escape. Heat is transferred from the flames by both radiation and convection. In multi-pot stoves these hot gases, after hitting the first cooking vessel, are channelled to other pots. With these latter designs a chimney is sometimes added to increase the draft and remove smoke. In both cases the heat transfer is sensitive to the relative positioning of the fuelbed and pot.

The heat transfer from the hot gases to the cooking pot can be increased by having the pot lower in the stove body. Heat losses from the pan can be reduced by insulation or by using a lid. The burning rate of the fire can be controlled by moving the wood in or out of the fire, or through the use of dampers.

The performance of various improved stoves within these two categories will be similar. Any difference in fuel economy will be due to variations in critical parameters such as the pot/fuelbed distance (see Chapter 5; Bussmann et al, 1983) or the velocity of the hot gases (de Lelpeleire et al, 1981). Fuel consumption will also depend on the skill of the stove user and both the size and type of fuel used in the tests.

A potential adopter of a new/improved stove is likely to be interested in a stove which is simple to use, fits in with traditional cooking practices, has a low cost (either in monetary terms or construction time), easy to maintain, has a low fuel cost and produces low levels of smoke if used in an enclosed space (Dunn, 1985). A summary of such features are given for stoves promoted as being both smokeless and fuel efficient (Table 3.4) and stoves that were fuel efficient (Table 3.5). Detailed comments about each stove are given in section 3.5.1 and 3.5.2.

Nearly all the stoves promoted as being both fuel efficient and smokeless, were constructed from mud (unfired clay) and were not generally portable (Table 3.4). Most of these stoves had dampers (to control the heat output of the burning fuel). In effect, they were not simple to use and the cook had to be taught how to use the dampers. The designers of most of these stoves claimed fuel savings of around 50%

Table 3.4

Stoves claimed by their designer's to be smokeless and fuel efficient
(see section 3.5 for more details)

Features of stove	Malawi mud stove type A	Malawi mud stove type B	HERL chulha	Improved Egyptian stove	Singer stoves	GS stove	Ghanian stove	Nepali chulha	Lorena stove	Magan chulha
approx. year of design	1984	1984	1953	1953	1961	1980	c.1960	1979	1976	1957
Cost (£)	n.a.	n.a.	n.a.	n.a.	n.a.	1	n.a.	n.a.	3	n.a.
Construction time*	n.a.	n.a.	n.a.	n.a.	3-4 days	n.a.	n.a.	n.a.	n.a.	2-4 hrs
Fuel savings claimed by designer (%)	ncm	5	50	30	60-75	50	50	50	50	>50
PHU at BP1 from WBT's (in lab)	n.a.	n.a.	n.a.	4-5	20-30	n.a.	n.a.	n.a.	n.a.	4-12
Fuel savings in cooking food (in lab) (%)	50	50	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Level of fuel savings observed in field trials	n.a.	14	n.a.	n.a.	n.a.	n.a.	none	n.a.	none	n.a.
Complicated to use/training required to use stove	n.a.	n.a.	yes	yes	yes	yes	yes	yes	yes	n.a.
smokeless in practice	n.a.	n.a.	no	n.a.	no	n.a.	no	n.a.	no	n.a.
No. of dampers	none	none	1	1	1	1	2	2	2	none
Construction material	mud	mud	mud	mud	mud	mud	mud	mud	mud	fired clay
Grate	no	no	no	no	no	no	no	yes	no	yes
Estimated lifetime (years)	0.5	0.5	3	n.a.	n.a.	<6	n.a.	n.a.	2	2
Portable version	no	no	no	no	no	no	no	no	no	yes
Mass (kg)	n.a.	n.a.	150	300	1000	70	1000	n.a.	200	100
No. of pot holders	2	1	2-4	2	2-3	2	3	3	2 or more	2 or more

*construction time in <u>hours</u> by <u>potter</u> to fabricate ceramic stove

Key
n.a. - information not available;
ncm - no claim of fuel saving made by stove designer.

Table 3.5

Stoves claimed by their designer's to be fuel efficient

(see section 3.5 for more details)

Features of stove	Economical Indian chulha type A	Economical Indian chulha type B	Economical Indian chulha type C	1-pot Louga	Tungku Lowon	Malawi mudstove type C	new Keren	Tandoor	TERI/ ITDG	Tungku Lowon	Tungku Sae
approx. year of design	1978	1978	1978	1981	c.1979	1984	n.a.	1978	1980	c.1979	1980
Cost (£)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Construction time*	n.a.	n.a.	n.a.	n.a.	2-6 hrs	n.a.	1-2 hrs	6 hrs	n.a.	2-6 hrs	2-3
Fuel savings claimed by designer (%)	n.a.	n.a.	n.a.	30-60	50	0	ncm	ncm	ncm	ncm	ncm
PHU at BP1 from WBT's (in lab) (%)	16	12	14	n.a.	22-23	n.a.	16-20	14-18	20	n.a.	16-20
Fuel savings in cooking food (in lab) (%)	n.a.	n.a.	n.a.	n.a.	n.a.	60	n.a.	n.a.	n.a.	n.a.	n.a.
Level of fuel savings observed in field trials	n.a.	n.a.	n.a.	n.a.	n.a.	none	n.a.	n.a.	n.a.	n.a.	n.a.
Complicated to use/training required to use stove	n.a.	yes	yes	n.a.	n.a.	no	no	n.a.	n.a.	n.a.	n.a.
No. of dampers	none	none	none	none	none	none	none	one	none	none	none
Construction material	mud + sheet steel	as type A	as type A	mud	mud	mud	fired clay	fired clay	fired clay	mud	fired clay
Grate	no	yes	yes	no	no	no	yes	yes	no	yes	yes
Estimated lifetime (years)	n.a.	n.a.	n.a.	n.a.	two	0.5	two	two	two	n.a.	n.a.
Portable	no	no	no	no	no	no	yes	no	n.a.	yes	yes
Mass (kg)	20	20	20	100	80	n.a.	3	30	12	8	8
No. of pot holders	1	1	1	1	2	1	1	2	2	2	2

*construction time in hours by potter to fabricate ceramic stove

Key

n.a. - information not available;

ncm - no claim of fuel saving made by stove designer.

but gave no field data to substantiate this belief. Moreover, a number of these stoves were not smokeless in practice (see section 3.6a).

From the mid 70's attention shifted to designing and promoting stoves which were their designers claimed were fuel efficient (Table 3.5). A number of these stoves were made from fired clay and constructed by skilled potters in the space of a few hours. The time to build the fired clay stoves varies from 1 - 6 hours (Table 3.5), however, it is not clear why there should be such a wide variation in the construction time given that these stoves look remarkably similar. It is important to note however that for most of these stoves no claims of actual fuel savings are made.

3.6 Reasons for the "failure" of "Improved" Mud Stoves

"Improved" mud stove programmes in developing countries have failed to displace traditional designs to any extent. Various reasons have been put forward to explain this failure, and are considered below.

(a) "Improved" Mud Stoves did not Live Up to Expectations

"Improved" stoves were envisaged to reduce the time spent in firewood collection since the increased efficiency would reduce the demand for firewood. Not all "improved" mud designs were more efficient than traditional designs, moreover, stoves that did save firewood initially deteriorated very quickly over time.

One reason for the low efficiency of some of the "improved" stoves was poor or inaccurate construction. For example, a number of Lorena stoves in Indonesia were found to be constructed badly which increased their fuel consumption (Joseph, 1980). In Indonesia, Dian Desa found that the trained stove builders were unable to build Lorena-type stoves according to design or effectively train others (Soedjarwo, 1982). In Sri Lanka, Lorena stoves had a lower efficiency than the traditional stove, since only 2 pot holes out of the 4 were used in cooking (Howes et al, 1983:24)

In any case an increase in the end use efficiency of fuelwood, may not reduce firewood consumption by as much as expected, since villagers may become less careful in their use of fuel or expect higher living standards. In the U.K., for example, higher insulation standards have led to higher house temperatures - as a result not all the potential energy savings have been realized (Chapman and Lowe, 1984).

More efficient stoves do not necessarily mean a fall in the time spent in collecting fuel, since fuel collection may be done in conjunction with other tasks (e.g. collecting fodder, cattle grazing, children playing). In addition, firewood collection is not universally regarded as a burden (see Chapter 2).

In other cases there were problems with smoke or the operation of the "improved" designs. For example, the "improved" stove promoted in Ghana gave off smoke when unused pot holders were not tightly covered (Martin, 1979). In Guatemala, some Lorena stoves created as much smoke as the traditional 3-stone fireplace (Shaller and Shaller, 1979). In the late 1950's, an 'improved' stove (said to be able to burn fuel very efficiently) was introduced in South India. There were two problems with this stove. Firstly, flames would rise to a height of about one metre, during the initial stages of operation. Secondly, the stove required the wood fuel to be cut up into lengths six inches by one inch, which the wood splitters were not prepared to do (Rao, 1962:22).

(b) <u>men control decision-making in the household</u>

It is argued (e.g. Gamser, 1979; Agarwal, 1980:78; Norman, 1981:5) that men perceive little gain from expenditure on technology which benefits primarily women, and hence are reluctant to buy or build an 'improved' stove. Makhijani (1979) with reference to the HERL chulha contends that

> "**in India many have designed more efficient stoves** using local materials and traditional techniques but these have made little headway. I suspect that lack of effective extension or higher first cost are not the fundamental causes of the failure... The fact that women collect wood and cook and face the smokey fire from the traditional stove may have more to do with this failure" (Makhijani, 1979:30) (emphasis added)

However, another reason could be that the HERL chulha is less efficient than the traditional designs.

(c) <u>The problems are perceived differently by the rural poor</u>

"Improved" stove programmes have focussed on efficiency and venting smoke from the kitchen. As will become clear, high cooking efficiency is only one feature of stoves and is not necessarily the one considered the most desirable. The following will show that one of the major barriers is the multiple role of traditional stoves and fireplaces in societies in developing countries.

"Improved" stove progammes emphasize savings of firewood and smoke-free kitchens, however, the rural poor perceive benefits differently. Villagers in Senegal (Evans, 1981: pers comm; Gern et al, 1981), Sri Lanka (Joseph, 1982: pers comm; Howes et al, 1983) and Indonesia (Joseph, 1980; Soedjarwo, 1982) were more concerned about being able to cook quickly than about fuel efficiency. The desirability of fast cooking has also been reported for charcoal stoves in Tanzania (Sneiders, 1984:16) and solar cookers in Sudan (Brattle, 1983).

In other cases, access to clean water for villagers can have a much higher priority than fuel supplies (Thomson, 1980). Hoskins (1979:19) reports that villagers in Burkina Faso (formerly Upper Volta) were more concerned about the water supplies, provision of education for their children, health care, jobs for young adults, and enough food and income to keep their families together, than about forestry products. Joseph (1980:8) comments that firewood gathering was not a high priority to villagers surveyed in Indonesia. The villagers main concerns after water was increasing their income. Desai (c.1978) argues that this is because there is no firewood problem and that no studies show an energy shortage being perceived by the rural poor.

The following examines why the perceptions of the villagers are not the same as "improved" stove designers. It will be argued that traditional stoves and fireplaces have to be seen in the context of the **rural energy system** within which they are situated - this is illustrated below by examples from Sri Lanka (taken from Howes et al, 1983) and Bangladesh (taken from Islam, 1980).

In Sri Lanka, there is a strong **association** in the minds of the villagers **with installing a new stove and building a new kitchen,** such that (in some cases) there has been resistance to making one of these changes without the other. Traditionally the kitchen has a roof made out of coconut leaves, whereby smoke can escape. Consequently, villagers do not regard smoke as a problem. With the higher income groups, the kitchen has a tiled roof, and smoke is a problem. In response to this, the stove (on an elevated platform) has a chimney.

In Bangladesh, constructing a below ground (or pit) chulha, increases the distance between the stove and the kitchen roof - thereby reducing the fire risk. This is important as the kitchen is usually made from wood and leaves (Islam, 1980:63). In addition, the pit can be used to store ash (Islam, 1980).

Moreover, traditional stoves and fireplaces in developing countries are not simply used for cooking but serve a number of practical and socio-cultural functions.

In practical terms, traditional stoves produce light, heat, and smoke all of which may be considered useful.

Heat from the fire can be used for cooking food, brewing beer, providing space heat and drying things (e.g. firewood, clothes, crop residues).

Traditional stoves and fireplaces are versatile. For example, the 3-stone fireplace and will perform reasonably well over a range of cooking activities (Dickinson, 1980: pers comm). The 3-stone fireplace in Zimbabwe is also used to support a large oil drum for brewing beer (see Chapter 6) as well as cooking and after a meal has been cooked, the hot ashes can be used to roast tubers, (IEA, 1979:16; Dunkerley, 1979:359). A variety of cooking fuels can be used in the traditional

Sri Lankan stove. This is important since crop residues are used when available. However, crop residues are much more 'bulky' than firewood; the design of stoves is such that the distance between the pot and hearth between 12 and 17cm. This distance is much larger than would be the case if only firewood was used, and the main aim of the cook was to minimize firewood consumption. Where there is a very high reliance on crop residues the gap may be even greater (e.g. 20 - 23cm). However, this large gap allows more crop residues to be placed in the hearth as well as reduce the amount of time spent in tending the fire.

Some of the various functions of stoves and fireplaces (in addition to cooking) are outlined below:

Utilization of Heat

In Guatemala, the major source of resistance (Shaller and Shaller, 1979) to the Lorena stove (purposely designed to have a high mass and low thermal conductivity), was that it gave out very little space heat. Some were prepared to put up with this inconvenience, while others used the Lorena stove for cooking, and used the traditional 3-stone fireplace for the provision of heat - the latter practice defeating the primary objective of reducing firewood consumption!

In Fiji, fires are kept burning all night in the sleeping quarters of old people, and in parts where it is cold (Siwatibau, 1981:71).

In the traditional Fijian kitchen, the fireplace is at ground level above which a drying rack is built - this rack holds firewood and other items to be dried e.g. clothes and crops (Siwatibau, 1981:7). Public health authorities in Fiji advised women to raise this fireplace

(0.6 -0.9m) above the ground and to place a broad chimney over the fire to vent the smoke; these are known as "Indian fireplaces" (Siwatibau, 1981:71). However, it was no longer possible to place a drying rack above the fireplace, and the Indian fireplace was not used for drying. This modification may have increased firewood consumption since the drier the firewood, the less the heat energy lost in driving away the moisture.

Social and Cultural Functions

Traditional fireplaces may provide a social focus (Brokensha and Riley, 1978; Stryker, 1982) as well as have a symbolic value. In Ghana, the 3-stone fireplace symbolises a united family (Martin, 1979).

In parts of Nepal, villagers believe that a spirit dwells in their traditional hearth. According to Bajrachaarya (quoted in Makhijani, 1979:26) this is why the villagers do not use other "more efficient" stoves.

The manifold functions has been highlighted in Kenya, where

> "a fire is regarded as being essential at night, to keep away hyenas and other wild animals, to deter thieves and intruders, and to serve as a focal point for a range of activites -- these included story-telling to children, conversations with visitors, or discussions with elders. For older people, the fire was especially important as a welcome source of warmth: although Mbere Division never registers really cold temperatures, the month of Githano (July)

> is always overcast and old people (presumably because older people feel the cold more) complain about the penetrating cold and damp mists." (Brokensha and Riley, 1978:2-3).

In these respects, the concept of high cooking efficiency has little value or meaning. The importance of the multiple functions of stoves and fireplaces is beginning to be recognized (e.g. O'Keefe, 1982; Foley and Moss, 1983).

However, whilst traditional stoves and fireplaces in developing countries perform a number of functions, this does not mean that villagers are unwilling to change, provided there are **perceived** benefits. For example, in Ghana,

> "Although the three-stone stove is used as a symbol of a united family this emotional factor has not stopped women from using alternative fireplaces for specific purposes. They also alter the three-stone fireplace by putting rocks or earth between two of the stones when there is wind, etc. Women are willing to experiment with new stoves. If a stove really saves up to half the daily fuel or more, what woman would choose the extra hours of hauling wood?" (Hoskins, 1979:41).

Whilst in this case, there does not seem any significant difference in a user modifying their stove or fireplace by the addition of a few other rocks or earth for stability or windy conditions, villagers in Zimbabwe have **spontaneously** transferred from the 3-stone fireplace to stoves which they perceived to be better (see Chapter 6)

3.7 Reactions to Failure of "Improved" Mud Stove Programmes

The previous section has shown that in many cases, "improved" mud stoves **used the same or more fuel than the traditional designs.** "Improved" mud stoves that did use less firewood were prone to deterioration in performance over 6 - 9 months.

This section examines the strategy adopted by stove promoters in Sri Lanka and Indonesia to the failure to achieve widespread dissemination of "improved" mud stoves. Background information is given below on two organizations (Sarvodaya and Dian Desa) which initiated "improved" stove programmes in the late 1970's. These organizations have been singled out for two reasons: firstly, both organizations appear to be having some level of success in disseminating "improved" stoves, and secondly a great deal of information is available on their respective stove programmes.

(a) Sarvodaya Movement

Improved stoves have been promoted in Sri Lanka since 1979 by the Sarvodaya Movement. Sarvodaya is a Non-Governmental Organisation (N.G.O.) established in 1978 to "promote an **integrated approach** to rural development" (Howes et al, 1983:2) (emphasis added). Emphasis is placed on "both widespread participation and a reassertion of traditional cultural values of cooperation and self reliance" (Howes et al, 1983:2). The main aims of the stove programmes are threefold: firstly, to improve the quality of womens lives (e.g. reducing the time spent in fuel collection and cooking as well as removing smoke from the kitchens);

secondly, to improve the kitchen environment (in terms of appearance and hygiene in food preparation); thirdly to reduce firewood consumption.

(b) Dian Desa

Dian Desa is based in Indonesia and is involved in "training village workers in all aspects related to community development" (Joseph, 1982:4). These village workers are trained in agriculture, health and hygiene, small village industries and water supplies.

Dian Desa's aims in disseminating "improved" stoves are similar to those of Sarvodaya (Soedjarwo, 1982:2). In addition, it is argued that if women spend less time in cooking and collecting fuel they would be able to spend time in economically productive activities.

For "improved" stoves to have a significant impact on fuel consumption a large number of stoves need to be disseminated. Dian Desa aimed to do this by transferring the skills of stove construction to the users (Seodjarwo, 1982:3).

Dian Desa decided to shift to a new stove design and an alternative dissemination strategy as a consequence of the following problems: firstly, the general failure of the Lorena-type stoves to save fuel, the difficulty in obtaining stoves which were built according to the given design parameters, and finally the bottleneck caused by the low productivity of the Lorena stove builders to this type of design.

The new stove designs were modifications of traditional Indonesian designs - this is an important consideration as it would reduce socio-cultural resistance.

As users in both Sri Lanka and Indonesia were not particularly worried about smoke, it was not necessary to have stoves with chimneys. In addition, stoves with chimneys need more attention (Loose, 1984:pers comm). **High chimneys** can easily create high drafts leading to rapid burning of the fuel. The hot gases produced are quickly lost through the chimney. This means that baffles (which have to be adjusted) are needed. These problems are much less severe if **low chimneys** (which would vent the smoke at a greater height than would have been the case in a chimneyless stove) are used (Joseph, 1984:pers comm).

Dian Desa and Sarvoydaya both opted for the dissemination of "improved" **ceramic insert** stoves (see section 3.3.2). The pottery liner stoves promoted were based on the Tungku Lowon design - for at least three reasons (Soedjarwo, 1982): firstly, initial testing of improved ceramic stoves suggested that they were capable of high efficiencies (the Tungku Sae "achieved efficiency ratings of 20%"); secondly, it was possible to produce large numbers of (accurately made) stoves at a high rate of productivity by experienced artisans - the pottery liners could be also surrounded by mud (e.g. the fixed Magan Chulha); thirdly these pottery liner stoves were prone to slower physical deterioration through use compared with mud designs.

Potters in Sri Lanka can produce between 150 and 200 pottery liners per month (Howes et al, 1983:28; Sepp, 1984:22). In 1983, women in Sri Lanka were ordering ceramic insert stoves at the a rate of about 200 per month (Joseph, 1983:15). An estimated 6,000 of these stoves have been sold in Sri Lanka between 1982 and 1984 - the retail price of each 2-pot design is around 17 Rs (note 34Rs = £1) (Young, 1984:pers comm). In Indonesia these "improved" ceramic insert stoves were planned to be disseminated (!) using the existing family planning network in villages.

3.8 Conclusions

A traditional cooking stove or fireplace is a deceptively simple technology, but its functions in rural societies in developing countries are multifaceted, and may be intimately linked to social and cultural factors. Any substitute must give an overall benefit, if it to be favourably received. In addition, the users or stove designers may not necessarily be aware of the ecological bases of traditional practices or designs - the use of smoke as an insect repellent is a case in point.

Because of these manifold functions within the village system, stove efficiency may not have the highest priority from the point of view of the stove user. Other features such as versatility, speed of cooking, convenience, and status, also need to be taken into account.

Fuel efficient stoves can essentially be categorized into 1-pot and multi-pot designs. The performance of stoves within these categories should be more or less the same. Differences in the measured fuel economy of stoves within each of these categories will be a result of differences in critical parameters such as fuelbed/pan distance, arrangement of baffles, and so on, as well as the skill of the operator.

Most early "improved" stoves had a high mass and were constructed from mud. Attempts to achieve widespread dissemination of these improved mud stoves have largely been characterized by failure. A number of these "improved" mud stoves were less efficient than traditional ones. In addition, the performance of improved mud stoves deteriorated over a period of 6 - 9 months. Consequently, maintenance is required, either by stove artisans or (preferably) the user themselves.

As a consequence of the realization of the **technical** shortcomings of "improved" mud based stoves (e.g. rapid deterioration of performance, high labour cost) there has been a shift to "improved" pottery liner stoves based on traditional designs. Skilled artisans can produce these stoves accurately and at high rates of productivity.

The chances of successfully diffusing new stoves would be enhanced by modifying the traditional stove (if possible) rather than introducing something completely new. This would also bypass any sociocultural constraints, since it is a design which is already acceptable to users. Additionally, designing <u>with</u> people rather than simply <u>for</u> people, as well as producing a stove which has a low opportunity cost to obtain and maintain (whether in terms of labour or cash) would all help.

One of the key assumptions of the strategy to reduce firewood demand by promoting "improved" stoves was that traditional stoves were very inefficient. However, it has been found that not all traditional stoves were less efficient than the 'improved' designs that were promoted. The next chapter examines the basis of this belief in the low efficiency of traditional stoves and fireplaces as modes of cooking.

Chapter 4

TRADITIONAL STOVES AND FIREPLACES

4.0 Introduction

The main reasons for introducing "improved" stoves in developing countries were to decrease firewood consumption and the amount of smoke produced during cooking in rural kitchens. This chapter will show that:

(1) it is widely believed that traditional stoves and fireplaces used in developing countries are thermally very inefficient (with efficiencies ranging between 5% - 10%);

(2) experimental work shows that whilst some stoves are inefficient (with PHU's <10%), efficiencies are considerably higher (PHU's in the range 10% - 28%) depending on the type of stove and skills of the user;

(3) efficiency is a complex question and depends on the whole **system** of cooking (e.g. fuel, stove, cooking pots, and cooking practices) - this point is also taken up in Chapter 5 which details the experimental tests carried out on traditional stoves by the author at the Open University.

4.1 Efficiencies of cooking stoves and fireplaces

Values of cooking efficiency have been given for a number of stoves and fireplaces used in developing countries. Most authors give values of the efficiency for the "stove" type, whilst a few authors give values simply for the fuel used (Table 4.1) (e.g. Kaskhari, 1977; Openshaw, 1980). Some authors refer to the cooking method they are considering (e.g. 3-stone fireplace or brick chulha). Others generalize about all stoves in developing countries, for example there are references to "stoves and fireplaces in Third World homes" (Knowland and Ulinski, 1979) and "stoves in developing countries" (Baron, 1980).

There is some confusion in the literature about the various types of fireplaces used in developing countries. For example, the terms "open fire", "hearth" and "3-Stone fireplace" are often used interchangeably. In the cases of both Siwatibau (1978, 1981) and Weir and Richolson (1980) reference is made to the Fijian 'two stone' fireplace as the 'open fire'.

4.2 Basis of Efficiency Data

The basis for the data reported in the literature on the 'efficiency' of traditional stoves and fireplaces can be divided into four categories: firstly, data which is "anecdotal", secondly where the author refers to another source, thirdly data obtained by comparing the magnitude of cooking energy consumption in two countries and finally data based on empirical work.

Most of the work cited falls into the first two categories. The figures in these two categories are remarkably consistent, (mostly in the range 5 - 10%), and are almost all derived from literature written between 1978 and 1981. One explanation is that these authors have either drawn upon each other or another common source.

Table 4.1

"EFFICIENCY" DATA WITH NO ORIGINAL SOURCE GIVEN

COOKING METHOD	AUTHOR	QUOTED 'EFFICIENCY' (%)
Stoves in general		
"stoves in developing countries"	Baron (1980)	"grossly inefficient"
"woodstoves"	Mackillop (1983)	10
"stoves and fireplaces in Third World homes"	Knowland and Ulinski (1979)	3-8
"Primitive stoves"	Desch (1973)	10
cooking in developing countries	Hayes (1977)	<9
Open fires and variations		
Hearth	McGranahan *et al* (1980)	10
	Smith (1981)	6-8
	Stanford (undated)	8
Open fire	Desch (1973)	10
	Digernes (1978)	6-8
	IEA (1978)	5-10
	Dunkerley (1979)	10
	Gamser (1979)	10
	ROCAP (1979)	<10
	Morgan and Moss (1980)	5-10
	Norman (1981)	5
	Hottenroth (1982)	6
	Tiwari (1982)	"very low efficiency"
	Munasinghe (1983)	5
	Sodha and Prasad (undated)	5-10
3-Stone fireplace	Club du Sahel (1978)	3-8
	KiZerbo and de Lepeleire (1979)	3-8
	Mnzava (1980)	10-12
	Vita (1980)	"Very wasteful on fuel"
	Norman (1981)	7
	Smith (1981)	6-8
	Moss and Hall (1981)	7-8
	Lequeux (1982)	<5
	Thomas and Amalfitano (1982)	"wasteful of heat"
Mud stoves		
"Open chulha"	Raju (1955)	"extremely low efficiency"
"chulha"	Prasad *et al* (1974)	11
"Mud chulha"	Gupta (1982)	"very low efficiency"
"Brick chulha"	" "	" " "
"open chulha"	Nanda (1982: 58)	17 (firewood) 11 (cow manure)
"chulah"	Tiwari (1982)	"very low efficiency"
Fuel		
Cowdung	Kashkari (1975)	11
Firewood	Openshaw (1980)	7-8

4.2.1 'Anecdotal' Data

The first category contains those figures which are apparently anecdotal and have no acknowledged source or direct literature reference (Table 4.1). This category contains the largest number of efficiency figures given in the literature - thirty six in all. Nearly all the efficiency values are in the range 5-10%.

4.2.2 Efficiency Data Where the Author Cites Another Source

Fourteen references fall into this category (Table 4.2). Of 11 authors whose sources where checked, there were eight end references (Fig 4.1). Of these eight ultimate source references, four have relied on published experimental testing methods. Data by Ascough (pers comm) and Franklin et al (1977) are unpublished and unavailable, despite several requests; both Revelle (1976) and NCAER (1959) are considered in section 4.2.4. The data by Makhijani and Poole (1975) is discussed in section 4.2.3. Both the paper by Makhijani (1976) and Prasad et al (1974) do not give a source for the efficiency figure, and hence fall into the category of 'anecdotal' data listed in Table 4.1. Makhijani (1976) explicitly states that he has assumed the efficiency value.

An example of how evidence can get passed on and become part of the accepted wisdom can be seen in the following flow of citations: Arnold (1979) cites Floor (1978) as his reference source, whilst Floor (1978) refers to an earlier paper by himself (Floor, 1977). Floor (1977) refers to Le Developpement Voltaique (1976) as his ultimate source this does not contain any efficiency data! Floor (1981: pers comm) acknowledges this and cites two other references ("a publication by the Village and Khadi Commission on Gobar gas, and a shorter Makhijhani

Table 4.2

AUTHOR REFERS TO ANOTHER SOURCE

COOKING METHOD	AUTHOR	QUOTED 'EFFICIENCY' (%)	SOURCE OF DATA
Stoves in general			
"traditional modes of cooking"	Floor (1978)	8	Floor (1977)
(closed) "wood fire"	Vanin et al (1980)	10-43	Goldemberg and Brown (1979)
"wood stoves"	Revelle (1980)	5-10	Revelle (1976)
	Pearson and Stevens (1984)	6	Makhijani (1976)
Open fire and variations			
open fire	Revelle (1978)	10	Revelle (1976)
	Goldemberg and Brown (1979)	5-10	Franklin et al (unpublished)
	FRIDA (1980)	2.5	Ascough (pers comm)
	Newham (1984)	5	Makhijani (1976)
3-Stone Fireplace	Arnold (1979)	8	(a) Makhijani and Poole (1975) (b) Floor (1978)
	Floor (1977)	8	Le Developpement Voltaique No. 40 (August, 1976
	Morgan et al (1979)	5-10	Goldemberg and Brown (1979)
Mud stoves			
chulha's			
	Bene et al (1978)	5 to 11	Makhijani and Poole (1975)
			Prasad et al (1974)
	Somasekhara (1978)		NCAER (1959)

Table 4.3

SOURCE OF 'EFFICIENCY': COMPARISON OF DOMESTIC ENERGY

Cooking Method	Author	"Efficiency"	Source of efficiency data
Open fire	Makhijani and Poole (1975)	5%	Comparison (domestic) energy used in U.S.A. and India

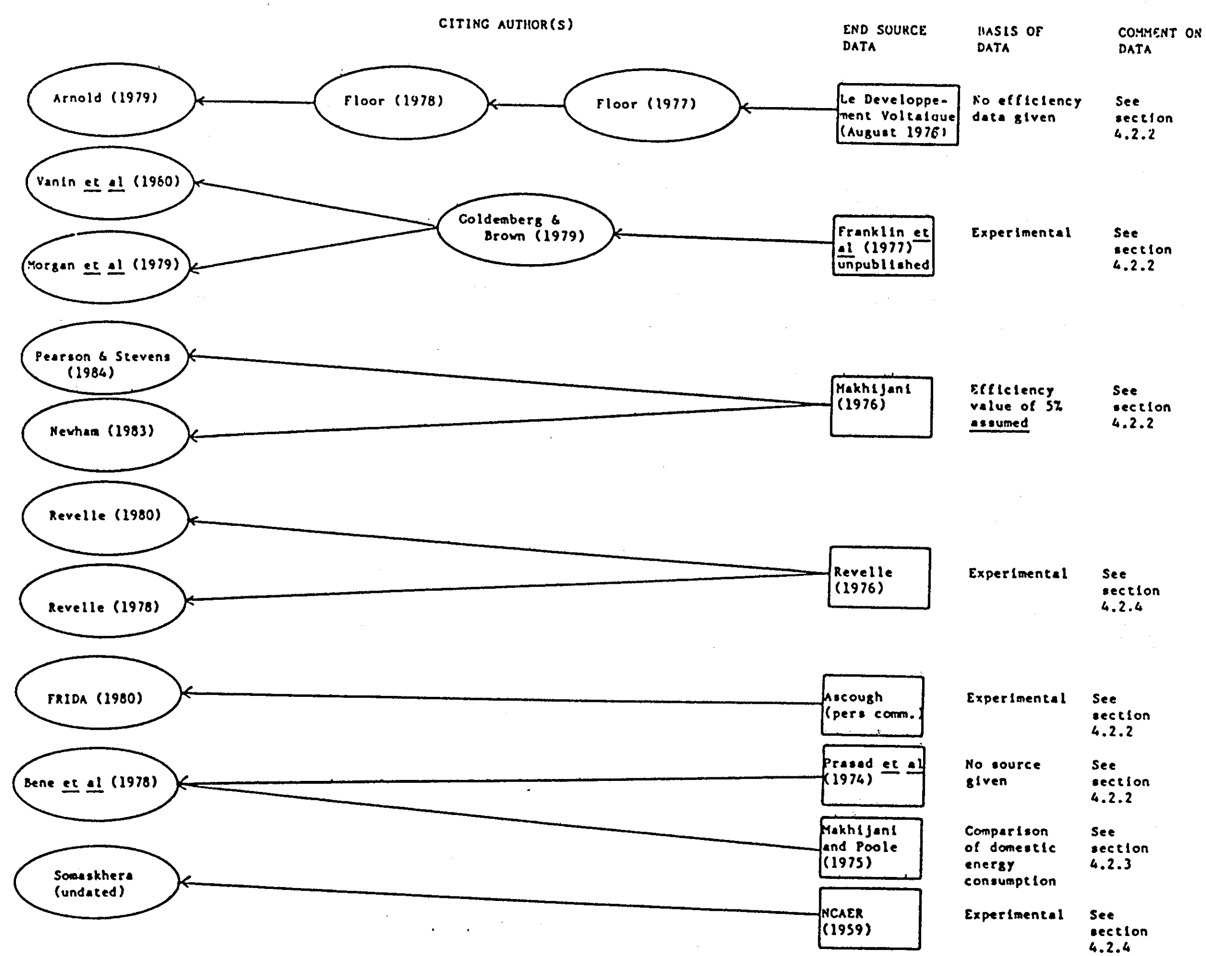


Fig 4.1 Citation flows for stove "efficiency" data

study") from which he obtained the data.

4.2.3 Comparison of Cooking Energy Consumption in Different Countries

There is only one example in this category: Makhijani and Poole (1975) who compare the magnitude of domestic energy use in rural India - based on work by Revelle (1976) - and the U.S.A. From these data, the domestic energy use per capita figure for India is four times that of the USA, whence, the efficiency of cooking in India is calculated to be one-quarter of that in the United States. In addition,

> "If we assign an efficiency of 20 per cent to gas stoves - **somewhat arbitarily** - then the efficiency of rural cooking would be about 5 per cent." (Makhijani and Poole, 1975:27) (emphasis added).

This is the underlying logic that Makhijani and Poole use to arrive at the 5% figure of efficiency (Table 4.3). Assuming for the moment this logic to be valid, then simply altering the value of the assumed efficiency of gas cookers will change the calculated efficiency of cooking in rural India. Values of efficiency of gas cookers in the U.S.A. varies between 30% and 60% (depending on the power output and type of pan) (Knapp et al, 1966) - these figures would mean that the calculated efficiency of cooking in rural India would lie between 7.5% and 15%.

However, this method of estimating efficiencies may contain further errors, as there are difficulties in comparing the magnitude of domestic energy in the US and India. For instance, foods purchased in the US will tend to be processed, pre- or partially cooked. All these will reduce the domestic cooking energy demand. Another implicit assumption in this analysis is that the same amount of food is cooked, (i.e. same useful cooking demand). The average US citizen does not eat the same amount of food as the average rural Indian. These would have to be taken into account in any attempt at comparison.

4.2.4 Data based on empirical work

Data based on experimental work gives a wide variation in the values of "efficiency" (Table 4.4).

(a) Cooking in India

Revelle (1976) obtains a figure of just under 9 per cent for the efficiency of fuel use in India. The empirical basis for Revelle's efficiency figure is as follows:

> "two experiments with rice cooking showed that the energy required to bring the cooking water to boiling and to boil away the requisite quantity of water is about 600 kcal/kg, or 17.5 percent of the food energy content of rice" (Revelle, 1976:972)

Revelle makes the following assumptions: firstly other food grains behave similarly to rice (ie they also require 17.5% of their calorific value to be cooked); secondly that 75% of the energy "biomass" (ie firewood, crop residues and animal manure) is available for cooking food. A value of the efficiency of cooking fuel can then be calculated if the food energy intake and energy from firewood, crop residues and animal manure are known. Revelle estimates that the average food energy intake per capita per year is 0.78×10^6 Kcal, and the energy from the

Table 4.4

SOURCE OF 'EFFICIENCY' DATA: EXPERIMENTAL WORK[1]

COOKING METHOD	AUTHOR	QUOTED PHU[2] (%)
cooking in India	Revelle (1976)	<9
Open fire and variations		
"fire under 3-legged pot"	Best (1979a, 1979b)	1.27-7.33
3-Stone fireplace	Brattle (1979)	11.2-25.5 (13.3-30.3)
	Visser et al (1979)	13-26
	Joseph and Shanahan (1981)	14-30
	Visser and Verhaart (1980)	11-23
	Ascough (1980)	3.5
	Bussmann et al (1983)	22-36
	Ouedraogo et al (1983)	4.9-17.4
3-Stone fireplace + grate	Visser and Verhaart (1980)	11-26
"Fijian" Fireplace	Weir and Richolson (1980)	3.8-5.1
	Siwatibau (1981)	5-10
Bangladeshi Chulha's		
"one-mouth" chulha	Islam (1980)	4.3-10.0
"two-mouth" chulha	" "	12.5-19.5
Mud stoves		
one-pot stoves		
Indian brick 'U' chula		
(firewood logs)	NCAER (1959)	13-15 (17-19)
(small pieces of firewood)	" "	19.1 (24)
Indian 'U' chulha		
(firewood)	Salariya (1978, 1983)	12.3
(cow manure)	N.C.A.E.R. (1959)	10.1-10.7
Indian 'U' chulha + grate (firewood)	Salariya (1978, 1983)	15.8
Sri Lankan 'U' chulha	Joseph and Loose (1982)	10.4-16.2
Two-pot stoves		
Egyptian design	Theodorovic (1954)	3-4.4
Indonesian design	Singer (1961)	6-7
Indonesian "	Joseph (1983)	1217
Indian design	Geller (1980)	6-14
Three-pot stoves		
Indonesian design	Singer (1961)	6-7
Indian design	Geller (1980)	8-14
" "	Geller (1982)	3-9

[1] WBT's were used by all authors except Revelle (1976) who conducted two experiments cooking rice.

[2] see text for explanation of PHU figures in brackets.

biomass sources for domestic use is 1.57 x 10^6 Kcal/capita/year. Hence,

$$\text{"efficiency of cooking"} = \frac{\text{food energy intake/capita/year} \times 0.175}{\text{domestic energy from biomass} \times 0.75} \times 100 \ \% \quad \text{Eqn 4.1}$$

$$= \frac{0.78 \times 10^6 \times 0.175}{1.57 \times 10^6 \times 0.75} \times \frac{100}{1}$$

$$= \mathbf{11.6\ \%}$$

Revelle's figure is 9%, which suggests that he has made an arithmetical error.

Revelle gives very little detailed information regarding the rice cooking tests he conducted on rice. Popali et al (1979) obtained values around 1210 kcal/kg to cook rice. Using this data would roughly double the value of the efficiency of cooking from 11.6 to 23%.

However, the determination of the energy required to cook food items is not simple since the energy needed is not a constant quantity, but depends on the physical properties of the food (e.g. the size or degree of fibrous material), as well as subjective qualities (e.g. when the food item is regarded as being "cooked"). Food can be cooked much more quickly and use less energy through being cut into small pieces compared large pieces. Similarly, the energy required to cook pulses can be reduced if they are soaked prior to cooking.

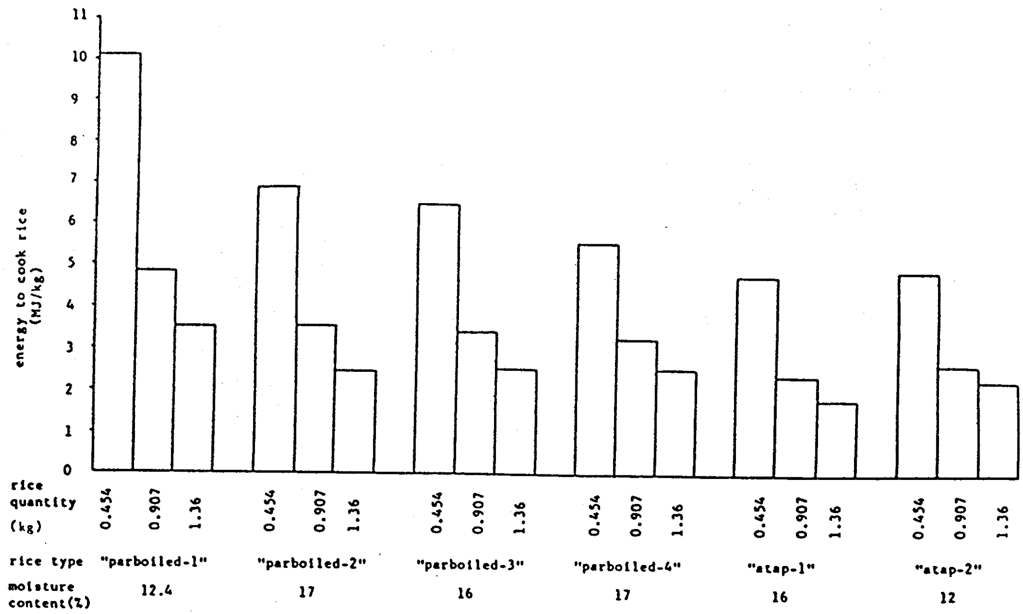
Islam (1980:111) describes two methods used to cook rice. In one method, the amount of water added to the rice is such that no water remains when the rice is fully cooked; this is termed the "dry method". In the second method, rice is cooked with "excess" water, such that water remains at the end of the cooking process. This water is poured away once the rice is cooked. The amount of water, in excess of that required for cooking rice using the "dry method", depends on the quantity and type of rice used (Islam, 1980).

Experimental work by Islam (1980) showed that the amount of energy to cook rice depends not only on the type and quantity of rice, but also on the amount of water used (Fig 4.2) and the type of cooking vessel: cooking rice in a pan with a round bottom used about three-quarters of the energy required with pan with a flat bottom.

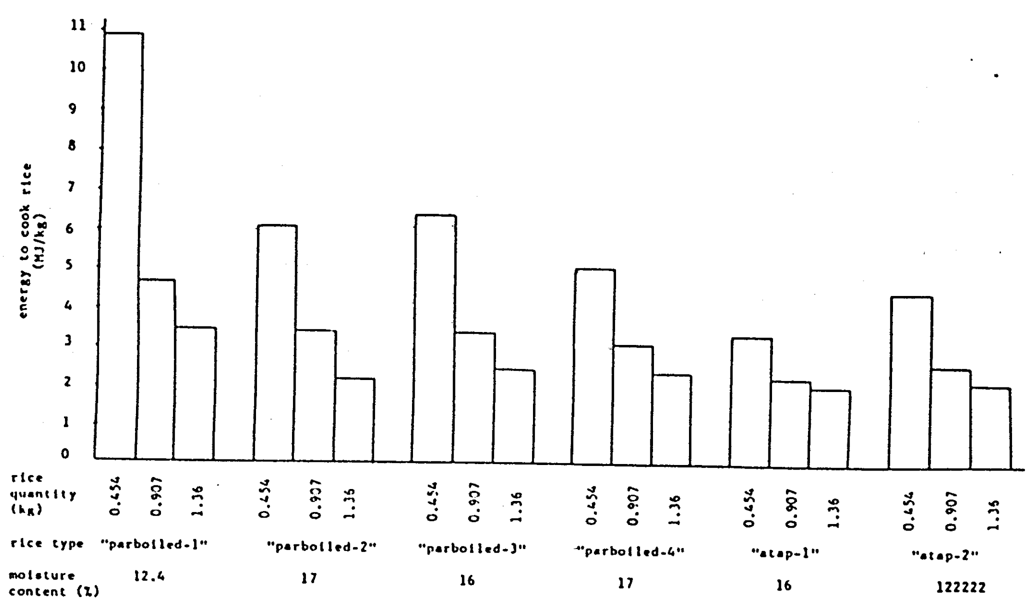
(b) Fire under a three-legged pot

Best (1979a, 1979b) describes one traditional method of cooking in Southern Africa as "a fire underneath a three legged pot (Fig 3.1). Best defines the efficiency only for the process of bringing water from ambient temperature to boiling point. No correction is made for the moisture content on the calorific value of the fuels; all the values he uses for the calorific value of both firewood and animal manure are for oven-dry material.

Best does not mention wind speed. For experiments performed outside, Joseph and Shahanan, (1981) found that high winds decreased the measured value of PHU of the 3-stone fireplace from 30% to 12%. French (1984) similarly reports the adverse effects of wind in field tests in Malawi on the fuel consumption of the 3-stone fireplace. In data by Best (1979b),PHU's obtained for tests inside a cooking hut were higher than those performed outside: **the maximum value using firewood was only 7.33%**, (cf minimum of 1.52% for results obtained outside). Lower PHU's were obtained using manure (Table 4.5).



(a) cooking rice with the "dry method"



(b) cooking rice with the "excess water" method

Fig 4.2 Energy to cook rice using Kerosene
(Islam, 1980)

Table 4.5

"Efficiencies" measured with "fire under 3-legged pot" (Best, 1979b)

	Place	Air temp (°C)	Location	Wood (kg)	Dung (kg)	Total energy (MJ)	Time of test (min)	Volume of water (litres)	Temp. rise of water (°C)	Fuel	Efficiency (%)
1	Joz Nek	13	outdoors	0.60	1.88	35.26	34	3	78	dung	2.77
2	Joz Nek	13	outdoors	0.32	0.82	16.76	22	1	82	dung	2.05
3	Joz Nek	17	outdoors	1.45		33.07	16	1.5	80	wood	1.52
4	Joz Nek	17	outdoors	1.69		38.48	21	3	78	wood	2.54
5	Malefiloane	12	outdoors	0.32	2.01	30.44	23	2	83	dung	2.14
6	Malefiloane	15	outdoors	0.40	4.10	35.68	30	2	83	dung	1.94
7	Malefiloane	14	outdoors	0.80		18.61	17	2	77	wood	3.46
8	Mashunka	19	inside	0.45		9.46	19	2	83	wood	7.33
9	Mashunka	19	inside	0.76		9.83	14	2	77	aloe*	6.55
10	Malefiloane	21	inside	0.20	1.38	29.33	21	2	85	dung	2.42
11	Malefiloane	21	outdoors	0.40	3.95	54.61	30	2	83	dung	1.27
12	Malefiloane	21	inside	0.40	2.93	43.48	42	2	78	dung	1.50
13	Mashunka	16	inside	0.79		16.61	10	2	82	wood	4.13
14	Mashunka	16	outdoors	1.18		24.82	12	2	79	wood	2.66

* plant with erect spikes of flowers

(c) 3-Stone Fireplace

Experimental tests on the 3-Stone fireplace have been reported from the late 70's onwards: Visser et al (1979), Brattle (1979), Joseph and Shanahan (1981) and Visser and Verhaart (1980). More recent work has been reported by Bussmann et al (1983) and Ouedraogo et al (1983). All these tests employed water boiling tests (WBT's). Tests using three bricks were conducted by Visser et al, Brattle, and Visser and Verhaart; Joseph and Shanahan, Bussmann et al, and Ouedraogo et al, all refer to tests carried out on "3-Stones".

Ouedraogo et al (1983) and Joseph and Shanahan (1981) carried out tests in the field but only the latter mention the effect of wind on the PHU; tests by all the other authors were conducted in a laboratory.

Visser et al (1979), Visser and Verhaart (1980) and Bussmann et al (1983) employed the same WBT methodology, and most of their testing was carried out under similar conditions (Table 4.6).

Visser et al do not mention the method used to light the fire, whilst both Visser and Verhaart, and Bussmann et al lit the fire by holding a propane torch on the firewood for approximately 30 seconds. In each case, 5kg of water were heated in an aluminium pan (diameter 28cm and height 24cm). Evaporated water was included in the definition of PHU; the PHU was measured after allowing the water to simmer: Visser et al do not give the length of time the water was allowed to simmer, whilst the simmering time for Visser and Verhaart was between 30 and 70 minutes, and Bussmann et al terminated the test once the water had stopped boiling. This ill-definition of simmering time makes it difficult to compare their data with work in which the PHU has been measured after a definite cooking time, e.g. Brattle (1979), Joseph and Shanahan (1981).

Table 4.6
Experimental Set-up for testing "3-Stone Fireplace"
(at Eindhoven University)

Author	**Visser et al (1979)**	**Visser and Verhaart (1980)**	**Bussmann *et al* (1983)**
Set Up	3-bricks	3-bricks	3-stones
Mass water	5kg	5kg	5kg
Pan type	Aluminium	Aluminium	Aluminium
Lid	Yes	Yes	Yes
Fuelbed/Pan distance (f.b.p.d.)	11cm, 18cm	5-23cm	7-15cm
Kindling	n.a.	propane torch	propane torch
Firewood species	n.a.	n.a.	various (see table 5.8)
Firewood dimensions (cm)	1.5 x 1.5 x 5 3 x 3 x 30	1.5 x 1.5 x 5 3 x 3 x 30	2 x 2 x 6.7 cm
Fuelbed diameter (f.b.d.)	n.a. (cm)	26 (cm)	18 (cm)
Evaporated water included in PHU term	Yes	Yes	Yes
Constants	mass of water pan f.b.d.	mass of water pan f.b.d.	mass of water pan f.b.d. charge size
Variables	f.b.p.d. wood size moisture content charge size	f.b.p.d. wood size moisture content charge size addition of grate	f.b.p.d. wood size moisture content power output addition of grate wood species
PHU - measurement	BP1S't'	BP1S't' (t= 30 -70 mins)	BP1S't'
PHU values (%)	13-27	11.8-23.6	22-36

In order to obtain measurements under steady state conditions (Visser and Verhaart, 1980) firewood was added to the fire in "charges" each time the flames died down: charges used by Visser *et al* ranged from 100 to 400g; Visser and Verhaart used charges varying from 50g to 400g; Bussmann *et al* conducted all their tests with 100g charges.

Visser *et al* (1979) describe briefly the results of preliminary laboratory based tests: WBT's were carried out at two heights (11cm and 18cm) with two sizes of pieces of firewood: "small" - 1.5 x 1.5 x 5cm and "large" - 3 x 3 x 30cm, with oven dried wood used in the vast majority of tests.

For tests conducted at a height of 11cm using the small pieces of oven dried wood in charges of 200g, PHU's of 18.9% and 19.5% were obtained. Reducing the charge size to 100g gave values 25% and 26%. Using 100g charges with a moisture content of 10.8% gave PHU's of 21% and 26.8%; Visser and Verhaart (1980) observed that a moisture content of around 5% increased the PHU (Figure 4.3).

Increasing the height to 18cm decreased the PHU: using 400g charges of the small pieces of wood gave PHU's around 13%; using the large sized pieces of wood in charges of 200g gave a PHU of 16.6%. Later work by Bussmann et al (1983) highlights the importance of the distance between the fuelbed and pan.

From this data, Visser et al conclude that small pieces of wood, small charges and (to the same extent) moisture, all enhance the PHU.

In further work, Visser and Verhaart (1980) systematically examined the effect on the PHU of parameters such as the moisture content, quantity and size of the fuel wood, distance between the fuelbed and pan, and the addition of a grate (Fig 4.3 and 4.4). Visser and Verhaart's initial testing method involved feeding small charges of wood varying from 50g to 400g into the fire. As the size of the charges was decreased the PHU increased: the PHU was 12% and 24% when using firewood charges of 400g and 100g respectively. Consequently, subsequent tests (to examine the effect of the distance between the fuelbed and pan) were carried out using fuel charges of 100g.

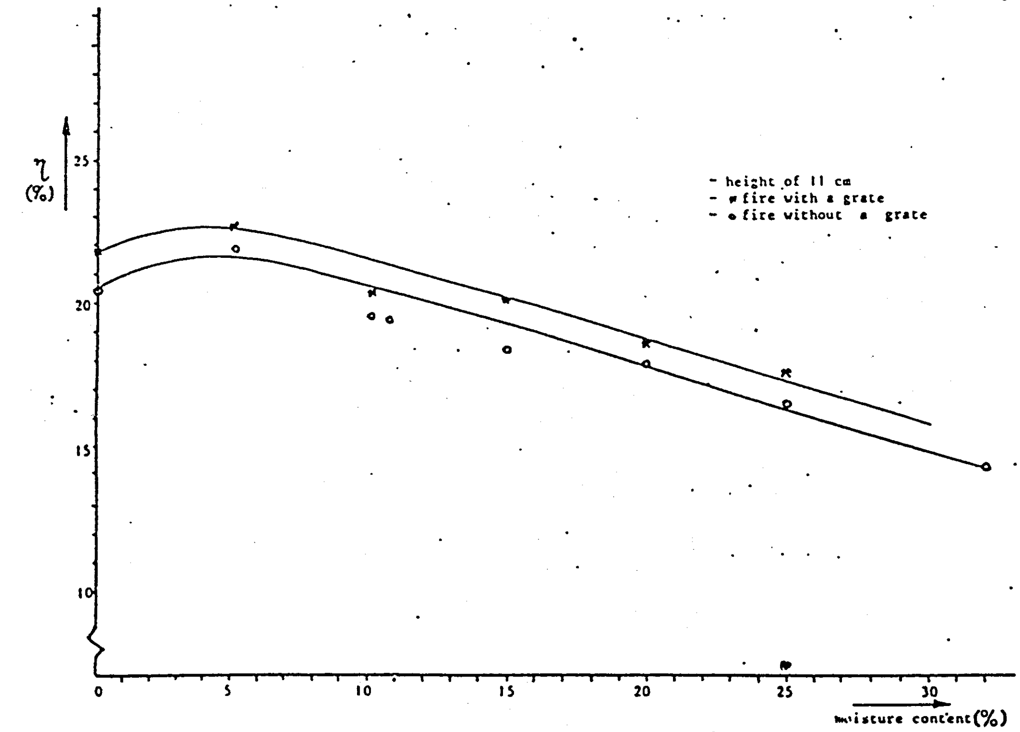


Fig 4.3 Effect of moisture content on PHU
(Visser and Verhaart, 1980)

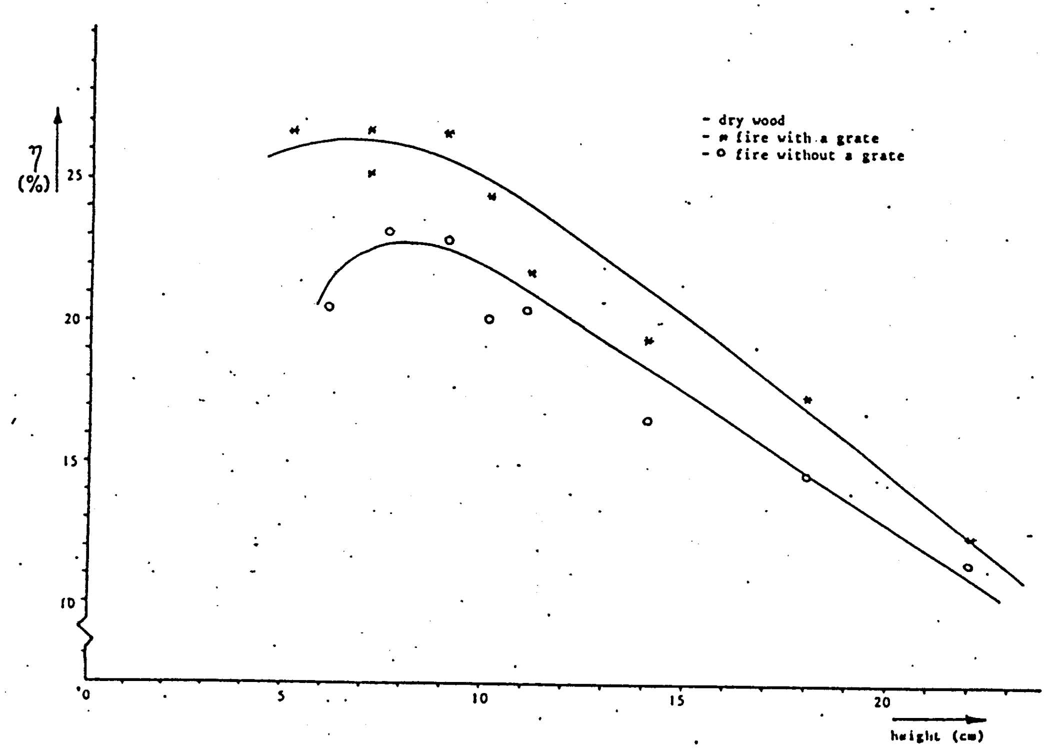


Fig 4.4 Effect of fuelbed-pan distance on PHU
(Visser and Verhaart, 1980)

The optimum height was found to lie between 5cm and 10cm: heights less than 5cm led to substantially increased quantities of smoke as well as reducing the rate of combustion. Increasing the height beyond 10cm led to a drop in PHU owing to a decrease in the transfer of heat for two reasons. Firstly, flames could not reach the pan bottom. Secondly because the pan bottom would intercept an increasingly smaller solid angle subtended by the fire, it would absorb proportionally less radiated heat energy from the fuelbed (Goldemberg and Brown, 1979; Bussmann et al, 1983).

The next series of tests examined the effect of moisture content on the PHU, and though, the optimum height was found to lie between 5cm and 10cm these follow-up tests on their 3-Stone fireplace with a height of 11cm. This would have the effect of lowering the PHU by about 10%. The PHU was at a maximum when firewood with a moisture content of around 5% was used (Fig 4.3). As expected, increasing the moisture content beyond 5% decreased the PHU as more energy is required to evaporate the moisture in the wood.

The effect of a grate is to increase the PHU (Fig 4.3 and 4.4), which Visser and Verhaart attribute to higher combustion efficiency.

Bussmann et al (1983) follow up the work of Visser et al (1979) and Visser and Verhaart (1980) and consider in detail the effects of six parameters (power output, wood species, moisture content, wood size, height of pan from the fuelbed and the addition of a grate) on the PHU of a 3-stone fireplace (Table 4.6 and 4.7). The PHU was measured at BP1S"t"; the length of time "t" the water was simmered is not given and not constant since each test was terminated when the water had stopped boiling.

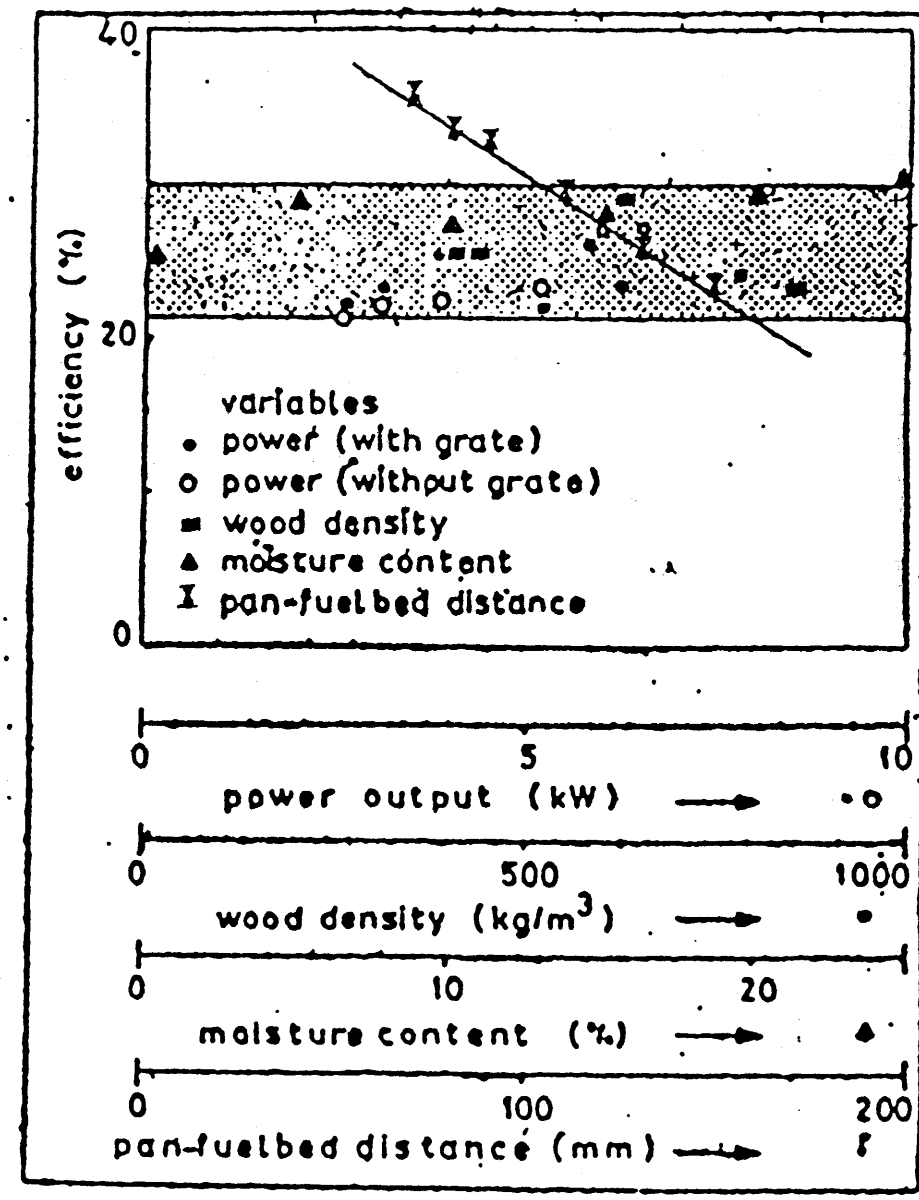


Fig 4.5 "efficiency" as a function of a number of parameters (Bussmann et al, 1983)

Table 4.7
Firewood Species Used by Bussmann et al (1983)

Botanical name	Common name	Density (kg/m^3)
Piecea abies	White fir	400
Dyera Costulata	Jelutong	440
Chlorophora regia	Iroko	580
Shorea	Meranti	600
Quercus robus	Oak	620
Fagus sylvatica	Beech	650
Intsia bijuga	Merbau	850

The PHU was not affected by altering any of the following: **power output** over the range 2.5 to 8.5kW; **density of the wood** (300 to 700 g/m^3); **woodsize** (volume-to-surface-area ratios ranging from 3.3 to 7.0); **moisture content** (oven dry wood to a moisture content of 20%); and addition of a **grate.**

The key parameter which affected the PHU was the distance between the fuelbed and the pan: a PHU of 36% was obtained when the pan was lowered to the minimum height of 7cm. Increasing this height lowered the PHU, for example, PHU was between 22 and 26% at a height of 13cm) (Fig 4.5).

Bussmann et al go on to describe a model of the open fire. This model predicts that the overall efficiency (of heat transfer due to convective and radiative components) should be independent of both the nominal power output and fuelbed-to-pan distance. Whilst no significant variation in efficiency was observed in varying the nominal power output, changing the fuelbed/pan distance had a dramatic effect on the efficiency. Bussmann et al suspect that this conflict between prediction and observation is a result of an invalid assumption in the model that the volatiles stop combusting when they impinge on the pan bottom.

WBT's by Brattle (1979) and Joseph and Shanahan (1981) were carried out at ITDG'S stove testing workshop in Reading, involving a similar set-up

(Table 4.8). Their results (along with those of Ouedraogo et al (1983)) are shown in Fig 4.8.

Table 4.8
Experimental Set-up for testing of 3-Stone Fireplace

Author	Brattle (1979)	Joseph and Shanahan (1981)	Ouedraogo et al (1983)
Set Up	3-bricks	3-Stones	3-Stones
Mass water	1.5 litres	2 - 4 kg	3kg
Pan type	Aluminium	Aluminium	Aluminium
Lid	Yes	Yes	No
Fuelbed/Pan distance	10cm	11cm	10cm
Kindling	paper	Paper + Parana Pine	Kerosene (1ml)
Firewood species	Iroko	Iroko Jelutong	n.a.
Firewood dimensions	3.8 x 3.8 x 45cm	2.5 x 2.5 x 50 cm	3 x 3 x L L=20-30cm
Fuelbed diameter	n.a.	n.a.	10 - 20 cm
Evaporated water included in PHU term	Yes	Yes	Yes
Constants	Fuelbed/Pan distance Pan type Firewood species Mass of water Size of firewood	Fuelbed/Pan distance Pan type	Fuelbed/Pan distance
Variables	Power output	Power output Firewood moisture content Mass of water	Pan type Fuelbed di--ameter Mass of water
PHU - measurement	BP1S60	BP1 BP1S30 BP1S60	Lo/Hi power tests
PHU values (%)	13-30	14-30	5-17

Joseph and Shanahan examined the effect on the PHU of wood size, wood type and moisture content. A standard height of 8.5cm (from the fuel surface to the bottom of the pan) based on the work of Visser and Verhaart (1980).

Two tropical species of wood were used: Iroko (Chlorophora regia), a dense wood which burns slowly with small blue flames, and Jelutong (Diera Costulata) a low density wood which burns much more rapidly with long yellow flames. WBT's were carried out using an aluminium pan (with a flat bottom) pan. Most tests involved heating 2 litres of water; 4 litres of water were heated in some tests.

Moisture content of the wood did not significantly affect the PHU - using wood with a moisture content of 57% (dry basis) only reduced the PHU from 20% to 17%. The most important variable was considered to be the wind around the fireplace.

Higher values of PHU were obtained for BP1S30 and BP1S60 compared to BP1 for low burning rates (power outputs) (Fig 4.6). The PHU for BP1S30 and BP1S60 fell much faster as the burning rate was increased.

Brattle's tests involved heating 1.5 litres of water (in an aluminium pan) and measuring the PHU (including water of evaporation) at BP1S60. Sticks of Iroko (Chlorophora regia), 3.8cm square (Brattle, 1984) with an oven dry moisture content 12% were used. A value of 19.58 MJ/kg is assumed for the calorific value of the Iroko, - Bussmann et al (1983) give an experimentally determined value of 18.1MJ/kg for Iroko.

Table 4.9
WBT Data on 3-Stone Fireplace
(adapted from Brattle, 1979)

Experiment No.	1	2	3	4	5	6
Power Output (Kw)	3.73	2.80	3.46	3.13	2.96	2.30
PHU* at BP1S60(%)	11.2	20	15.7	16.7	19.5	25.5
PHU (%) at BP1S60 (calorific value of firewood corrected for moisture content)	13.3	23.8	18.7	19.9	23.2	30.3

*PHU in bringing 1.5l of water to boil and simmering for 60 minutes, (evaporated water not treated as an energy loss).

Brattle's values of PHU at BP1S60 range from 14% to 30% (Table 4.9). Brattle explains the variation as due to her becoming more proficient at

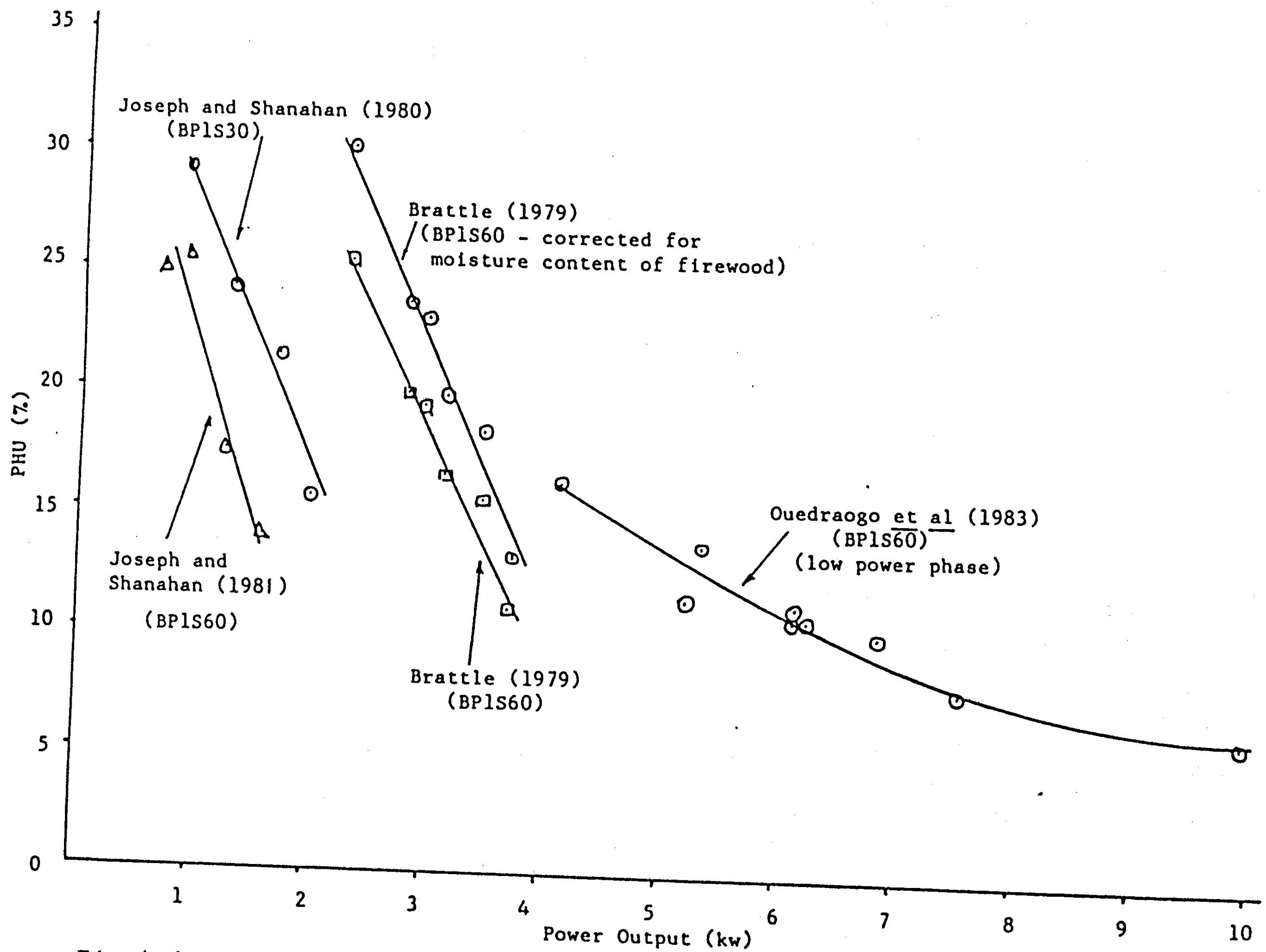


Fig 4.6 PHU VS power output
(Brattle, 1979; Joseph and Shanahan, 1980; Ouedraogo *et al* (1983)

tending the fire. Plotting the PHU against the power output shows that the observed variation is principally due to the tests being done at different power outputs (Fig 4.6), this may be a result of Brattle becoming more skilled at tending the fire.

Comparable results by Joseph and Shanahan differ from those obtained by Brattle (Fig 4.6). For Brattle, the PHU falls from 30% at 2.3kw to 14% at 3.7kw, whilst Joseph and Shanahan's data show a PHU of 25% at 0.7kw which falls to 14% at 1.6kw. One possible reason for this difference is that for Brattle the distance between the pan bottom is 6.2cm, whilst for Joseph and Shanahan this distance is 8.5cm. According to the variation of efficiency with the distance between the fuelbed and pan bottom observed by Bussmann et al, the efficiency data for Brattle would be 16% higher than that by Joseph and Shanahan. This is clearly not the case, though Joseph and Shanahan noted that the PHU for BP1S30 and BP1S60 were highly sensitive to the operating conditions or the tending skills of the user.

Ouedraogo _et al_ (1983) conducted high/low power WBT's (using 3kg of water) on a 3-stone fireplace surrounded by a 'U' shaped wind shield (80cm high, 70cm wide and 110cm deep). In the high power phase of the test, the water was brought to boiling point, and the water in the pot and the firewood used weighed (ie at BP1). This was followed by the simmering phase (low power output): the fire was relit and the wood burnt at a rate to maintain simmering; the temperature of the water was not allowed to fall below 90°C. After 60 minutes (ie at BP1S60) the test was terminated and the water, remaining firewood and charcoal weighed. Evaporated water was not treated as an energy loss for either part of the test. The amount of charcoal formed at the end of the first part of the test was not estimated or weighed but assumed to be equal to half of the charcoal that remained at the end of the complete test. This is likely to underestimate both the PHU and the charcoal that had formed and at the high output stage of the test: operating the fire at a high output will produce much more charcoal than in the low power stage (see for example the energy flow diagrams in chapter 5).

Ouedraogo et al (1983) obtained PHU's between 6.3% & 16.6%, and 4.9% & 17.4% at BP1 and BP1S60 respectively (Table 4.10).

Table 4.10
WBT Test Data on 3-Stone Fireplace (Oudraogo et al, 1983)

Test No.	BP1 Power output (Kw)	PHU (%)	BP1S60 Power Output (Kw)	PHU (%)	Average PHU (%)
11	7.5	8.1	3.5	14.0	9.9
132	4.1	16.6	3.5	15.5	15.3
151	5.3	14.1	5.2	14.3	13.8
166	5.2	11.7	4.5	16.8	14.0
184	6.2	10.7	4.2	12.9	11.3
216	6.1	10.9	4.7	13.2	11.8
231	6.8	10.3	5.2	13.7	11.9
249	6.1	11.6	3.9	17.4	14.1
267	9.9	6.3	10.4	4.9	5.4

(d) Fijian 'two stone' Fireplace

Weir and Richolson (1980) report the results of WBT's on a traditional Fijian fireplace. This arrangement consisted of a single pot supported by iron bars resting on concrete blocks with the pot 20cm above the ground and 10cm above the fire, and referred to as an "open fire".

The testing methodology is based on the stove testing methodology developed by Joseph and Shanahan (1980a),with the modification that the heat energy radiated and convected from the pot is included in the PHU. Their rationale is that this heat energy is channelled from the fire to the pot and hence should be included in the PHU term. This explanation is dubious, since this heat energy is simply lost to the environment and does not contribute to heating the food. However, the magnitude of this component is small and should not significantly affect the values given of the PHU.

The WBT procedure used by Weir and Richolson is as follows: a fixed amount of wood (2kg of firewood and 0.3kg kindling) were used to heat water (2kg) were used. Sticks of air dried mangrove wood were used and not disturbed in the fireplace once the fire had been lit. Only a small amount of unburnt firewood was left at the end since each test was carried out till the fire had burnt itself out. The water was heated from ambient to boiling point in an aluminium pan. Each test was conducted outside in the open and shielded from the breeze. Values of PHU (including evaporated water) range from 3.8% to 5.1% with an average value of 4.3% (Table 4.11).

Table 4.11
WBT test results for Fijian 'two stone' fireplace
(adapted from Weir and Richolson (1980))

Air speed (km/h)	Time to boil	simmering time (min)	PHU2 (%)	Burning rate (g/min)
3.1	15	40	4.2	41.8
3.3	11	47	5.1	40.0
-	11	47	4.4	40.0
2.8	18	45	3.9	36.5
4.4	18	50	3.8	33.8

Siwatibau (1981) also reports the results of WBT's carried out on the traditional Fijian fireplace - which she terms the "open fire". Very brief details are given of the tests carried out. Values of the measured PHU are in the range 5-10%; these are higher than the values obtained by Weir and Richolson (1980) and may be a result of the type of tests used. The values given by Siwatibau were obtained by averaging the results of two test procedures: one in which water was brought from ambient to 60°C, and in the other from ambient to 100°C.

(e) <u>Bangladeshi Chulha's</u>

Islam (1980) reports the results of WBT's on the "one mouth" and "two mouth" Bangladeshi chulha's. In addition, a survey of villagers' cooking practices and stoves was also carried out: data on cooking practices was based on the observation of the daily cooking of one family over a period of two months.

Stove testing involved heating a known mass of water until all the water had been evaporated. The hearth depth was varied in the initial tests, and two aluminium pans (one with a flat bottom and the other with a round bottom) were used. Subsequent testing involved using three different species of firewood.

Higher PHU's were obtained with the round bottom pan compared with the flat bottom pan (Fig 4.7): for the round bottom pan, as the stove depth decreased from 0.7m to 0.28m, the PHU increased from 6% to 10%; for the flat bottom pan, efficiencies as low as 4.5% were measured. The important finding here is that **decreasing the hearth depth increased the PHU.**

Smoke was produced as the hearth depth approached 0.43m. Further reductions in the depth of the hearth, led to a rapid increase in the amount of smoke. Moreover, decreasing the hearth depth below 0.43m, increased the time required to completely evaporate the water. The latter effect is a consequence of a fall in combustion efficiency with decreasing

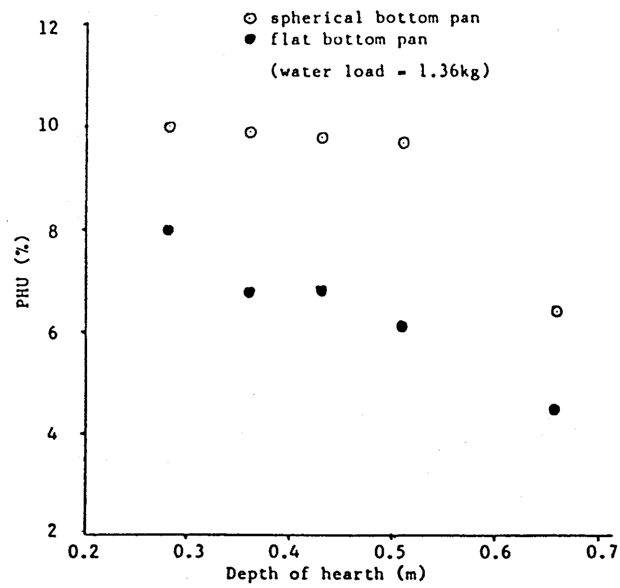


Fig 4.7 PHU VS hearth depth for "one-mouth" Bangladesh chulha (Islam, 1980)

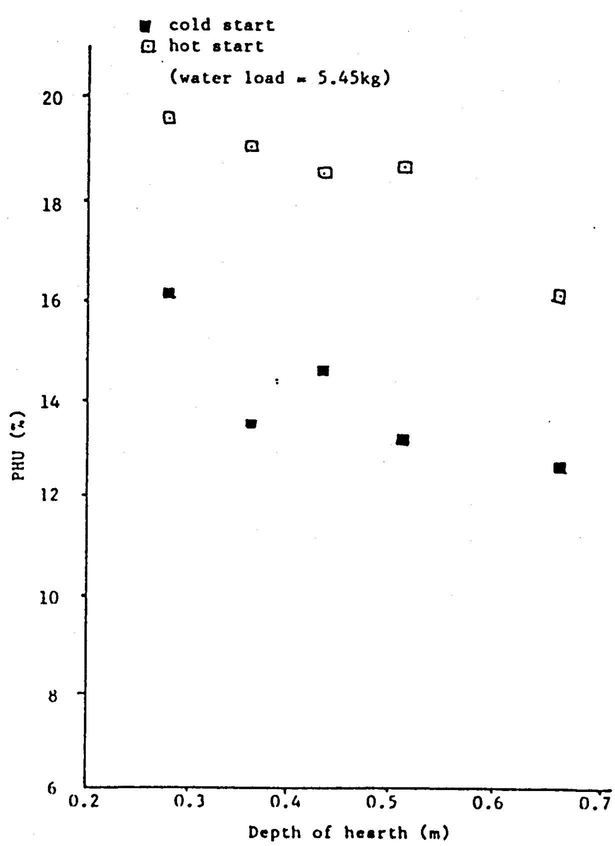


Fig 4.8 PHU VS hearth depth for "two-mouth" Bangladesh chulha

hearth depth; the degree of incomplete combustion (evidenced by the incidence of smoke) would lower the power output. On the other hand, the PHU would increase as the pan bottom would be nearer the flames (Bussmann et al, 1983). **Decreasing the hearth depth below 0.43m increased the amount of smoke.**

In effect, maximization of the PHU means a high degree of smoke production.

Survey results showed that for villagers who had "one mouth" stoves inside the sheltered kitchen, more than half (55%) had a stove depth between 0.38m and 0.58m, whilst only 22% had a stove depth less than 0.38m and 23% a stove depth of greater than 0.58m. A similar percentage (52%) of those who had their stove outside had a stove depth between 0.38m and 0.58m, whilst only 11% had a depth less than 0.38m and 36% a depth greater than 0.58m.

Islam (1980) reports a similar relationship between PHU and the depth of the stove hearth (Fig 4.8) for the two-mouth chulha. However, the hearth depth in this case when smoke was produced was slightly greater (0.51m) than for the one-mouth version. The values of PHU are significantly higher than with the one mouth chulha. However, because of problems in synchronizing the pots, the effective PHU is lower. The two-mouth chulha is used when several pots need to be heated at the same time.

Islam argues that stove designs acceptable to villagers involve trade-offs between a variety of aims which may conflicting (e.g. maximizing PHU, minimizing smoke production and speed of cooking). Design parameters such as the actual hearth depth is reflected in the compromises reached.

However, other factors also need to be taken into account. For example, stoves inside the sheltered kitchen are used during the wet season and those outside during the dry season. Associated with this seasonal change in cooking area is a change in the fuel mix. Firewood provides 80% of the cooking energy requirements in the wet season and only 32% in the dry season when crop residues play a much more important part. The depth of the stove has to accommodate both the fuel that is used as well as the amount of ash that is produced. Since the proportion of cooking energy supplied by firewood (a high density fuel producing little ash) in the wet and dry seasons is 80% and 32% respectively, the stove outside would be expected to have a larger stove depth on average compared with the stove inside, since a significantly higher percentage of low density bulky fuel is used outside. This appears to be borne out by the data - whilst only 23% of the stoves inside the kitchen have a stove depth greater than 0.58m, the figure is 37% for stove used outside (despite lowering the PHU).

(f) Indian and Sri Lankan 'U' Chulha

Details of the earliest experimental tests on single pot 'U' shaped (or hemi-spherical) Indian chulhas are given in two reports by the Indian National Council of Applied Economic Research (NCAER, 1959;1965) - the latter merely quotes the results from the former. Results are also reported by Salariya (1978, 1983). Joseph and Loose (1982) give results of WBT's carried out on the Sri Lanka 'U' chulha.

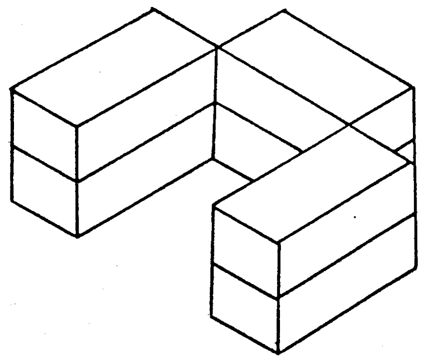
In the NCAER tests firewood ("logs" as well as in "small pieces") was burnt in a "brick chulha closed from three sides", whilst cow manure (in the form of "cow dung cakes") was used in a "hemi-spherical mud chulha". Diagrams of these stoves are not given by the NCAER, however, Salariya (1983:32) provides illustrations of both a three sided brick chulha and a hemi-spherical chulha (which he refers to as a "portable mud chulha") (Fig 4.9). Tests by Salariya were carried out on the mud chulha. Joseph and Loose refer to tests conducted on a Sri Lankan "traditional stove", which is a 'U' shaped (ie hemi-spherical) chulha (Fig 3.9).

In the NCAER (1959) study, calorific values of 19.6 MJ/kg and 8.9 MJ/kg (determined with a bomb calorimeter) were found for firewood and cow dung cakes respectively. According to Bialy (1979) the calorific value of virtually all oven dried tropical woods is around 20MJ/kg, hence, these tests were either carried out using oven dry wood or the calorific value was not corrected for the moisture content. Salariya (1983) quotes a calorific value (corrected for moisture content) of 15.3MJ/kg for the firewood used in his tests. If the calorific value used by Salariya (1983) is assumed, the PHU's obtained by NCAER (1959) will be almost one-third higher.

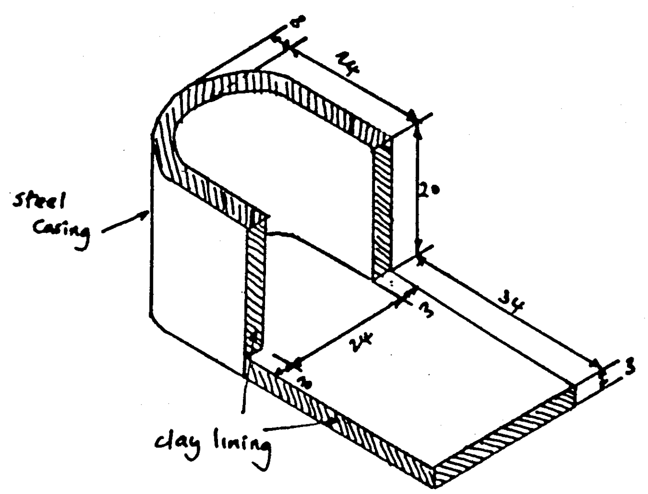
Joseph and Loose used firewood with moisture content (Table 4.12) ranging from 13-45% (dry basis), with a mean value of 24.3% and standard deviation of 9%.

Whilst all test data are from WBT's, it is difficult to compare the results, as different stove designs may have been used; the work by Bussmann <u>et al</u> (1983) shows the dramatic effect of simply changing the distance between the fuelbed and pan. Details of the test conditions are given below.

For the NCAER (1959) test, a known mass of fuel was burnt, and the PHU



(a) brick chulha



(all dimensions in cm)

(b) "portable mud chula"

Fig 4.9 Indian chulhas
(Salariya, 1983)

was defined in raising the temperature of water from "room temperature" (18°C) to 80°C or 90°C, and did not include energy associated with evaporated water. In these tests water was not heated to 100°C, as this led to considerable evaporation giving "high efficiency values" (NCAER, 1959:54). Several vessels were heated consecutively during the burning period of the fuel. Initial tests were carried out using cooking pots with and without lids, but the results were only reproducible in the former case. Rates of heat loss by radiation were determined from cooling curves of the pots. These heat loss rates were used to calculate the total heat radiated by the pot during each test.

Salariya (1978, 1983) does not define the temperature range over which the water is heated or the simmering time at which the PHU is measured. The PHU in his case does not include the energy in evaporated water.

Joseph and Loose give values of the PHU at BP1S30 (ie after allowing the water to simmer for 30 minutes), but do not say whether heat energy associated with evaporated water is included.

Details of the types of cooking vessel are not given by either Salariya or Joseph and Loose. In the NCAER (1959) study, two cooking vessels were used in the tests: a brass cooking vessel with a curved base of 21.6cm diameter (capacity 5 litres) and a flat bottomed aluminium pan with a base of 20.3 cm diameter (and 3 litres capacity).

For the brick chulha (NCAER, 1959), PHU's between 13% and 15% were obtained when logs of firewood were used. The highest value of PHU (19.1%) was obtained when the firewood was in the form of "small pieces" (NCAER, 1959:57). This finding is in agreement with the work of Visser et al (1979) who reported that decreasing the size of firewood (with the

3-stone fireplace) increased the PHU; though Joseph and Shanahan report that large pieces of firewood give higher efficiencies. If a calorific value of 15.3 MJ/kg (Salariya, 1983) is assumed the range of PHU's increases to 17% - 19% with firewood logs, and 24% with small pieces of wood.

For the hemispherical mud (or 'U' shaped) chulha, PHU's of 10.1% and 10.7% were obtained using cow manure (NCAER, 1959). Slightly higher values (viz. 11.3% and 11.7%) were obtained by including the estimated heat loss due to radiation from the cooking pot. Salariya (1978, 1983) gives a similar value for the PHU (12.3%) using firewood - the addition of a grate (Fig 3.25) increased the PHU to 15.8%.

Field measurements of PHU (including water of evaporation) at BP1S30 given by Joseph and Loose (1982) are in the range of 10-16%, with an average PHU of 14% and standard deviation of 2% (Table 4.12).

Table 4.12
WBT's results on traditional Sri Lankan stove (ie 'U' chulha)
(Joseph and Loose, 1982)

Pot[1]	wood type	m.c.[2] (%)	Initial water T (°C)	water evap (g)	wood used (g)	charcoal (g)	time boil (min)	PHU2 (%)
A	Veera	23	28	82	559	20	21	13.2
A	Veera	23	29	61	902	44	30	14.0
C	Veera	23	27	690	1388	20	47	15.1
A	Veera	23	22	181	1071	59	19	15.0
A	Veera	23	24	72	981	18	25	13.3
A	Veera	21	21	198	1393	30	40	10.4
A	Veera	13	23	42	1191	32	34	12.5
A	Veera	45	22	42	930	30	20	16.2

[1]A - aluminium; C - clay.
[2] - moisture content (dry basis)

For a brick chulha, PHU's between 13 and 24% have been obtained with firewood. PHU's between 10 and 11%, have been reported with WBT's on 'U' chulha's when using cow manure, and around 12% using firewood.

(g) 'Keren Stove'

This one pot stove (Fig 3.6) is reported to be widely used in parts of central Java (Joseph et al, 1980). Initial test results are quoted in Joseph et al (1980): WBT's were carried out in which 2kg of water was brought to the boil in an aluminium pot. Firewood in the form of 1 x 1 x 20 cm sticks and a moisture content of 16% were used. PHU values were in the range 16-20%. Details such as the total time of the test, whether or not evaporated water was taken into account, are not given.

(h) Multi-Pot Stoves in Egypt, Indonesia, and India

Experimental work on multi-pot traditional stoves has been reported by Theodorovic (1954), Singer (1961), Geller (1980, 1982), and Joseph (1983).

The earliest experimental work found was carried out by Theodorovic (1954) on the traditional Egyptian 3-hole stove (Fig 3.16). In the WBT's, 1kg water was brought to the boil in tinned brass pots. Although the stove design allowed three pots to be heated simultaneously, only two pots were used in the experiments: one pot was placed on the center hole (directly above the fire) and the other on the left pot holder. Five consecutive tests were performed, using **corn stalks and husks as fuels.** The PHU did not include energy associated with evaporated water.

An average value of 3% was obtained for the PHU in bringing the water in both pots to boiling point. A slightly higher PHU of 4.4% was obtained if the water was only brought to boil in one pot directly above the fire. These very low PHU's may be a consequence of using crop residues rather than firewood as the cooking fuel.

WBT's by Singer (1961) were conducted on a two-hole and three-hole cooking stoves; these stoves were constructed from burnt bricks consisting of 50% clay and 50% sawdust.

Each test involved heating 2kg of water in an aluminium pan (20cm in diameter) using 2.1 kg of wood. The precise details of the water boiling test methodology are unclear: for example, though Singer says that 2kg of water were heated, the quantity of heat released from the firewood is sufficient to heat six or more litres of water from around 25°C to 100°C! This may mean that 2kg of water were heated to boiling point and then allowed to simmer - hence a significant quantity of water would have been evaporated. However, this does not agree with Singer's statement in the report that the temperature of the water was taken at the beginning and at the end of each test: there is no need to take the temperature of the water at the end of the test since it would have to be 100°C. Though, Singer may well have measured the end temperature simply to make sure the water was boiling. Overall, Singer obtained PHU's around 7% (Table 4.13).

Table 4.13
Results of WBT's tests conducted by Singer (1961) on multi-hole stoves

Stove type	Quantity firewood (Kg)	duration test (min)	energy absorbed by water (kcal)	energy in wood (kcal)	B.R. (g/min)	PHU (%)	N_w (%)
3-hole	2.1	120	534	7312	17.5	7.3	7.1
	2.1	105	509	7312	20.0	7.0	6.8
	2.1	70	468	7312	30.0	6.4	6.2
2-hole	2.1	105	448	7312	20.0	6.1	6.0
	2.1	75	468	7312	28.0	6.4	6.2
	2.1	90	490	7312	23.3	6.7	6.5

Geller (1980) conducted WBT's and monitored the cooking in Ungra village in southern India. The WBT's simulated the cooking process. In the these tests three-pot and two-pot traditional stoves was used. For the stove with two openings, a pot containing between 2kg and 3kg of water was placed on each of the openings. Once the pot on the main opening of the stove reached boiling point, it was switched with a pot from one of the side openings. A similar procedure was adopted for the stove with three openings, except that a third pot was kept on the third opening and not moved throughout the test. Geller obtained values of PHU between 6% and 9%; higher values between 9% and 14% were obtained if the energy associated with evaporated water was included in the PHU (Table 4.14).

Table 4.14
Results of tests on multi-hole stoves by Geller (1980)

Stove Type	Pot	Fuel type	moisture content (dry basis) (%)	Test time (min)	Time to boil (min)	PHU1* (%)	PHU2* (%)
3-hole	clay	wood	10	38	23	7.9	14.1
3-hole	Al	wood	10	39	24	8.9	13.5
2-hole	Al	wood	10	42	27	8.2	14.1
2-hole	Al	wood	20	50	35	5.9	10.6
2-hole	Al	dung cakes	-	92	77	6.4	9.3

*PHU1 treats evaporated water as an energy loss, whilst PHU2 does not.

Geller also monitored the cooking of the evening meal of seven Ungra households (Table 4.15). Though villagers were reported to use both clay and aluminium pots, Geller does not make it clear which pots were used in the monitored meals. This is important since clay and aluminium pots will significantly affect the PHU (see for example, Geller (1982)).

A later report by Geller (1982) details results of tests carried out in 13 households during the preparation of their evening meal in Ungra village (South India): each family used a traditional 3-hole stove. The

Table 4.15

PHU of monitored meals (adapted from Geller, 1980)

House size[a]	Quantities of food cooked[b] (kg)	firewood consumed (kg)	cooking time (hours)	PHU1 (%)	PHU2 (%)
3	C - 1.0 O - 0.5	2.89	1.12	4.3	9.6
4	C - 1.5 O - 0.3	3.40	1.00	5.3	11.3
6	C - 2.4 O - 0.2	3.51	1.00	6.2	9.4
6	C - 2.6 O - 0.3	4.15	1.17	4.3	11.1
9	C - 3.9 O - 0.7	4.00	1.50	9.8	17.1
9	C - 4.6 O - 0.5	8.73	1.25	3.7	7.4
10	C - 4.0 O - 0.8	8.02	2.17	4.2	6.8
Average	C - 2.9	4.96	1.32	5.5	10.4

[a] adults and children counted equally.
[b] C - cereals; O - pulses and vegetables.

Table 4.16

Characteristics and "efficiencies" of 13 monitored meals (Geller, 1982)

House size	Pots[a]	Quantities of food cooked[b] (kg)	firewood consumed (kg)	cooking time (hours)	cooking efficiency (%)
3	3Cl	C - 0.96 O - 0.59	2.90	1.25	3.2
4	2Al, 1Cl	C - 1.45 O - 0.84	1.58	1.08	7.7
4	2Al, 1Cl	C - 1.47 O - 0.26	3.40	1.00	3.9
5	2Al	C - 1.63 O - 0.72	2.15	1.05	7.4
6	3Al	C - 2.35 O - 0.12	3.51	1.00	5.8
6	1Al, 2Cl	C - 2.62 O - 0.25	4.15	1.17	3.8
7	1Al, 2Cl	C - 1.87 O - 0.52	2.16	1.25	6.7
8	2Al	C - 2.38 O - 0.64	2.08	1.25	9.2
8	3Al	C - 3.28 O - 1.14	2.35	1.20	8.4
9	2Al, 1Cl	C - 3.87 O - 0.68	3.99	1.20	7.0
9	1Al, 2Cl	C - 4.59 O - 0.48	8.12	1.25	3.4
10	1Al, 2Cl	C - 4.02 O - 0.80	8.03	2.17	3.6
11	2Al	C - 2.15 O - 0.81	2.51	1.00	8.3
Average (6.9)	-	C - 2.51 O - 0.6	3.61	1.24	6.0

[a] Cl - clay, Al - aluminium
[b] C - cereals (rice and ragi), O - other (pulses, vegetables, meat)

equation for determining the overall efficiency of cooking included terms such as the energy required to raise the temperature of the cooking pots and contents, and the energy required to chemically convert the raw food into its cooked state (e.g. the gelatinization of rice - see Eqn 4.2). Evaporated water was regarded as an energy loss.

$$\text{cooking efficiency} = \frac{[(M_{pi}C_{pi} + M_{mi}C_{mi} + M_{fi})(T_{ci} - T_a) + M_{fi}K_{fi}]}{(M_wE_w - M_rE_r)} \qquad \text{Eqn 4.2}$$

The energy summation in the above equation is taken for each food item:

M_{pi}, M_{mi} and M_{fi} - the masses of each food
C_{pi}, C_{mi} and C_{fi} - the specific heats of the pot, cooking medium (ie water) and food, respectively.
T_a - the initial ambient temperature
T_{ci} - the temperature at which the food item is cooked.
K_{fi} - is a term to take into account the energy associated with the chemical reactions which take place in the cooking process.
M_w, M_r - the mass of wood consumed and charcoal residue left at the end of the experiment
E_w and E_r - the calorific values of the wood and charcoal respectively.
In the calculations the following values were assumed: C_{pi} = 0.21 kcal/kg/K (clay pots); C_{pi} = 0.22 Kcal/kg/K (aluminium pots); C_{fi} = 0.45 kcal/kg/K (for rice, ragi, flour, and dried pulses); C_{fi} = 0.93 kcal/kg/K (for fresh vegetables); K_{fi} = 41 kcal/kg (for rice, ragi flour and dried pulses) whilst set to zero for fresh vegetables; finally T_{ci} = 97°C.

Using clay pots gives a lower value of PHU than with aluminium pans: the average value of the PHU for meals in which one or more clay pots were used was 4.1%, whereas for meals prepared with aluminium pans the average PHU was 7.2% (Geller, 1982).

The highest PHU's for a traditional (two-pot) stove, the Tungku Muntilan (Fig 3.13) (used in both central Java and Indonesia) were obtained by Joseph (1983). The WBT's involved heating two aluminium pots (each containing 2 litres of water) to the boil and simmering for 30 minutes (ie PHU2 at BP1S30). PHU2 was 12% for the first test, and 17% for the third test (by which time the stove was hot). These results are summarized in Table 4.17.

Table 4.17
WBT's on multi-hole mud stoves

Stove Type	Pot[a]	Fuel	water heated (litres)	PHU1[b] (%)	PHU2[c] (%)	Source
3-hole	clay	wood	2-3	7.9	14.1	Geller (1980)
	Al	wood	2-3	8.9	13.5	" "
	Al	wood	2	7.3	-	Singer (1961)
	Al	wood	2	6.9	-	" "
	Al	wood	2	6.4	-	" "
	tinned brass	corn stalks /husks	2	4.4	-	Theodorovic (1954)
			2	3.0	-	
2-hole						
	Al	wood	2-3	8.2	14.1	Geller (1980)
	Al	wet wood[d]	2-3	5.9	10.6	" "
	Al	dung	2-3	6.4	9.3	" "
	Al	wood	2	6.1	-	Singer (1961)
	Al	wood	2	6.4	-	" "
	Al	wood	2	6.7	-	" "
	Al	wood	2		12	Joseph (1983)
	Al	wood	2		17	" "

[a] Al - aluminium
[b] PHU1 - water of evaporation treated as energy loss
[c] PHU2 - energy associated with water of evaporation taken into account.
[d]tests conducted by Geller (1980) moisture content of "wood" and "wet wood", 10% and 20% respectively

Values of PHU (excluding water of evaporation) are reasonably close for both Geller (1980) and Singer (1961). These figures are also in line with the higher values of efficiency obtained by Geller (1982) for the monitored meals in Ungra village.

Theodorovics's work gives the lowest values fo PHU (3-4%), which are comparable with the lowest efficiency figures obtained by Geller (1982). The low values by Thedorovic may be a reflection of having used a different pot material (ie tinned brass) and type of fuel (corn stalks and husks) from both other authors; the PHU's with animal manure also tended to be lower than those with firewood in the tests carried out by Best (1979a, 1979b). The highest PHU's were obtained by Joseph (1983).

4.3 Summary: major findings

The widespread assumption in the literature and elsewhere that the 'open fire' and traditional stoves have a low heat utilization only holds true for certain geometrical arrangements (see also Chapter 3). For instance, WBT's on a number of traditional stoves and fireplaces (e.g. Fijian two stone fireplace, a fire under a three-legged pot, the one-mouth Bangladeshi pit chulha, and some multi-pot traditional stoves used in India, Indonesia and Egypt) have given PHU's around 10% or less. However, changing the values of critical design parameters (see below) of these stoves would increase the measured PHU. Thus traditional stoves and fireplaces with optimum values of these critical parameters have higher PHU's e.g. 3-stone fireplace, the Bangladeshi two-mouth pit chulha, Keren stove, and both the Indian and Sri Lankan 'U' chulhas.

The most important parameters which affects the PHU significantly are the distance between the fuelbed and pan, and pot material. Other parameters are power output, size of firewood, presence of wind, moisture content of firewood, pan shape and material. For example, the higher values of PHU1 are obtained using an aluminium pan instead of a clay pot (Geller, 1980, 1982). Other work highlights the effect that a simple parameter such as the shape of the cooking pot can have on the PHU (e.g. Islam, 1980). However, whilst some researchers found that the PHU with small pieces of firewood was higher than with large pieces (e.g. NCAER, 1959; Visser and Verhaart, 1980) the opposite has also been reported (Joseph and Shanahan, 1981). PHU's are also affected by the type of fuel (see Thedorovic, 1959; Singer, 1961; Best, 1979a, 1979b) as the burning rate of dense fuels (e.g. wood) is different from bulky fuels (e.g. crop residues). This would give rise to different flame heights and hence a different optimum value of fuelbed/pan distance.

It was stated in the previous chapter that cooking efficiency is only one parameter of interest to stove users, who may be prepared to sacrifice fuel economy for other needs, e.g. fast cooking, space heat, social focus, presence or absence of smoke. Villagers have to decide which trade-offs they are prepared to make. For example, whilst the PHU's of the one-mouth and two-mouth Bangaldeshi pit chulha's are around 10%, villagers build a stove which balances smoke production and fuel efficiency. Moreover, villagers use pots with a spherical bottom in preference to ones with a flat bottom, thereby increasing the PHU. Overall, the choice of stove by any user depends on their felt needs (eg. low cost, easy to maintain, simple to use, and son - see Chapter 3).

Hence, any mode of cooking is a <u>system</u> comprising of:

(a) user preferences;
(b) fuel (type, size, moisture content);
(c) stove;
(d) pot (size and material);
(e) cooking procedure (preparation and food type).

As the literature had shown that traditional stoves and fireplaces were not inherently inefficient, it was decided to test some traditional designs. The next chapter gives details of the methodology employed, and results obtained for the various stoves tested.

Chapter 5

Laboratory tests on cooking stoves

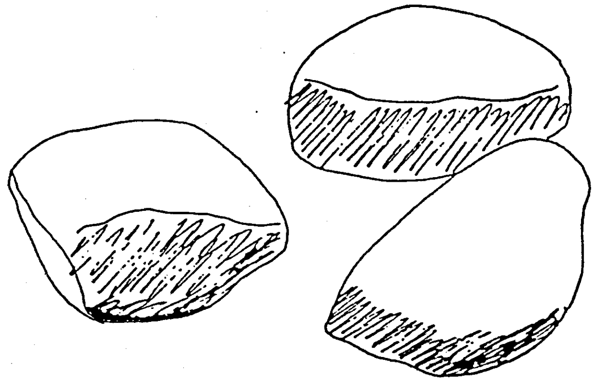
5.0 Introduction

The previous chapters have shown that not all traditional stoves and fireplaces are as inefficient for cooking as commonly quoted in the literature. Hence, it was decided to test some traditional stove designs. This chapter details WBT's which were conducted at the Open University on the 3-stone fireplace (Fig 5.1a) and the Indian 'U' chulha (Fig 5.1b). WBT's were also carried out on an "iron frame" stove (Fig 5.1c); a stove which had displaced the traditional 3-stone fireplace in Zimbabwe. Initial tests were carried out on the 3-stone fireplace to develop the experimental method, become familiar with WBT's and obtain consistency with other work. Tests were then conducted on a common traditional type of stove; the 'U' chulha was chosen as it is widely used (in India and Sri Lanka) and had not been so thoroughly tested as the 3-stone fireplace. Finally tests were carried out on the iron frame.

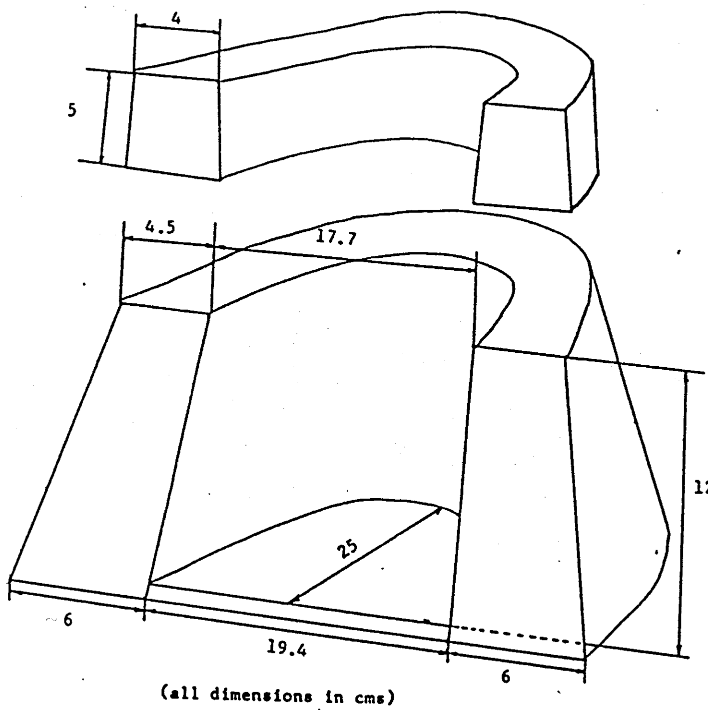
5.1 Methodology

An Indian 'U' chulha was built out of clay (15%), sand (31%), ash (8%), "grog" ie brick dust (31%), and cow manure (15%) mixed with water. The dimensions were obtained from photographs of a 'U' chulha.

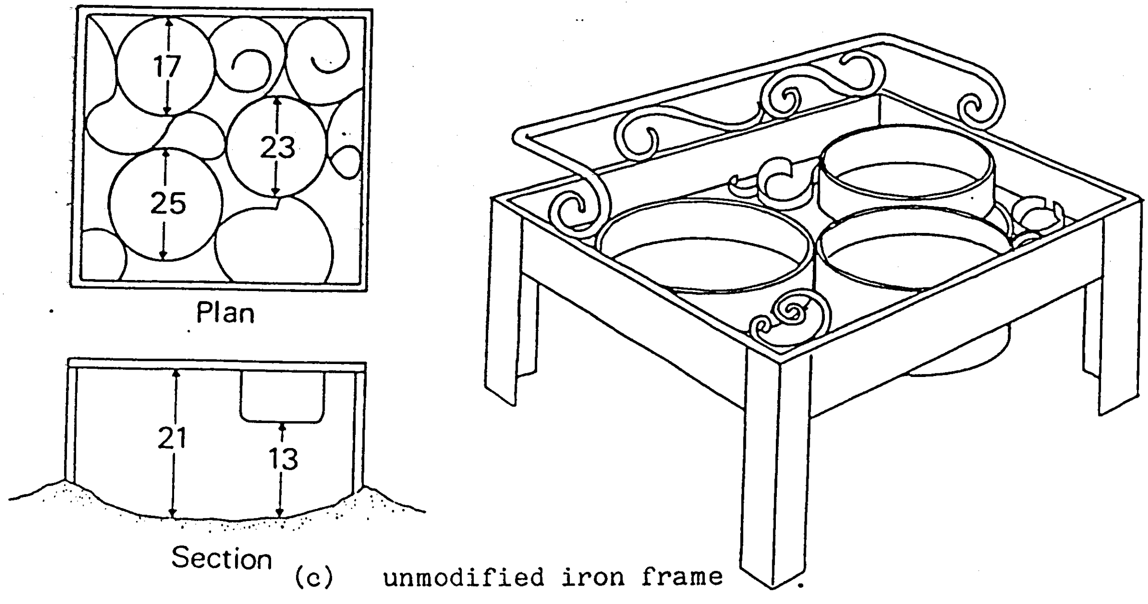
A base 1cm in thickness was made, on top of which the body of the 'U' chulha was placed. An additional 'U' shaped section was also made, which could be placed on the top of the chulha (Fig 5.1b) to increase



(a) 3-stone fireplace



(b) Indian 'U' chulha



(c) unmodified iron frame
(measurements in cms.)

Fig 5.1 stoves used in WBT's

the height. This arrangement allowed an aluminium cooking pan (Fig 5.2) to be placed at 9.5 cm and 14.5 cm above the firewood. A clay pot was also used in these tests: because of the spherical bottom of the clay pot it was closer to the firewood than the aluminium pan.

The "iron frame" stove used in the tests was bought in a market place in Harare (Zimbabwe) and brought back to England. WBT's were carried out on an unmodified iron frame (Fig 5.1c) as well as with limited wind shielding (by placing metal sheets around 3 sides of the iron frame Fig 5.3a) - these tests were conducted at the Open University.

McGarry (1985) also introduced wind shielding into the iron frame by constructing the iron frame from sheet metal (Fig 5.3b); this is referred to, here as the McGarry stove. Village women in Zimbabwe reported that firewood consumption with this modified iron frame was half that of the original iron frame according to McGarry (1985). In order to test this claim a series of WBT's were carried out at Reading University on the iron frame and the McGarry stove.

All WBT's on the 3-stone fireplace and 'U' chulha were conducted at the Open University.

5.1.1 Test conditions

All tests at the Open University were carried out in a fume cupboard: an extractor fan on the roof of the cupboard removed any smoke that was produced. Two wind speed settings were obtained whereby the mouth of the fan was either completely uncovered or half covered.

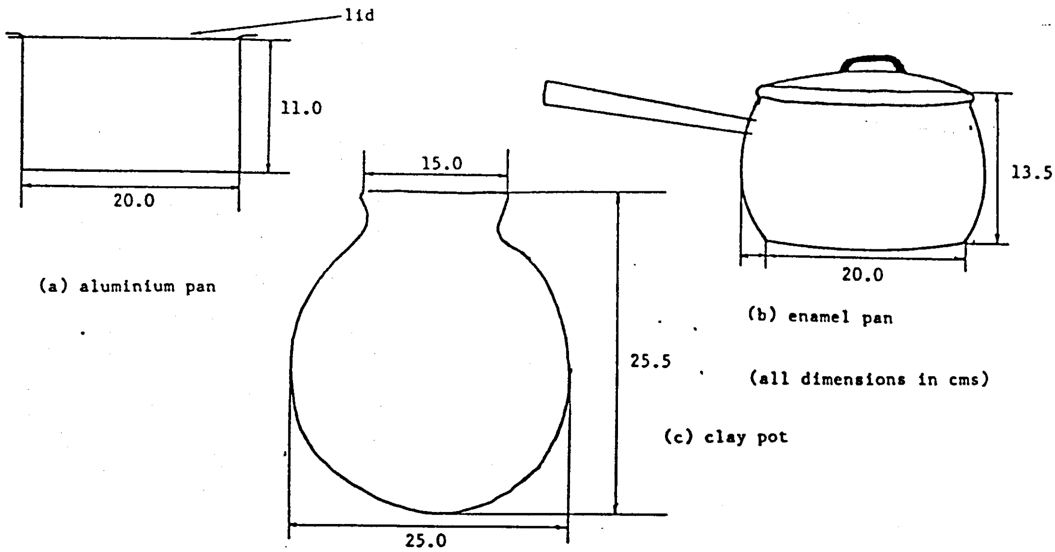
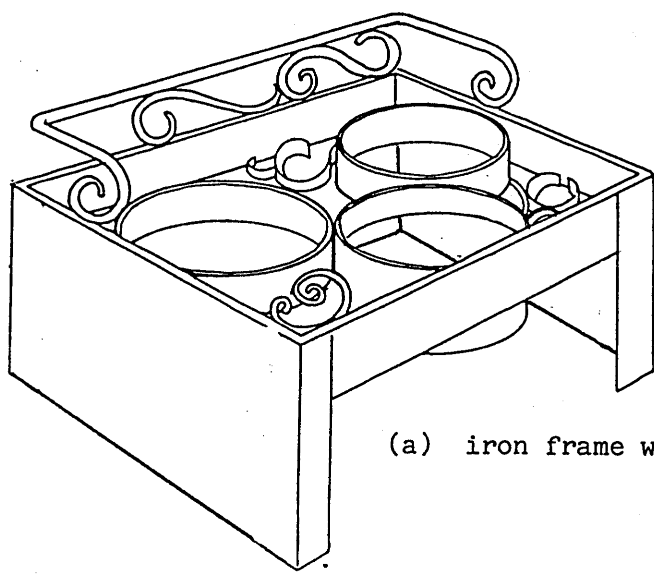
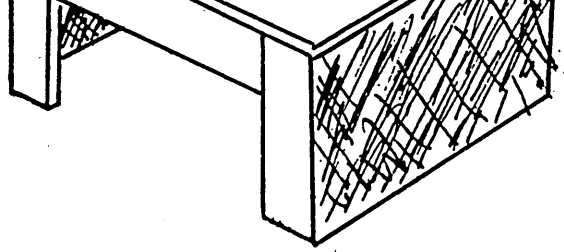


Fig 5.2 Cooking pans used in WBT's



(a) iron frame windshielded with 3 metal sheets



(b) "McGarry stove" (taken from McGarry, 1985)

Fig 5.3 Modifications to iron frame

An aluminium pan was used for all the tests on the 3-stone fireplace and most of the tests on the 'U' chulha: a small number tests on the 'U' chulha were conducted using a clay pot. An enamel pan which had been bought in Zimbabwe was used in all WBT's for the iron frame. All tests carried out on the iron frame at the Open University were conducted with the bottom of the pan at 10cm from the firewood - this was close to the optimum height found by Visser and Verhaart (1980) for the three stone fireplace.

WBT's carried out at Reading University on the iron frame and McGarry stove were conducted under conditions of "no wind", "slight" wind" (1 m/s) and "moderate" wind (1.5 m/s). WBT's at the various wind speeds were carried out with the wind blowing directly at the flames (ie open side of the McGarry stove) and repeated with one windshielded side placed in the way of the wind (by rotating the McGarry stove through 90°). All tests were carried out in a laboratory at Reading University, with a fan to provide the 2 wind speeds; these wind speeds were obtained by covering the air intake of the fan by an appropriate amount. Wind speed was measured with a thermal anemometer (Airflow Developments model TA3000); with an accuracy within 5% of the reading over the range of wind speeds measured. The average wind speed was obtained by taking measurements along the side of the stove. The distance between the enamel pan and the fuelbed was approximately 6 cm. All other test conditions are as described on the WBT's carried out on the iron frame at the Open University.

The tests carried out at Reading University also considered the heat transfer from the fuelbed to the cooking pot. In this analysis it was assumed that heat was transferred from the fuel to the pan by convection and radiation only. The magnitude of the radiative component was calculated from the fuelbed/pan dimensions and measurements of the surface temperature of the fuelbed: ten readings were taken of the surface temperature of the fuelbed using a thermocouple. Another ten readings were taken with the thermocouple inserted into the fuelbed. All these temperature measurements were carried out using a Comark stainless steel sheathed mineral coated Ni-Cr/Ni-Al thermocouple. The following equations were used to calculate the transfer of heat from the fuelbed to the cooking pot by radiation and convection:

Heat transfer by radiation,

$$Q_r = F_{1-2}\, O\, A\, (T_1^4 - T_2^4) \quad \text{equation (5.1)}$$

Q_r - the rate of transfer of heat by radiation;
F_{1-2} - related to the interchange coefficient, $\bar{F}$ (see below);
O - Stefan Boltzmann constant (5.6697×10^{-8} W/m^2K^4);
A - the area of the pan ($0.314m^2$);
T_1 - the temperature of the fuelbed (758K);
T_2 - the temperature of the pan (336K)

$$F_{1-2} = \frac{1}{\frac{1}{\bar{F}} + \left(\frac{1}{e_2} - 1\right)\frac{D_1^2}{D_2^2} + \left(\frac{1}{e_1} - 1\right)} \quad \text{equation (5.2)}$$

F_{1-2} - the interchange factor (from McAdams (1954:69) this has been taken to be 0.45 for the parameters in the WBT's carried out);
e_1 - the emissivity of the fuelbed (assumed to be 0.9 - see Karlekar and Desmond (1977));
e_2 - the emissivity of the black enamel pan (assumed to be 0.85, see Karlekar and Desmond (1977));
D_1 - the diameter of the fuelbed (0.2m);
D_2 - the diameter of the enamel pan (0.2m);

The convective heat transfer coefficient h, is given by the expression:

$$h = \frac{Q_c}{A\,\Delta T} \quad \text{equation (5.3)}$$

Q_c - the heat transfer by convection;
A - the area of the enamel pan ($0.0314m^2$);
ΔT - the temperature difference between the flames and pan (assumed to be 937K).

Two species of firewood were used: Jelutong (Diera Costulata) - a Malaysian hardwood and Iroko (Chlorophora regia) a hardwood from the

West African state of Cameroon. Jelutong is a fast burning wood which produces long flames, whilst Iroko is a slow burning wood and produces short blue flames. Sticks of Jelutong and Iroko (2.5cm square and 30cm in length) were used in WBT's on both the 3-stone fireplace and 'U' chulha. Thinner sticks of Jelutong (0.6cm square) were used in the tests on the iron frame; it was possible to obtain higher power outputs (up to 9kW) with the thinner sticks than the thicker sticks.

The moisture content of the firewood was determined by drying samples in a ventilated oven at 105^{o}C for 24 hours. The average moisture content (dry basis) of 5 samples of Jelutong and Iroko were 9.7% (0.2) and 9.2% (0.2) respectively; the figures in brackets refer to the standard deviation

5.1.2 Measurement of PHU

A procedure similar to that outlined by Joseph and Shanahan (1980a), was adopted and (unless stated otherwise) was as follows:

A small amount of kindling - 40g of Parana Pine and 6g of newspaper - was placed in the stove. A cooking pot of known mass containing 2kg of water at around 25°C was placed on the stove. The kindling was lit, and thirty seconds later, the sticks of firewood were placed on the fire. The temperature of the water was recorded at two minute periods (starting from the time the kindling had been lit) until the water reached boiling point. At this point the pot, charcoal, and the burning firewood were removed from the stove and weighed separately. These measurements were used to calculate the values of PHU in bringing the water to boiling point (ie BP1) using equation 3.6 and 3.7 (see Chapter 3), viz PHU1 and PHU2; PHU1 treats steam as an energy loss, whilst PHU2 does not. The calorific values of the firewood was corrected for the moisture content using equation 3.8 (derived in Appendix B), and a calorific value of 29MJ/kg was assumed for the residual charcoal.

The pan and the fuel were returned to the stove and heating continued such that the temperature of the water was above 95°C. After 10 minutes the cooking pot and contents, firewood and charcoal were again weighed separately. These measurements were similarly used to calculate the values of PHU at BP1S10.

The cooking pot and fuel were returned to the stove and again weighed after allowing the water to simmer for another 20 minutes and a subsequent 30 minutes after that.

The PHU's obtained at BP1, BP1S10, BP1S30, and BP1S60 refer to the values of PHU obtained in bringing the water to boil, and subsequent simmering for 10 minutes, 30 minutes and 60 minutes, respectively.

The average power output, during the WBT's, was calculated by dividing the heat energy of the consumed firewood (less the heat energy in residual charcoal) by the time for which the fire had been burning.

The cooking pot, water, firewood and charcoal were all weighed on a Salter LM10 multi-revolution scale (maximum capacity 5kg in 2g divisions). A Comarck digital thermometer type 3002 (accuracy $\pm$0.5°C) was used to measure the temperature of the water. A digital timer (Casio FX-8100) was used to give an audible signal at every two minutes.

A total of 8 WBT's were carried out on the 3-stone fireplace.

A total of 39 WBT's were carried out on the 'U' chulha: 8 with the clay pot and 31 with the aluminium pan. The effect of four parameters (height, wind speed, fuel type and pot material) on the PHU was investigated on the 'U' chulha using a factorial design experiment; a factorial design described in detail by Bialy (undated) was used. Two different values were used for each of the four parameters (Table 5.1).

Table 5.1
Values of parameters in factorial designed stove tests

Parameter	**Value** level 0	level 1
Fuel	Jelutong	Iroko
Height	12.0cm	17.0cm
Pan material	aluminium	Clay
Wind speed	"low"	"high"

A total of 39 WBT's were carried out on the iron frame at the Open University: 19 of these were on the unmodified stove, whilst another 20 were carried out with 3 sides of the iron frame shielded with pieces of sheet metal. At Reading University a further 8 WBT's were conducted on the unmodifed iron frame and McGarry stove.

PHU's for the iron frame were measured at BP1 and BP1S10; measurements at BP1S10 were taken, as the staple food in Zimbabwe (see Chapter 6) involved bringing water to the boil and simmering for about 10 minutes.

5.1.3 Energy losses

Steady state radiative heat losses from the pot and stove were estimated from the variation of the time for the water to reach boiling point with power output: the reciprocal of BP1 was plotted against power output, a curve was fitted to these points using the method of least squares; the steady state energy losses were then obtained from the intercept on the power output axis (Fig 5.6).

5.1.4 Energy flows

Energy flow diagrams were based on the calculations of the heat energy, in the water, steam, residual charcoal and the heat energy radiated from the pot and stove during the test. The method used to calculate the heat radiated from the pot and stove is given in section 5.1.3. These radiative heat losses were assumed to be negligible in bringing the water from ambient to boiling point, and hence are not included in the energy flow diagrams at BP1. The energy lost in the stack gases was calculated by subtracting the sum of the heat energy in the water, steam, residual charcoal and the heat radiated from the pot and stove, from the heat energy in the firewood burnt.

5.1.5 Statistical analysis of PHU data

(a) 'U' chulha

A statistical programme (available on the DEC-20 computer at the Open University) was used to analyse the PHU data obtained from the factorial design experiment on the 'U' chulha. This programme used standard statistical analysis of variance techniques. The output of the programme gave the level of significance of the main factors and two-way interactions.

(b) Iron frame

A t-test was used to analyse the PHU data with and without the 3 metal sheets on the iron frame (see section 5.2.3).

5.2 Results

5.2.1 Traditional 3-Stone Fireplace

At BP1, values around 20% were obtained for both PHU1 and PHU2 with Jelutong for power outputs from 2.1kW to 2.6kW. Slightly lower values for PHU1 (16%) and PHU2 (18%) were obtained with Iroko for power outputs around 2kW (Table 5.2).

Table 5.2
3-Stone Fireplace: PHU data
(Fuel: Jelutong)

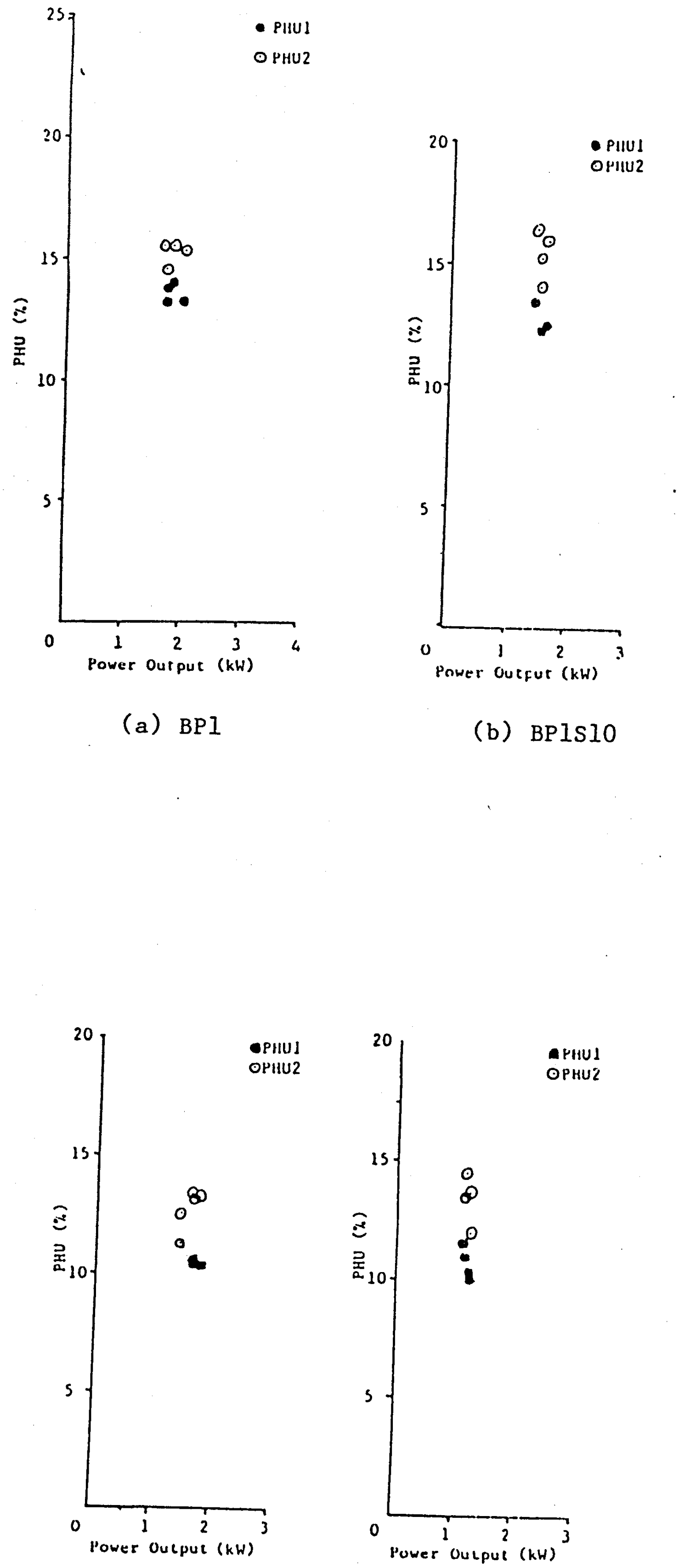
	BP1				BP1S10			BP1S30			BP1S60		
Time to boil (mins)	PHU1 (%)	PHU2 (%)	P_o (kW)	m_e (g)	PHU (%)	P_o (kW)	m_e (g)	PHU (%)	P_o (kW)	m_e (g)	PHU (%)	P_o (kW)	m_e (g)
24	19.5	20.4	2.21	12	19.4	1.84	9.5	16.1	1.43	62	14.5	1.13	90
26	18.7	19.3	2.14	9.5	16.1	1.95	24	14.1	1.51	39.5	11.9	1.19	45.5
21	19.0	19.7	2.60	11	18.0	2.24	56	15.9	1.62	74	13.7	1.21	81
20.3	19.6	20.4	2.61	12.5	17.5	2.35	16.5	15.2	1.48	23.5	13.4	1.12	43.5

Key
P_o - Power Output of firewood;
m_e - mass of water evaporated

Table 5.3
3-Stone Fireplace: PHU data
(Fuel: Iroko)

	BP1				BP1S10			BP1S30		
Time to boil (mins)	PHU1 (%)	PHU2 (%)	P_o (kW)	m_e (g)	PHU (%)	P_o (kW)	m_e (g)	PHU (%)	P_o (kW)	m_e (g)
35	15.9	16.7	1.86	13.5	14.6	1.68	17	12.5	1.41	29
32	17.3	17.7	1.89	6	15.5	1.79	33	13.2	1.59	68
30	17.8	18.2	1.96	6	15.3	2.01	49	13.3	1.67	76
33	16.8	17.8	2.01	16	15.5	1.66	49	13.8	1.64	89

For Jelutong, PHU2 varied from 16% to 19% and PHU1 from 15% to about 17% at BP1S10, whilst for Iroko PHU2 varied from 14.5% to 16% and PHU1 from 13% to 14%. At BP1S30, for Jelutong PHU2 had fallen to between 14% -



(a) BP1

(b) BP1S10

(c) BP1S30

(d) BP1S60

Fig 5.4 PHU data for 3-stone fireplace using Jelutong

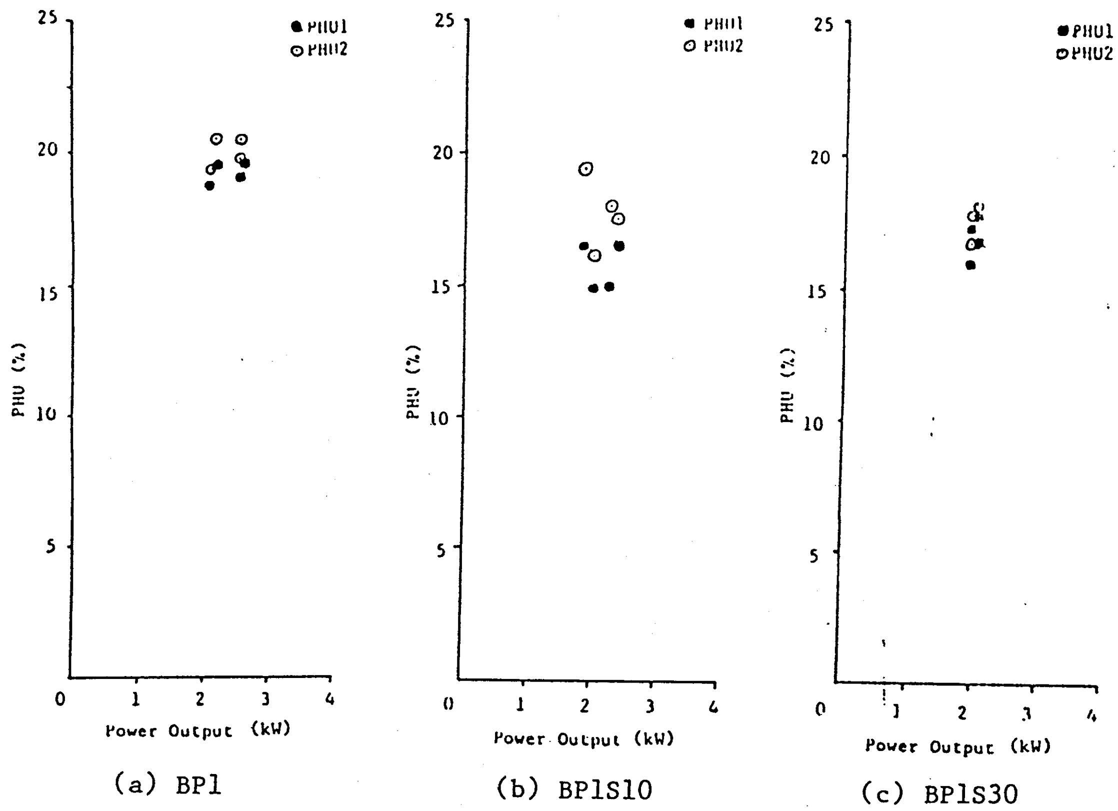


Fig 5.5 PHU data for 3-stone fireplace using Iroko

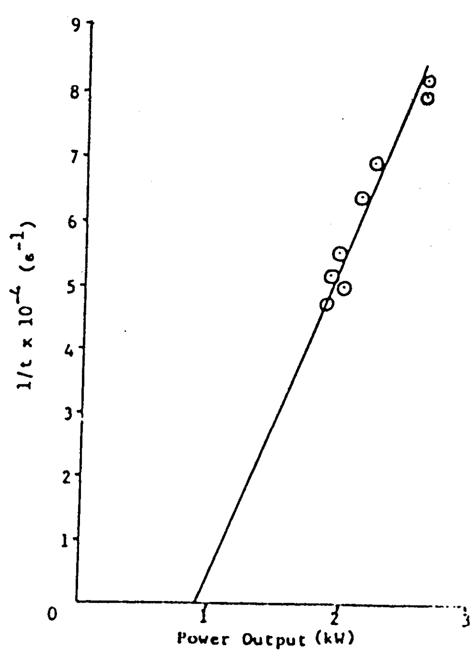
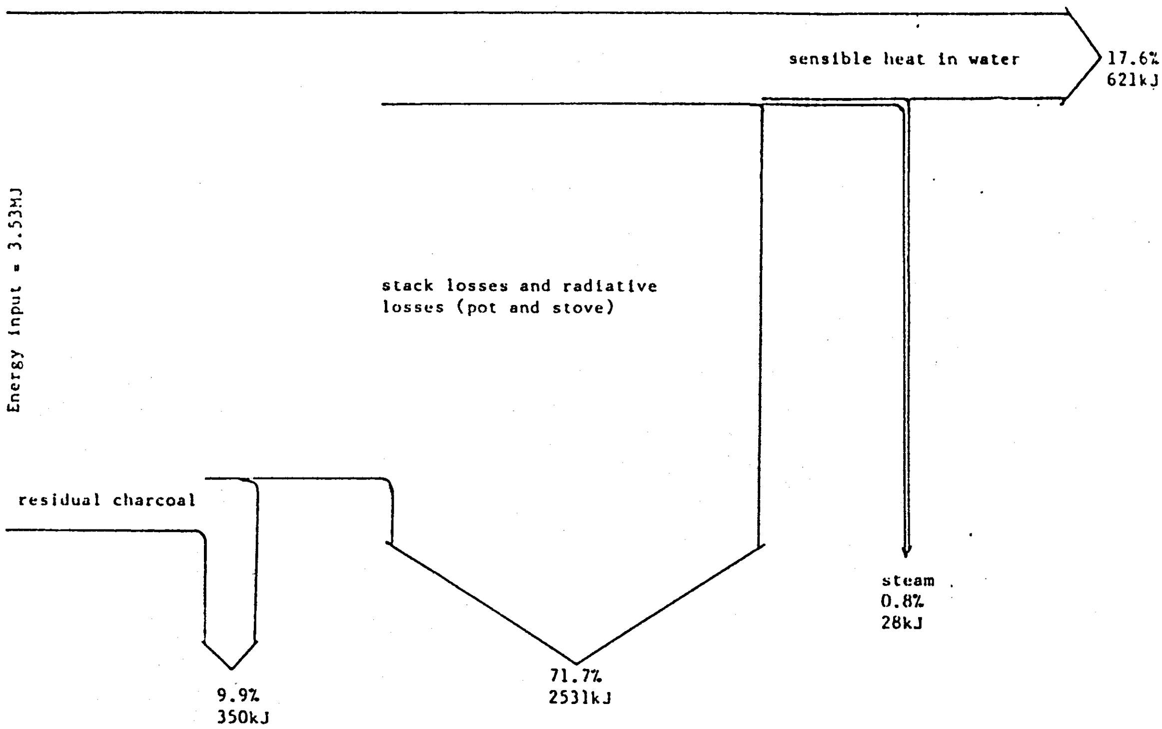
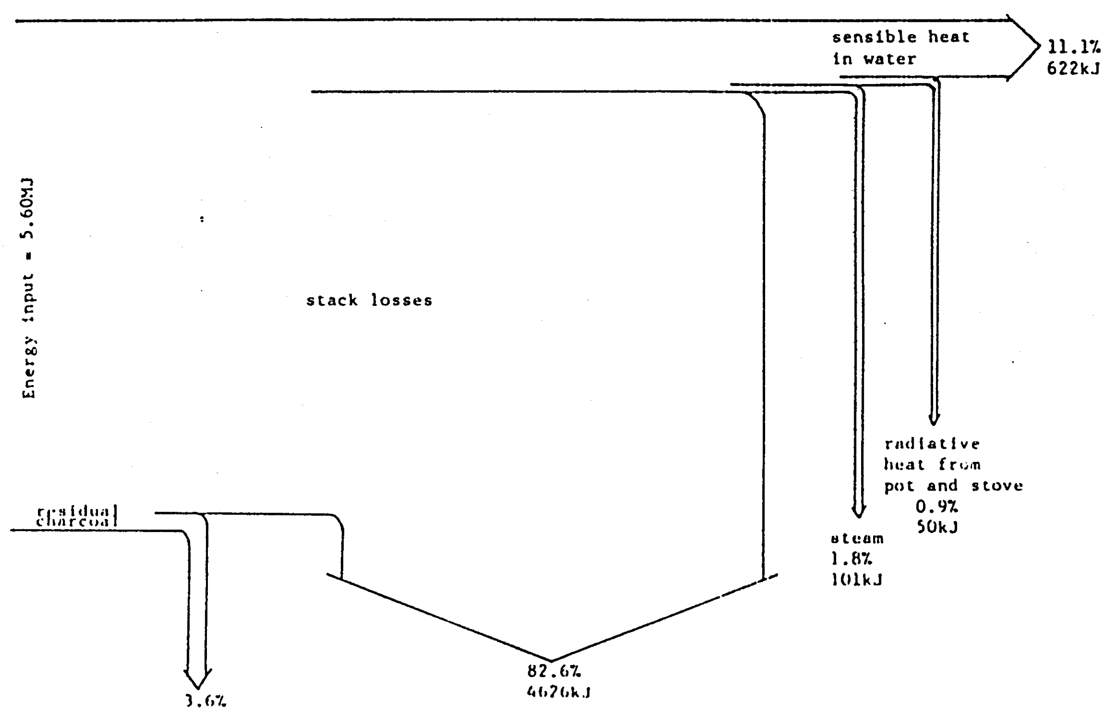


Fig 5.6 Estimation of steady state radiative losses from pot and 3-stones (plot of 1/BP1 vs power output)

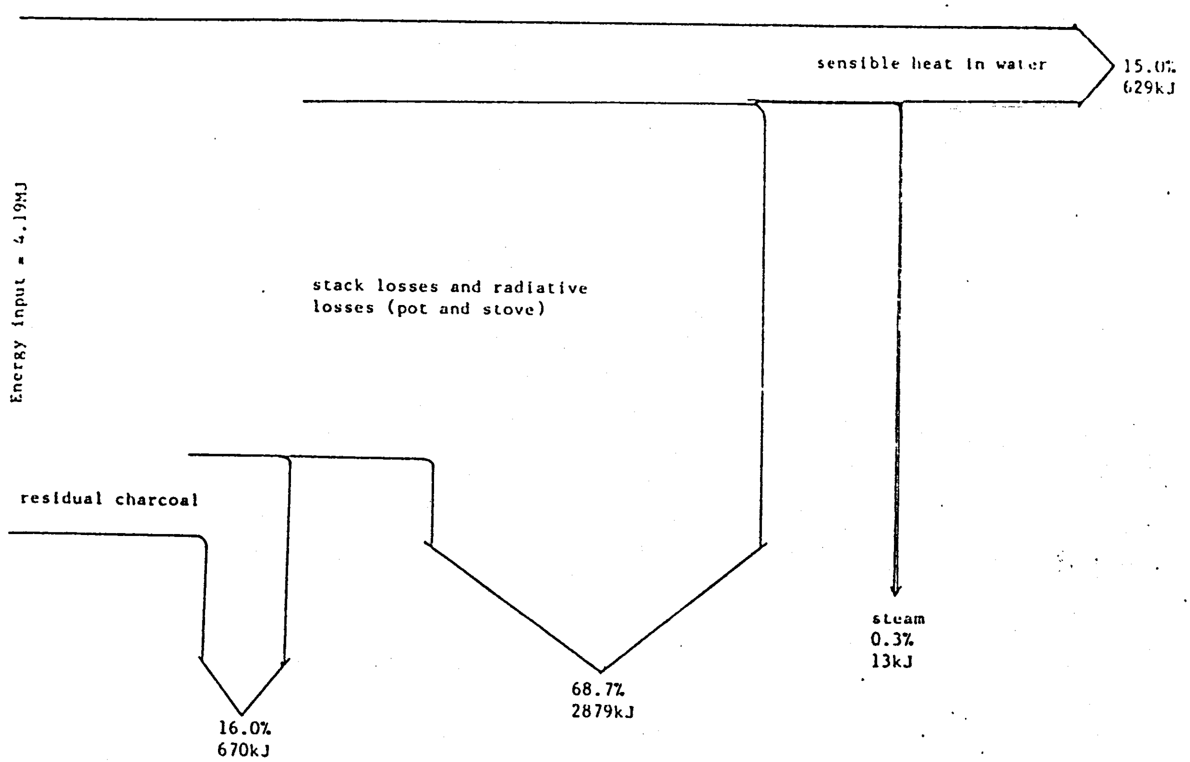


(a) BP1

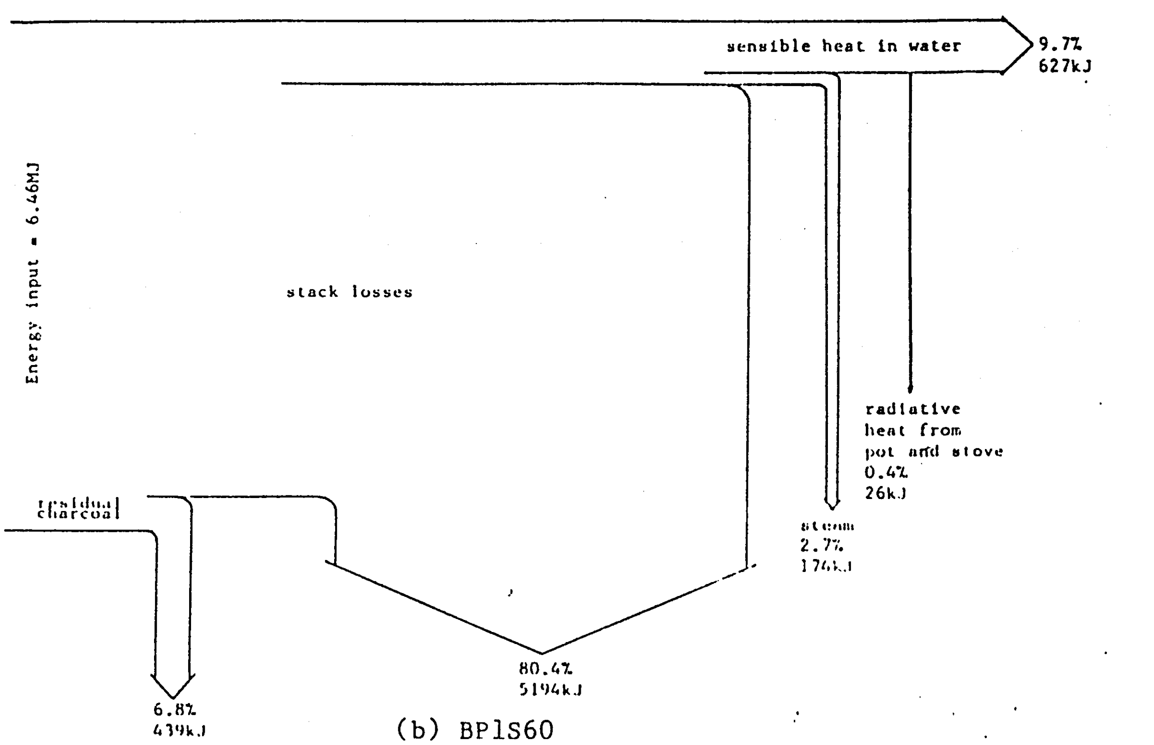


(b) BP1S60

Fig 5.7 Energy flows in 3-stone fireplace using Jelutong as fuel (highest PHU)



(a) BP1



(b) BP1S60

Fig 5.8 Energy flows in 3-stone fireplace using Iroko as fuel (highest PHU)

16%, and to 12% - 14% for PHU1, whilst for Iroko PHU2 was between 12% and 14% and PHU1 between 10% and 11%. At BP1S60, for Jelutong, values of PHU2 had fallen to between 12% and 14.5% and PHU1 between 10% and 11.5% (Fig 5.4 and 5.5).

The mean values of PHU fall for both Jelutong and Iroko as the simmering time increases: the mean value of PHU2 for Jelutong was around 20% for both BP1 and BP1S10, 15% for BP1S30 and 13% for BP1S60. Similarly, the mean values of PHU1 also decreased with simmering time, though PHU1 fell much more rapidly than PHU2: for Jelutong, whilst the mean value of the energy associated with evaporated water is 4% of PHU2 at BP1 this has risen to 20% at BP1S60.

Steady state energy losses from the aluminium pan and stove at BP1 were estimated to be around 0.9kW (Fig 5.6). Estimated radiative heat losses were 0.4% and 0.9% of the energy input for Iroko (at BP1S30) and Jelutong (at BP1S60) respectively.

Most of the heat energy lost is contained in the stack gases (Fig 5.7 and 5.8). At BP1, between 16 and 19% of the input energy was absorbed by the water; less than 1% was lost in the steam. Energy contained in the residual charcoal at BP1 was about 10% for Jelutong; with Iroko the residual charcoal contained 16% of the energy.

Stack and steam losses both increased with simmering time.

5.2.2 'U' Chulha

Unless otherwise stated the text refers to tests carried out with the aluminium pan.

(a) Summary: test data

PHU data for the WBT's conducted on the 'U' chulha are summarized in Table 5.4 and 5.5.

It was difficult to obtain high burning rates with Iroko and a maximum of 4kW (cf 6kW with Jelutong) was obtained in the tests. More smoke was produced with Iroko than Jelutong and it took longer to bring water to boiling point. Smoke and small flames were characteristically produced at low power outputs for both Jelutong and Iroko. As the power output was increased, less smoke was produced and the flame length increased. Flames from Iroko were usually smaller than with Jelutong, and hence did not always reach the pan bottom. However, with Jelutong at the highest power outputs (at the low height) flames tended to go around the sides of the aluminium pot.

Generally, under the same test conditions, PHU's with Iroko were lower than with Jelutong. At the "low" and "high" heights the maximum values of PHU2 with Iroko were 12% and 18% respectively, compared with 15% and 23% with Jelutong.

At the "low" and "high" height the maximum values of PHU2 with the clay pot were 17% and 23%: small flames could reach the bottom of the clay pot though not the aluminium pan owing to the curved bottom of the clay pot.

(b) Statistical significance of the main factors and interaction effects

According to the statistical analysis of the factoral experiment, the effect on the PHU of "wind" and two-way interactions (e.g. wind-pot,

Table 5.4
PHU data from complete factorial design on 'U' chulha

Level of factor (see Table 5.1)	BP1				BP1S10		BP1S30		BP1S60	
	Time to boil (mins)	PHU1 (%)	PHU2 (%)	P_o (kW)	PHU (%)	P_o (kW)	PHU (%)	P_o (kW)	PHU (%)	P_o (kW)
F H P W										
0 0 0 0	20	21.5	22.7	3.2	17.5	2.5	15.0	1.9	11.9	1.5
0 0 0 1	13	20.3	22.0	3.8	18.6	3.0	15.8	2.2	14.1	1.5
0 0 1 0	28.5	11.4	22.6	3.3	21.1	3.2	21.3	2.6	20.9	2.0
0 0 1 1	16	12.1	18.3	5.2	19.2	4.2	19.3	3.3	19.0	2.6
0 1 0 0	28	11.4	12.4	3.2	11.6	2.9	10.6	2.3	9.6	1.7
0 1 0 1	18	13.6	14.6	4.3	12.5	3.4	10.8	2.6	9.2	2.0
0 1 1 0	34	5.7	17.2	5.4	17.3	4.9	16.0	5.0	16.1	3.8
0 1 1 1	29.5	8.3	15.0	4.4	14.1	4.8	13.7	4.0	13.3	3.6
1 0 0 0	35	15.1	16.0	1.9	15.2	1.8	13.0	1.5	11.6	1.3
1 0 0 1	35	15.8	16.4	1.9	14.8	1.7	13.1	1.4	10.7	1.2
1 0 1 0	80	5.9	19.7	2.2	20.1	2.2	19.4	2.1	18.9	1.9
1 0 1 1	34	12.2	19.9	2.5	19.7	2.4	19.0	2.2	18.2	1.9
1 1 0 0	40.5	10.1	10.7	2.5	10.6	2.6	10.2	2.4	9.2	2.1
1 1 0 1	52	9.1	9.6	2.2	9.2	2.1	8.5	2.0	7.6	1.7
1 1 1 0	42	7.4	12.2	3.4	12.0	3.3	12.2	2.9	11.2	2.8
1 1 1 1	52	6.2	11.7	3.2	11.5	3.4	11.6	3.2	11.5	2.9

Table 5.5
PHU's for follow up WBT's on 'U' chulha
(all tests conducted with aluminium pan)

Level of factor (see Table 5.1)	BP1				BP1S10		BP1S30		BP1S60	
	Time to boil (mins)	PHU1 (%)	PHU2 (%)	P_o (kW)	PHU (%)	P_o (kW)	PHU (%)	P_o (kW)	PHU (%)	P_o (kW)
F H P W										
0 0 0 0	11	17.2	19.5	5.5	19.1	4.3	15.6	3.1	17.5	2.2
0 0 0 0	12	14.7	16.3	5.9						
0 0 0 0	12.8	19.1	20.6	4.4						
0 0 0 0	26.5	17.2	18.5	2.3						
0 0 0 0	37	15.2	16.4	1.8	14.3	1.8	14.1	1.4	12.5	1.1
1 0 0 0	26.5	15.7	16.4	2.5	16.2	2.4	15.9	2.3	15.4	2.0
1 0 0 0	25	16.6	17.8	2.5	17.7	2.4				
1 0 0 0	27	15.1	16.0	2.6	10.0	3.6				
1 0 0 0	23.5	16.1	17.1	2.7	17.6	2.5	17.2	2.4	17.1	2.0
0 1 0 0	13.5	12.6	13.5	6.1	14.2	4.6	14.6	4.6	14.9	3.2
0 1 0 0	15	12.8	13.6	5.4	14.2	4.2	13.7	3.7	14.3	3.0
0 1 0 0	12.8	13.1	13.8	6.2	15.1	4.6				
0 1 0 0	23	11.9	12.6	3.8	12.4	3.4	12.1	3.0	11.1	2.4
1 1 0 0	37	9.3	10.0	3.0	9.5	2.9	8.4	2.4	7.9	2.2
1 1 0 0	25	10.5	11.5	4.0	11.2	3.5	10.3	2.7	9.3	2.4
1 1 0 0	32	10.4	11.1	3.1	10.7	3.1	10.0	2.7	9.3	2.3
1 1 0 0	23.5	11.7	12.6	3.8	11.3	3.3	10.0	2.7	9.3	2.3
1 1 0 0	28.5	11.1	11.8	3.3	11.6	3.0	10.3	2.6	9.5	2.3

fuel-height, height-wind and so on) were not significant (Table 5.6).

Table 5.6
Statistical level of significance of changing various factors for PHU2)

Factor	BP1[1]		BP1S10	BP1S30	BP1S60
fuel	1.4%	(3.2%)	1.9%	1.4%	2.2%
height	0.2%	(0.3)	<0.1%	<0.1%	0.1%
pot material	n.s.[2]	(0.2%)	1.0%	<0.1%	<0.1%
wind	n.s.	(n.s.)	n.s.	n.s.	n.s.

[1] figures in brackets refer to PHU1
[2] n.s. - not statistically significant

At BP1 the effect on PHU2 of changing either the firewood species or height on PHU2 was statistically significant at the 3% and 0.2% level respectively.

The effect of changing from the clay to aluminium pot was statistically significant at times greater than BP1 (Table 5.6). Increasing simmering time tended to increase the statistical significance of the main factors.

(c) Effect of fuel

Iroko was difficult to burn, especially in the initial stages of lighting the fire and the flames were easily extinguished; Jelutong burnt very easily. In some cases, bellows were needed with Iroko to prevent the fire from being extinguished. The range of power outputs obtained with Iroko (2-4kW) was smaller than with Jelutong (2-6kW) (Fig 5.9 - 5.12). A smokey fire was evident at low power outputs and the early stages of combustion for both firewood species.

At BP1, the PHU tended initially to increase with power output, reach a maximum and then fall; there is insufficient data to confirm whether this was the case for Iroko at the "low" height.(Fig 5.9 - 5.12).

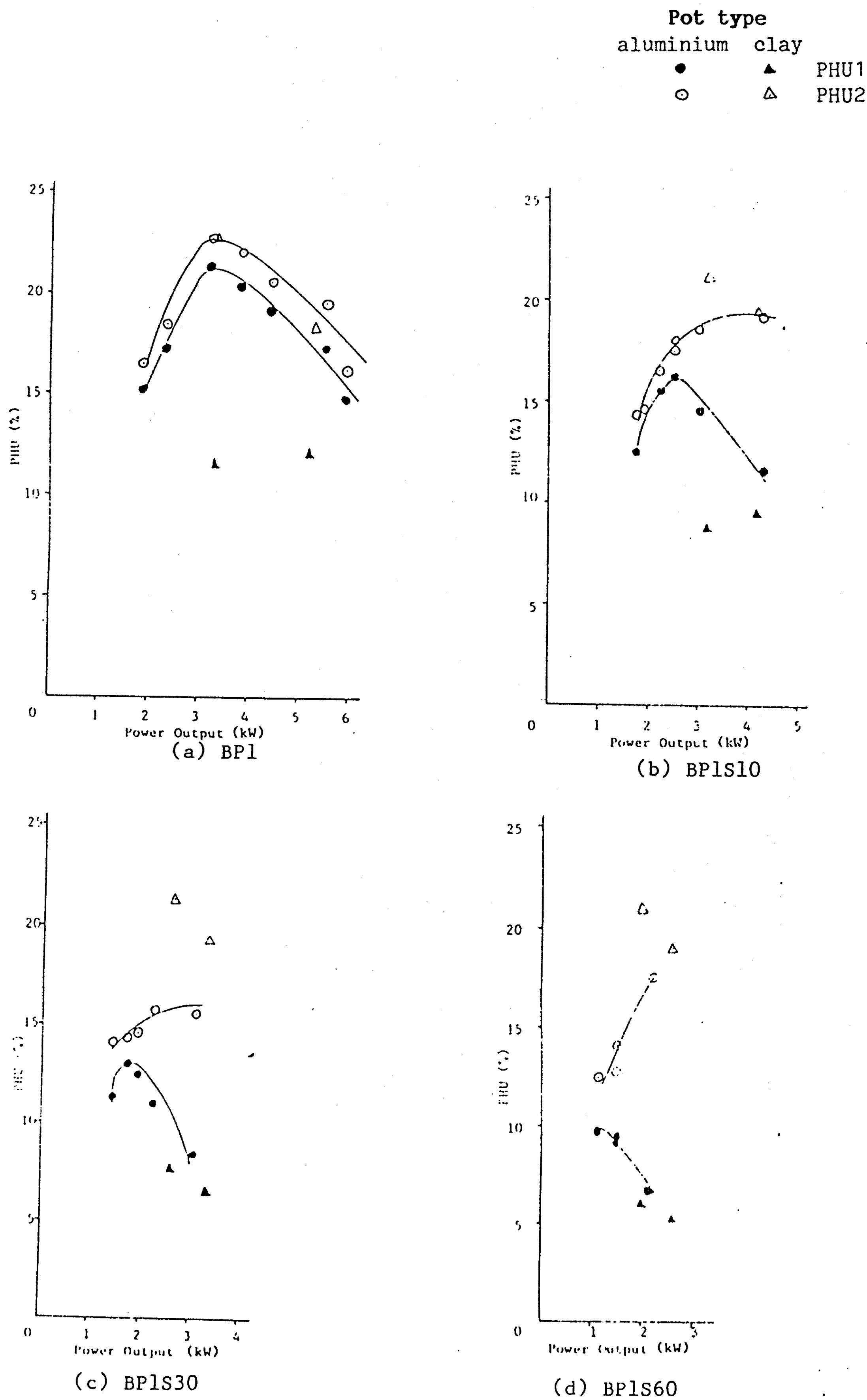


Fig 5.9 PHU vs power output for 'U' chulha at "low" height using Jelutong

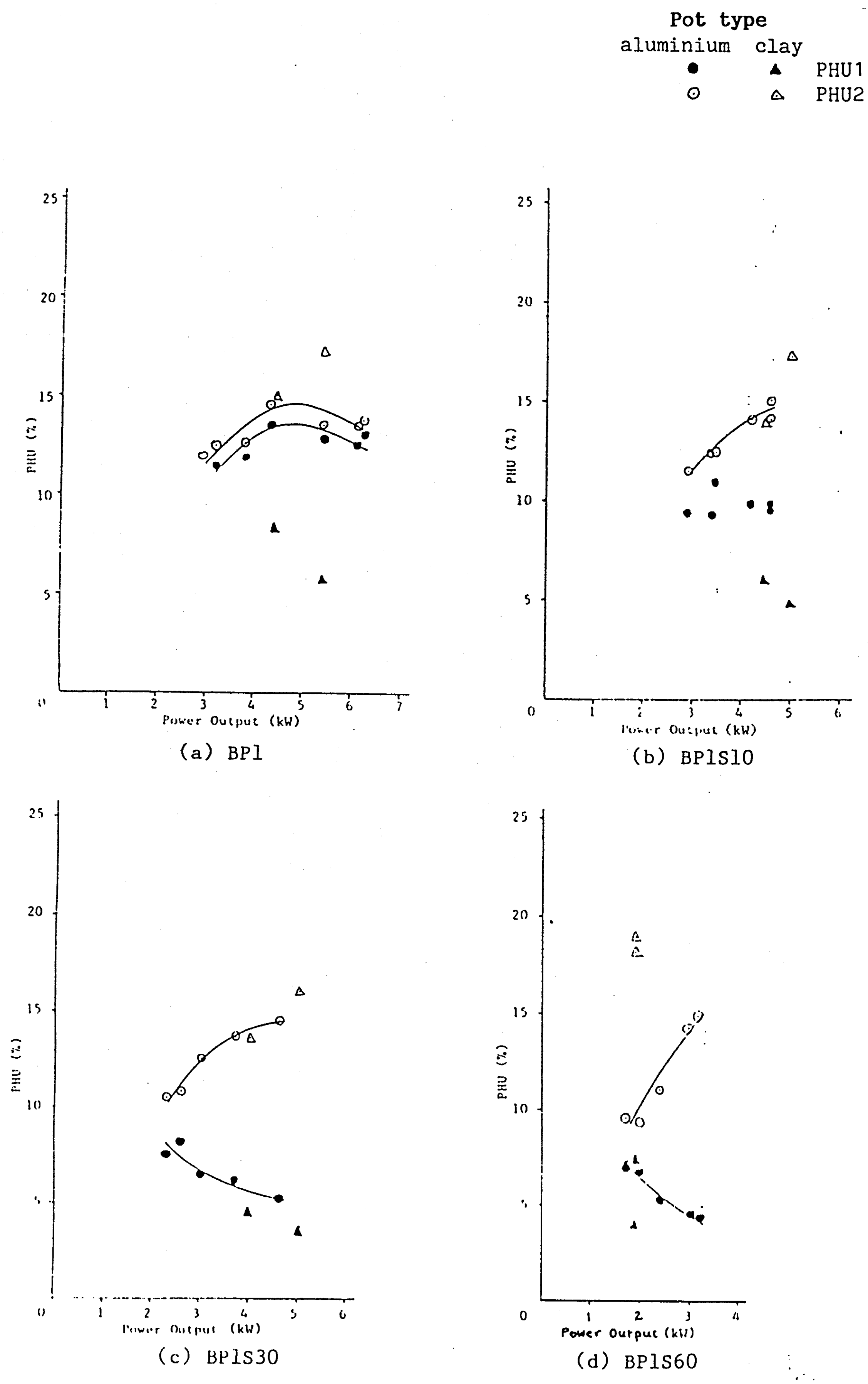


Fig 5.10 PHU vs power output for 'U' chulha at "high" height using Jelutong

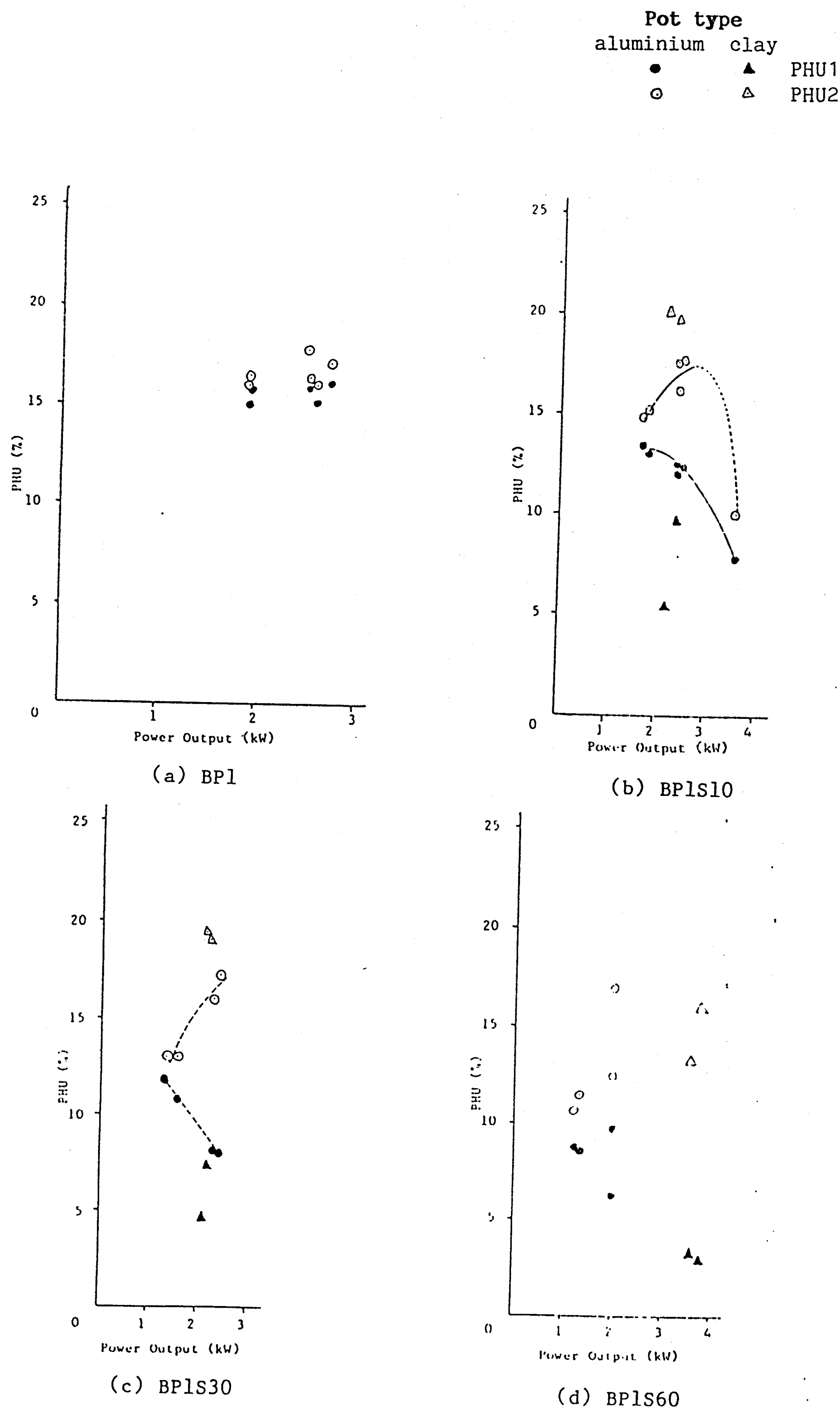


Fig 5.11 PHU vs power output for 'U' chulha at "low" height using Iroko

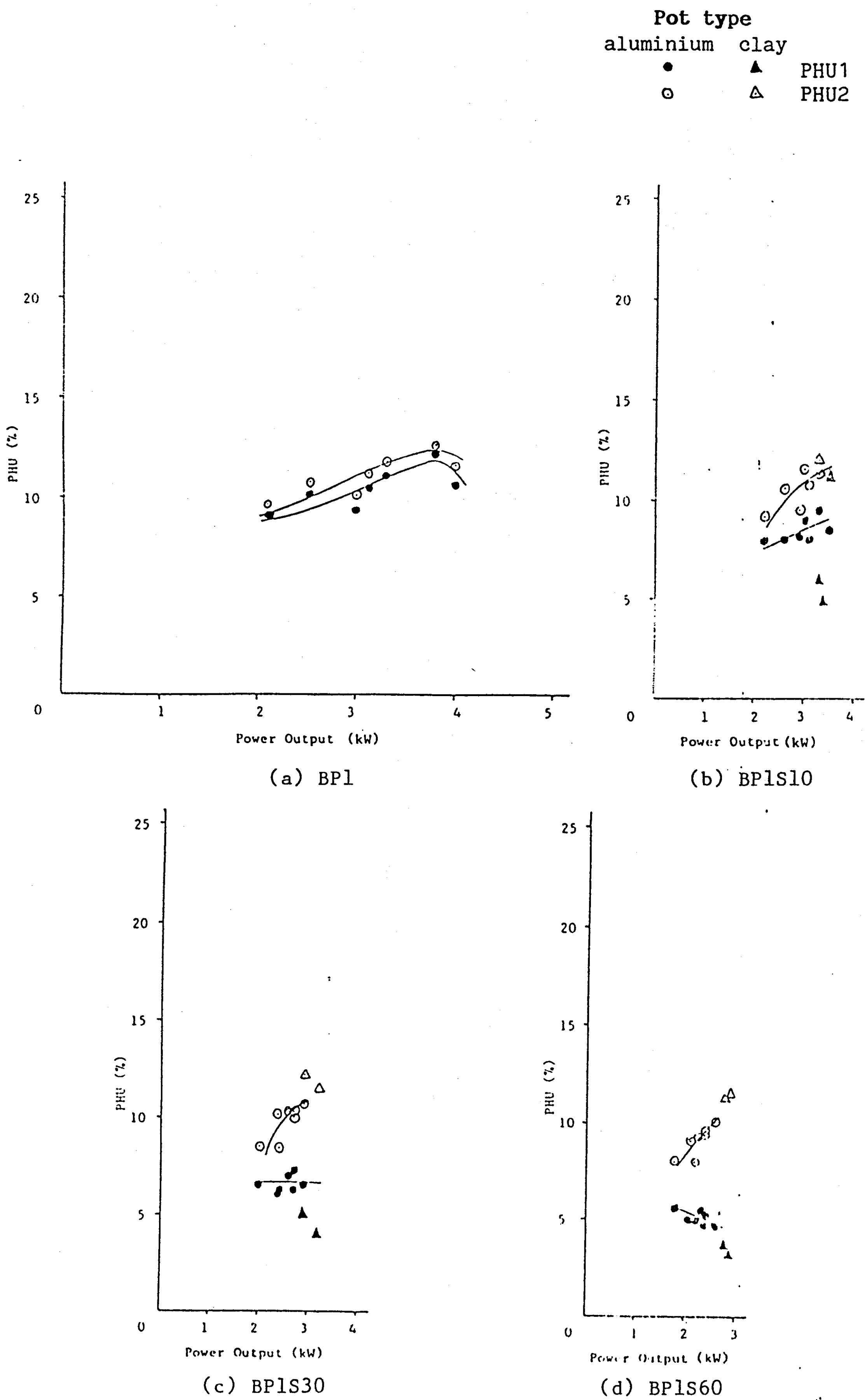


Fig 5.12 PHU vs power output for 'U' chulha at "high" height using Iroko

PHU's at BP1 with Iroko (Fig 5.11 and 5.12) were lower than those with Jelutong (Fig 5.9 and 5.10).

The maximum value of PHU2 fell with simmering time - this was especially noticeable with WBT's using Jelutong (Fig 5.9 and 5.10).

(d) **Effect of height**

Iroko burnt with small flames and lower power outputs, hence, the flames did not always reach the pan bottom: this was particularly pronounced at the "high" height and the flames did not reach the pan bottom at power outputs less than about 3kW. In addition, a dark brown oily liquid (creosote) was deposited on the bottom of the aluminium pan.

With Jelutong, the flames reached the pan bottom at the "low" height; the flames tended to go around the aluminium pan at power outputs greater than 5kW. At the "high" height, the flames only reached the pan bottom at power outputs of around 5kW.

For Jelutong, increasing the distance between the firewood and pan decreased the proportion of flames reaching the pan bottom and had three effects on the PHU as a function of power output at BP1 (Fig 5.9 and 5.10): firstly, the maximum value of PHU2 fell from 23% to 15%; PHU1 fell from 21% to 14%. Secondly, the PHU vs P_o curve was much flatter. Thirdly, the peak values of PHU1 and PHU2 ocurred at a higher power output, viz from 3kW at the lower height to 4.5kW at the greater height.

For Iroko, increasing the height decreased the PHU (Fig 5.11 and 5.12). There was little change in the energy associated with steam as a proportion of the total energy.

(e) **Effect of pot material**

Less time was taken for the water to reach boiling point with an aluminium pan compared with the clay pot at either height (Fig 5.13): with an aluminium pan the time to bring the water to boiling point was about 50 minutes at 1.7kW, begining to level off at around 10 minutes for 6kW.

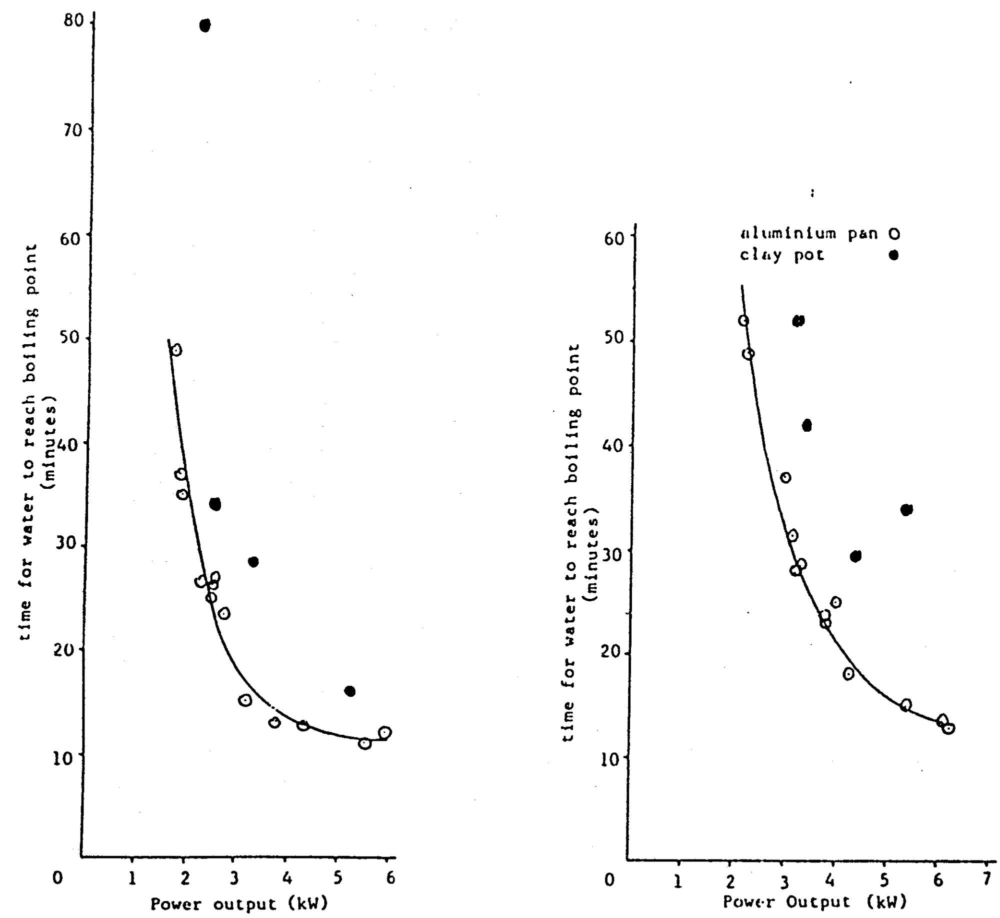
As the bottom of the bottom of the clay pot was nearer to the fuelbed, flames reached the bottom of the clay pot more easily than of the aluminium pan: values of PHU2 obtained for the clay and aluminium pan were similar.

Owing to the large mass of water evaporated, the lowest values of PHU1 were obtained when a clay pot was used; several hundred grammes (up to 600g) of water were evaporated when a clay pot was used compared with typically 20g to 30g with the aluminium pan.

Overall, the lowest and highest values of PHU2 were of similar magnitude with both types of cooking pot (Table 5.4).

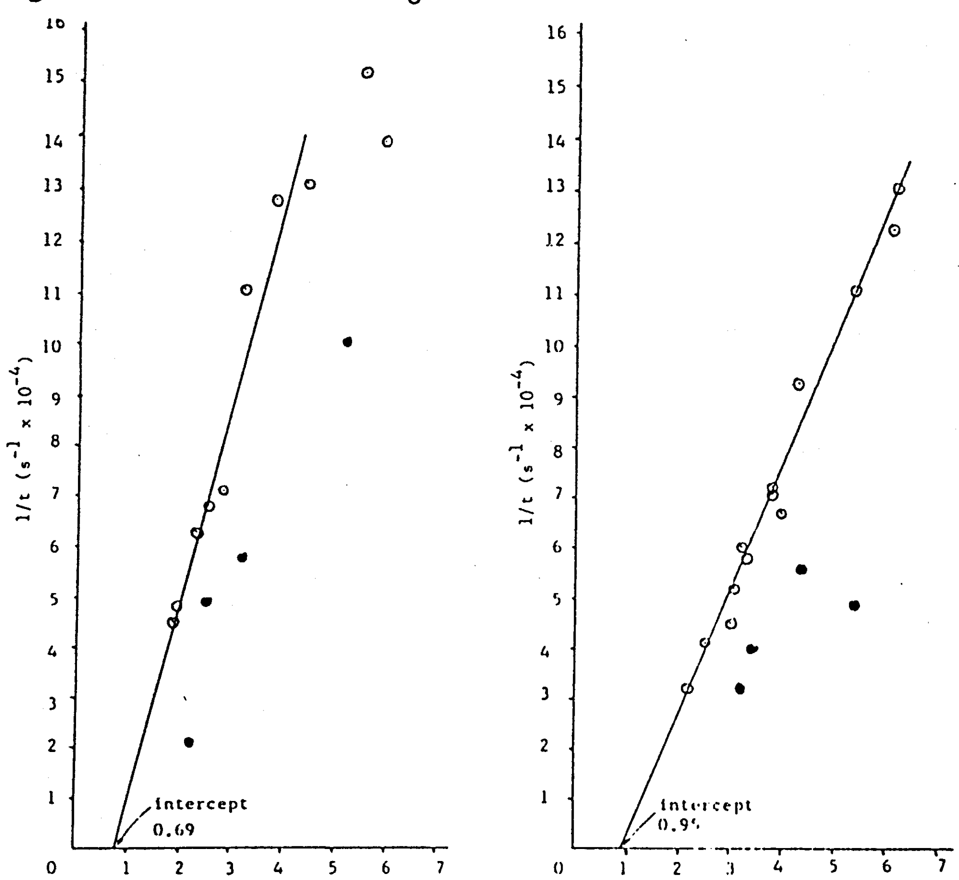
(f) **Energy losses**

The reciprocal of BP1 plotted against power output for both heights are shown in Fig 5.14. The best fit lines to these data have been drawn using the standard techniques of linear regression. The correlation coefficients at the low and high heights are 0.970 and 0.989 respectively. Intercepts on the power output axis (ie estimated rates of heat loss at BP1) are 0.69kW and 0.95kW for the 'low' and 'high' height respectively; in the 'low' height case the data points at the two



(a) "low" height (b) "high" height

Fig 5.13 Time to boil vs P_o for clay and aluminium pot on 'U' chulha



(a) "low" height (b) "high" height

Fig 5.14 Estimation of steady state radiative heat losses from 'U' chulha (plot of 1/BP1 vs power output) highest power outputs have been excluded.

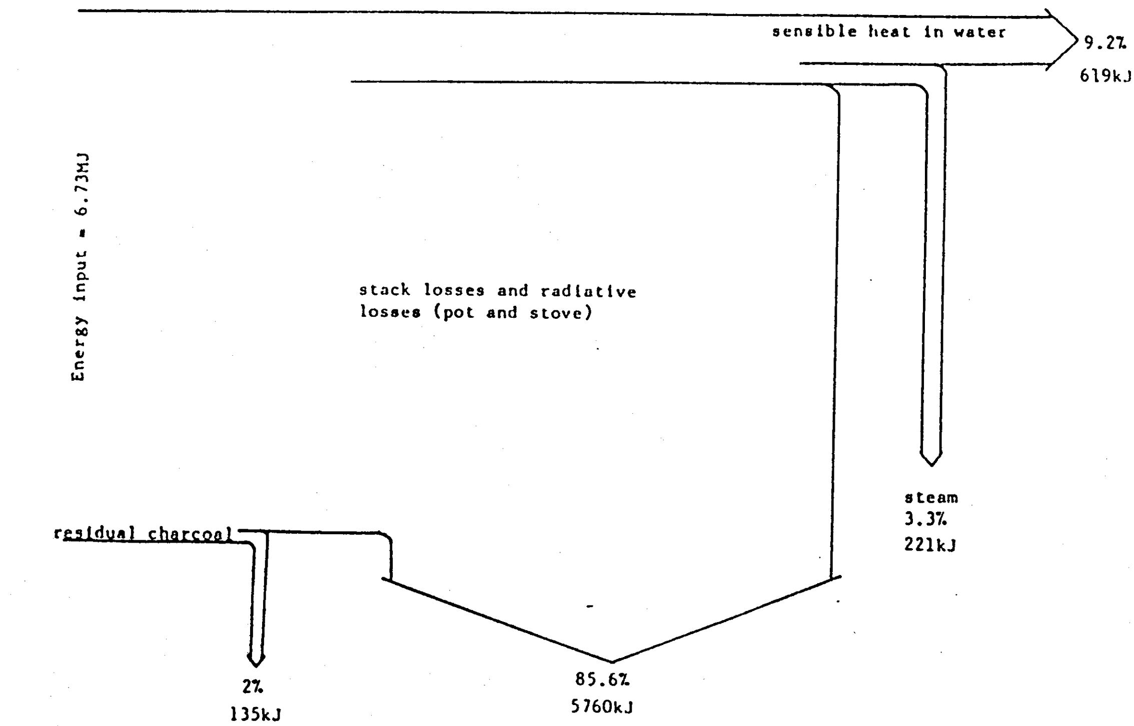
(g) Energy flows

Theoretically the energy required to heat 2kg water from 25°C to 100°C is 625kJ. Because the water was heated from a temperature slightly different from 25°C the energy absorbed in heating the water (the sensible heat) is not exactly 625kJ. The percentage heat energy absorbed by the water is slightly smaller than PHU1 or PHU2 as energy associated with the residual charcoal is included in the energy flow diagrams (Fig 5.15 to 5.18).

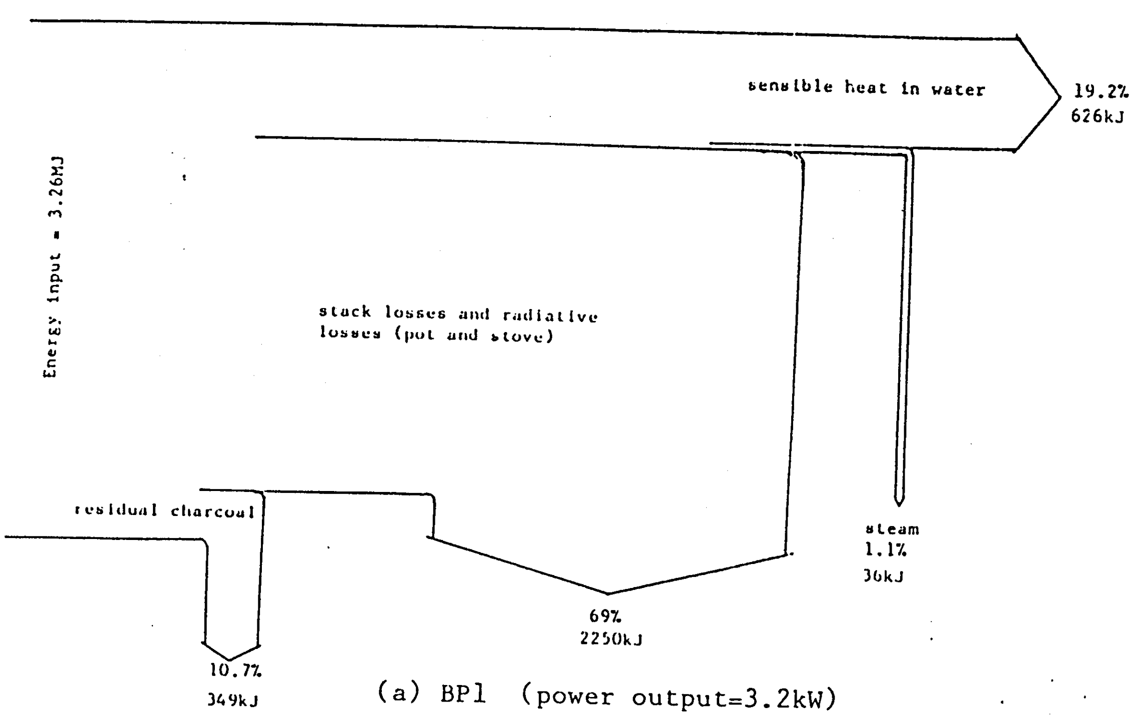
Energy losses due to radiation from the pot and stove have not been included in the energy flow at BP1: estimated radiative energy losses at BP1S60, as a proportion of input energy are small (41.4kJ and 57kJ at the "low" and "high" heights respectively) - these are less than 1% of the input heat energy. However, all the energy flows are dominated by the energy lost in unburnt hot gases which increase with time: more than two-thirds of the heat energy given out by the firewood was lost in the stack gases (Fig 5.15 - 5.18).

At BP1, the amount sensible heat absorbed by the water in the clay pot was comparable to the heat content of the escaping steam. Heat lost in steam with the aluminium pan was an order of magnitude smaller (compare Fig 5.15 and 5.16 & Fig 5.17 and 5.18). Overall, energy losses associated with steam increased with simmering time with both types of pan.

At BP1, up to 20% of the input energy was stored in the residual charcoal. The mass (and hence energy content) of this charcoal



(b) BP1S60 (power output=1.4kW)



(a) BP1 (power output=3.2kW)

Fig 5.15 Energy flows in 'U' chulha with aluminium pan: highest PHU (Jelutong, "low" height)

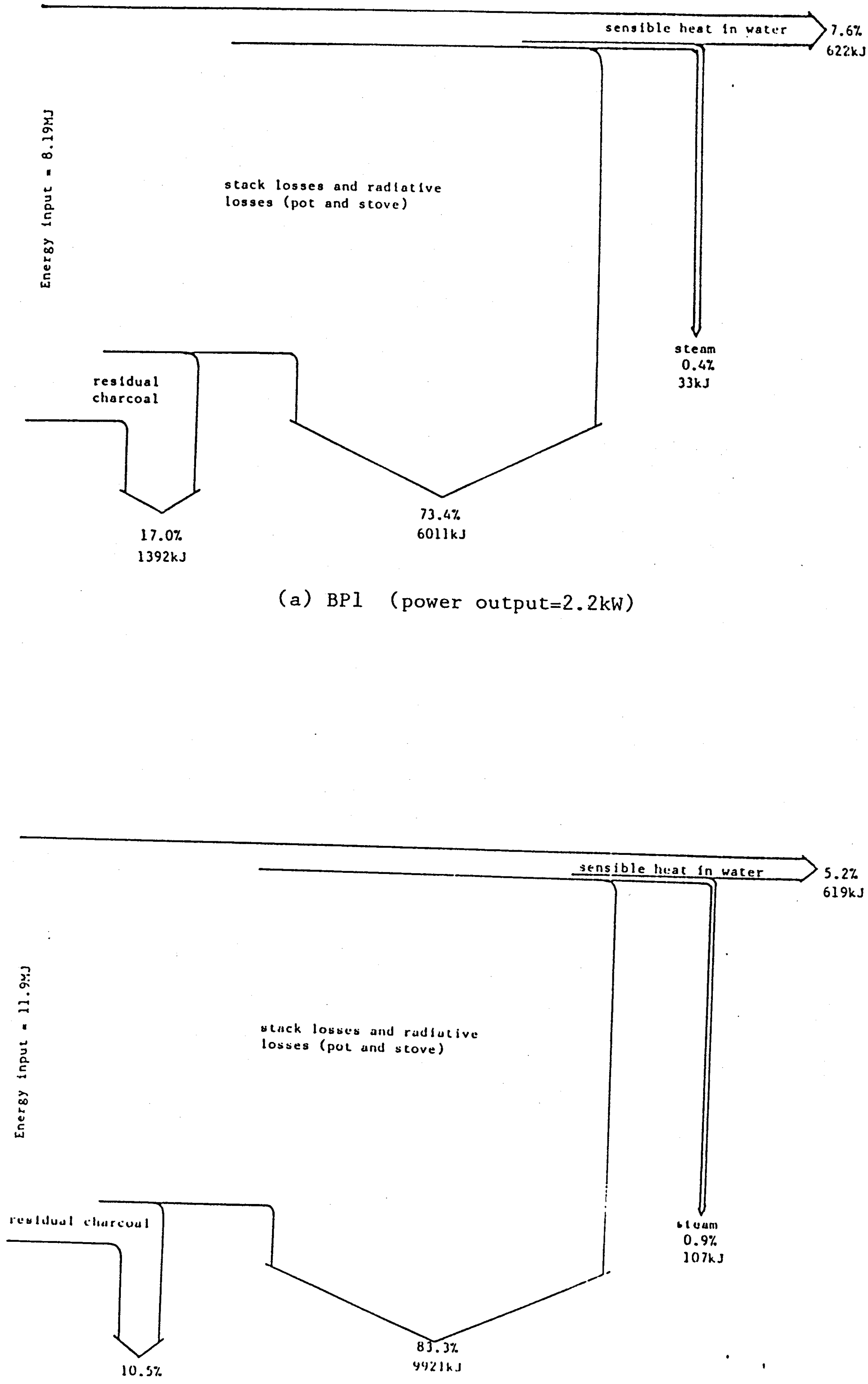
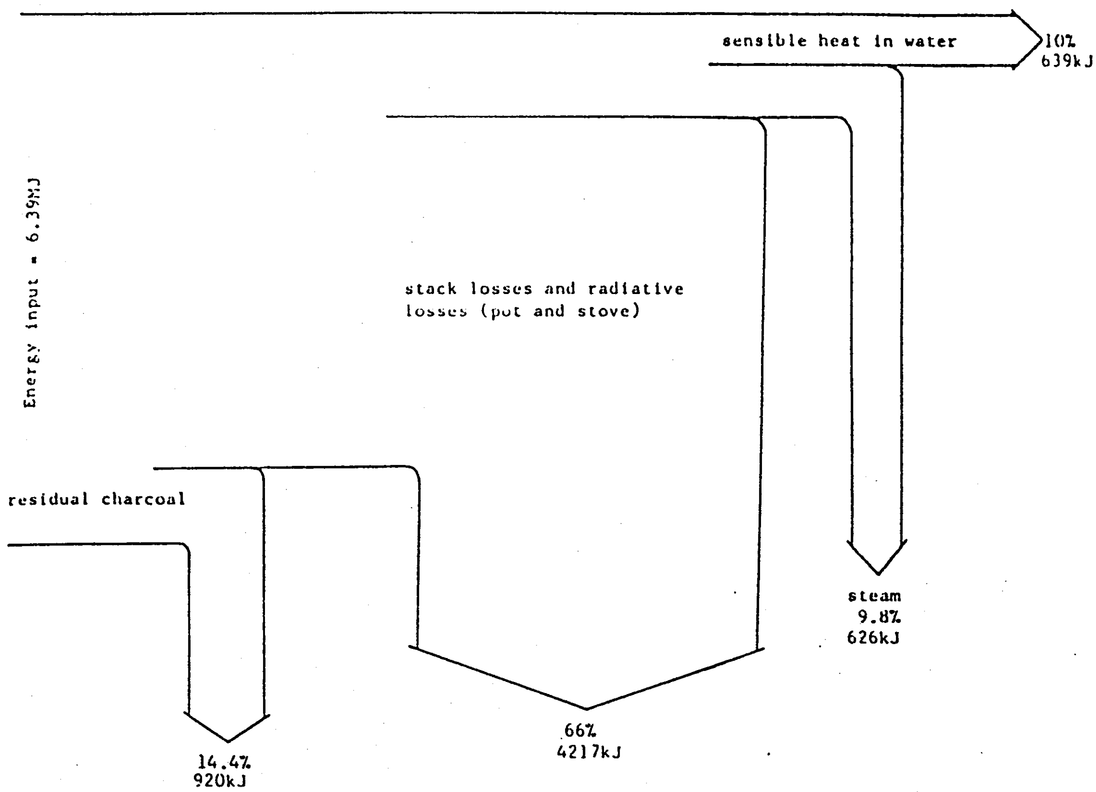
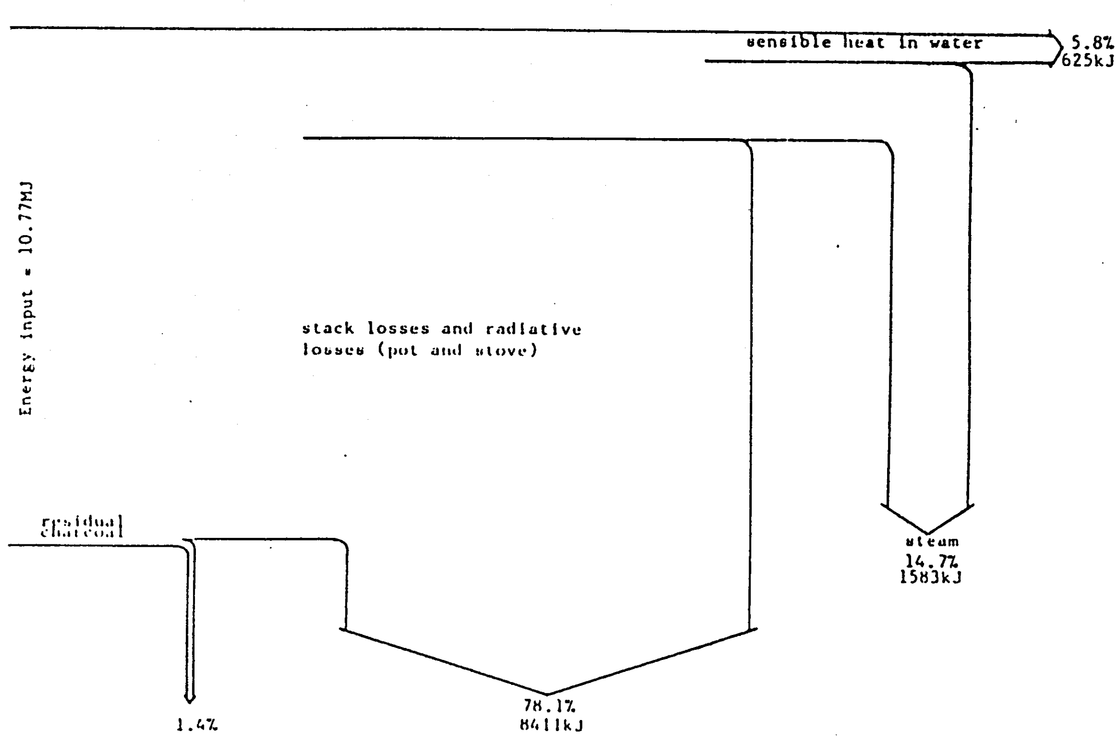


Fig 5.16 Energy flows in 'U' chulha with aluminium pan: lowest PHU (Iroko, "high" height)

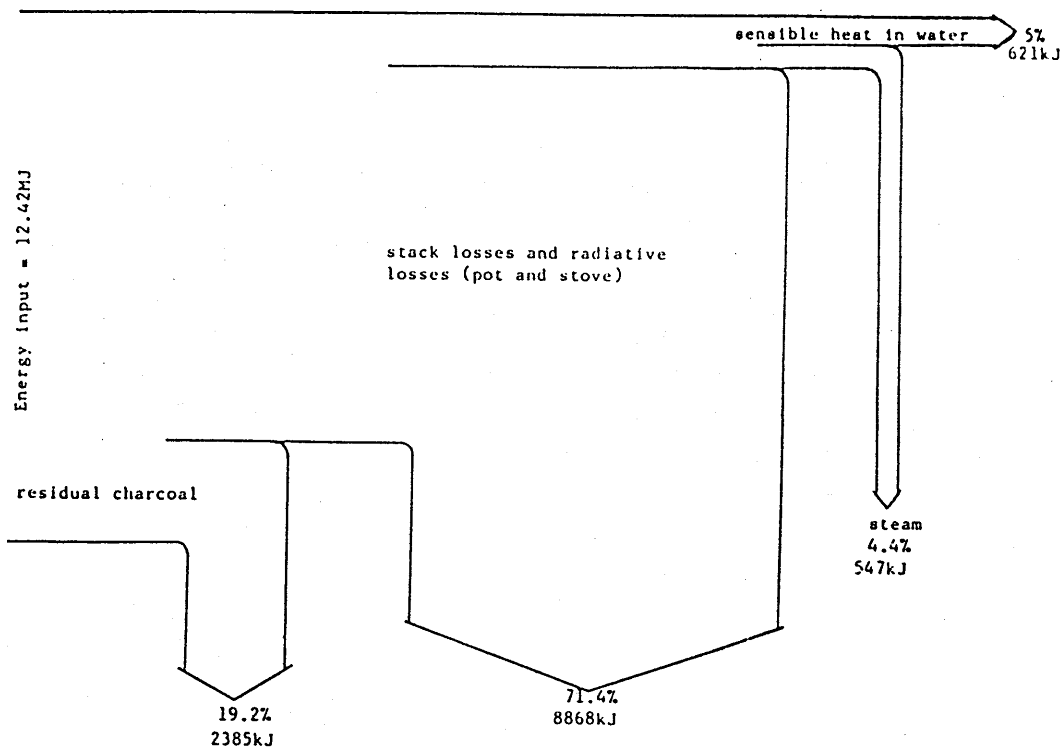


(a) BP1 (power output=3.3kW)

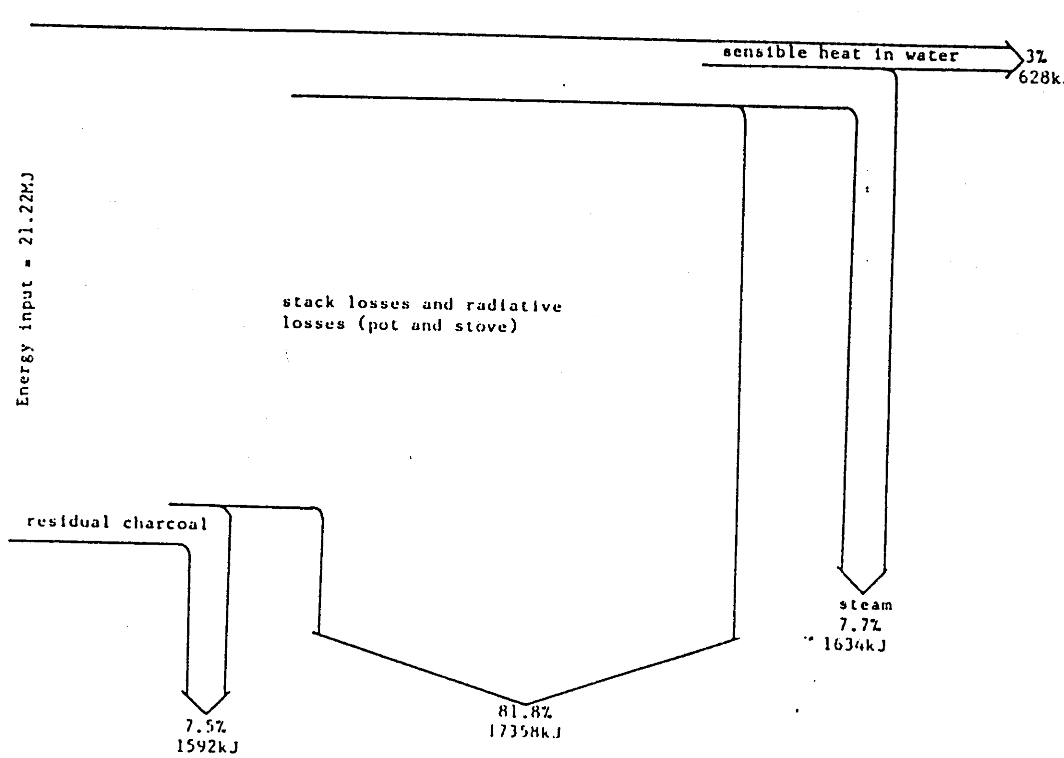


(b) BP1S60 (power output=2.0kW)

Fig 5.17 Energy flows in 'U' chulha with clay pot: highest PHU (Jelutong, "low" height)



(a) BP1 (power output=3.2kW)



(b) BP1S60 (power output=2.9kW)

Fig 5.18 Energy flows in 'U' chulha with clay pot: lowest PHU (Iroko, "high" height)

Table 5.7

PHU* data from WBT's

(iron frame without windshield)

		BP1						BP1S10		
PHU1 (%)	PHU2 (%)	Power Output (Kw)	time to boil (min)	Charcoal left (g)	Wood used (g)	PHU1 (%)	PHU2 (%)	Power Output (Kw)	Charcoal left (g)	Wood used (g)
11.3	12.0	3.58	26	25	356	9.2	11.7	3.18	14	418
12.5	13.3	4.03	20.75	20	322	9.3	12.1	3.65	21	422
11.9	12.7	4.80	18.33	23	342	8.6	10.9	4.30	16	447
11.8	12.6	6.21	14.33	21	340	8.9	12.3	4.85	14	430
12.5	13.4	7.16	11.66	33	343	9.0	11.1	5.34	21	434
9.8	10.3	8.53	12.5	20	355	7.5	10.5	6.16	24	472
11.7	12.6	7.69	11.50	27	350	8.4	12.0	5.82	19	463
11.4	11.9	7.12	12.75	24	353	8.1	10.6	5.63	17	470
11.6	12.4	4.64	19.33	22	346	8.2	11.0	4.33	24	478
12.1	12.9	4.29	20.25	23	338	8.0	11.4	4.33	27	497
11.3	11.7	4.94	18.67	27	363	7.5	10.5	4.83	27	523
11.7	12.9	5.07	17.5	26	349	7.3	11.7	5.15	26	532
12.9	13.7	5.97	13.5	27	323	7.8	11.8	5.65	24	498
12.1	13.0	6.24	13.67	27	339	7.2	11.7	6.06	31	546
11.2	11.8	3.59	26	18	352	8.7	10.3	3.32	13	434
12.1	12.9	7.14	16	16	322	7.6	12.3	6.23	27	518
12.6	13.6	7.38	11.17	31	336	7.6	12.6	6.42	32	522
10.3	11.1	2.80	36	18	377	8.4	9.6	2.67	15	449
11.3	12.4	9.01	10.25	34	375	6.7	11.2	7.7	34	596
9.8	10.6	2.86	37.25	23	406	7.3	9.2	3.05	23	535

Table 5.8

PHU* data from WBT's

(iron frame + windshield)

		BP1						BP1S10		
PHU1 (%)	PHU2 (%)	Power Output (Kw)	time to boil (min)	Charcoal left (g)	Wood used (g)	PHU1 (%)	PHU2 (%)	Power Output (Kw)	Charcoal left (g)	Wood used (g)
10.0	10.6	6.39	16.5	35	422	6.8	9.2	5.8	22	567
10.8	11.4	4.17	22.83	28	436	6.6	8.7	4.8	22	534
9.0	9.8	6.46	17.75	31	447	6.2	8.8	6.03	29	625
9.4	10.0	5.56	20	29	432	6.9	9.0	5.01	26	562
8.6	9.3	7.09	17	34	472	6.2	8.7	6.17	28	575
10.5	11.7	7.09	14	34	399	6.2	0.6	6.93	37	635
8.4	9.2	8.10	15.25	36	486	8.4	9.2	6.50	25	608
9.7	10.3	5.70	18.75	29	417	7.2	9.6	5.00	22	528
8.8	9.6	4.08	19	23	446	7.1	9.0	3.76	20	539
9.7	10.8	6.59	16.25	34	426	6.9	9.1	5.79	23	562
9.7	10.3	3.90	27.5	22	406	7.4	9.1	3.72	22	518
11.0	11.6	4.70	20	22	361	7.7	0.2	4.47	20	496
10.7	11.3	5.37	18	24	373	7.3	0.1	5.03	21	521
11.2	11.9	6.70	14	25	365	7.6	1.0	5.75	27	521
10.5	11.2	7.34	13.25	26	387	6.8	1.1	6.51	27	534
9.4	10.5	2.94	37.5	17	409	7.8	9.1	2.8	8	476
9.4	9.9	3.08	36	17	410	7.4	9.5	3.04	16	509

decreased from BP1 to BP1S60.

5.2.3 Iron frame

(a) PHU as a function of power output

PHU data from the WBT's for the iron frame are summarized in Table 5.7 and 5.8.

The plots of PHU vs power output at BP1 and BP1S10 without a windshield are shown in Fig 5.19. Corresponding PHU's vs power output without a windshield are given in Fig 5.20.

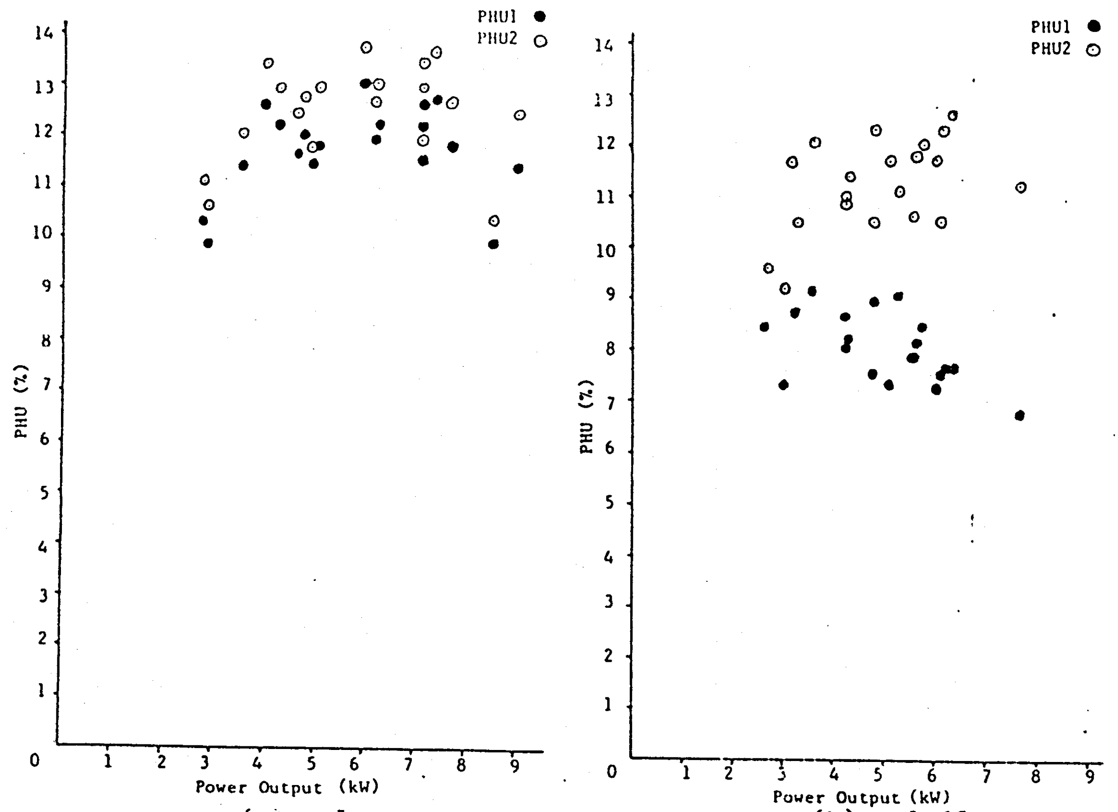
(b) the effect of the windshield on the PHU

A t-test was carried out to determine the effect on the PHU of having a windshield on the iron frame. The PHU's were split into 3 sections by vertical lines corresponding to power outputs in the range below 4kW, in the range 4-8kW and power outputs above 8kW (Fig 5.21). Only PHU's in the power output range of 4kW and 8kW were used in the statistical analysis; PHU's outside these power outputs showed a great deal of variance. This t-test gave the following results:

Table 5.9
Statistical tests on PHU data for iron frame

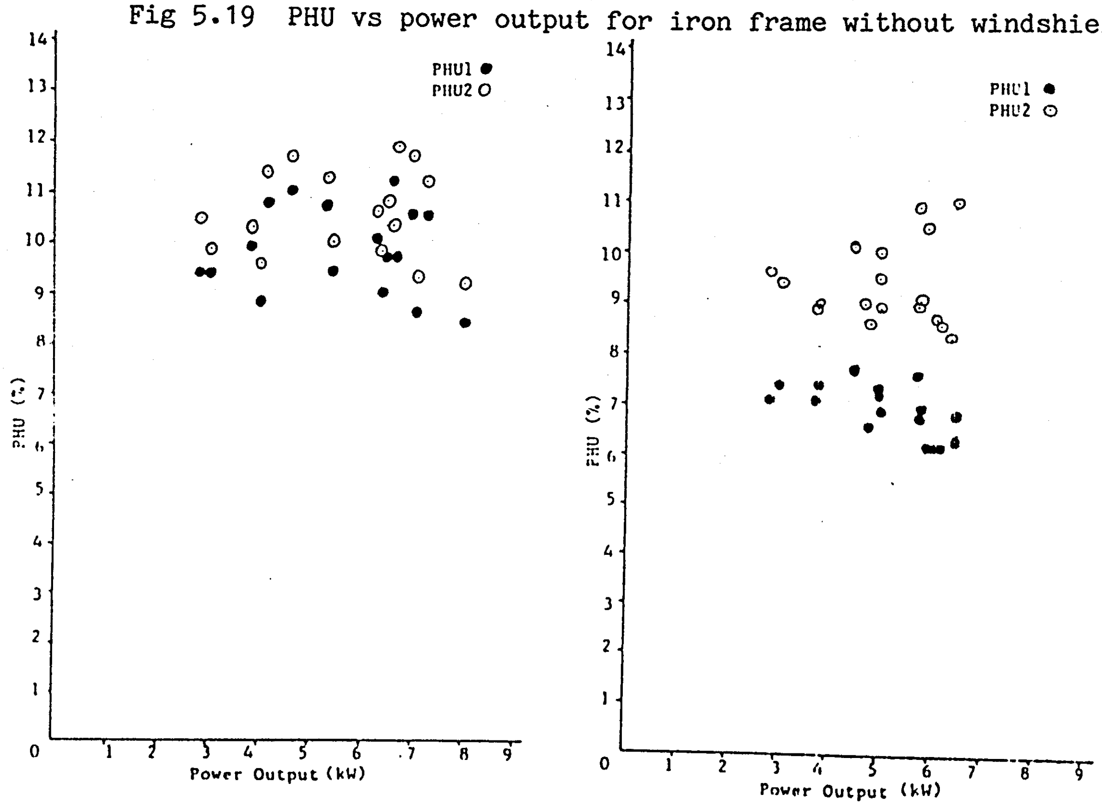
	No. of data points	Mean PHU (%)	S.E.
without windshield	14	12.8	0.58
with windshield	13	10.7	0.86

The t-test shows that the effect of the windshield is to significantly ($p<0.001$) reduce the PHU.



(a) BP1 (b) BP1S60

Fig 5.19 PHU vs power output for iron frame without windshield



(a) BP1 (b) BP1S10

Fig 5.20 PHU vs power output for iron frame with windshield

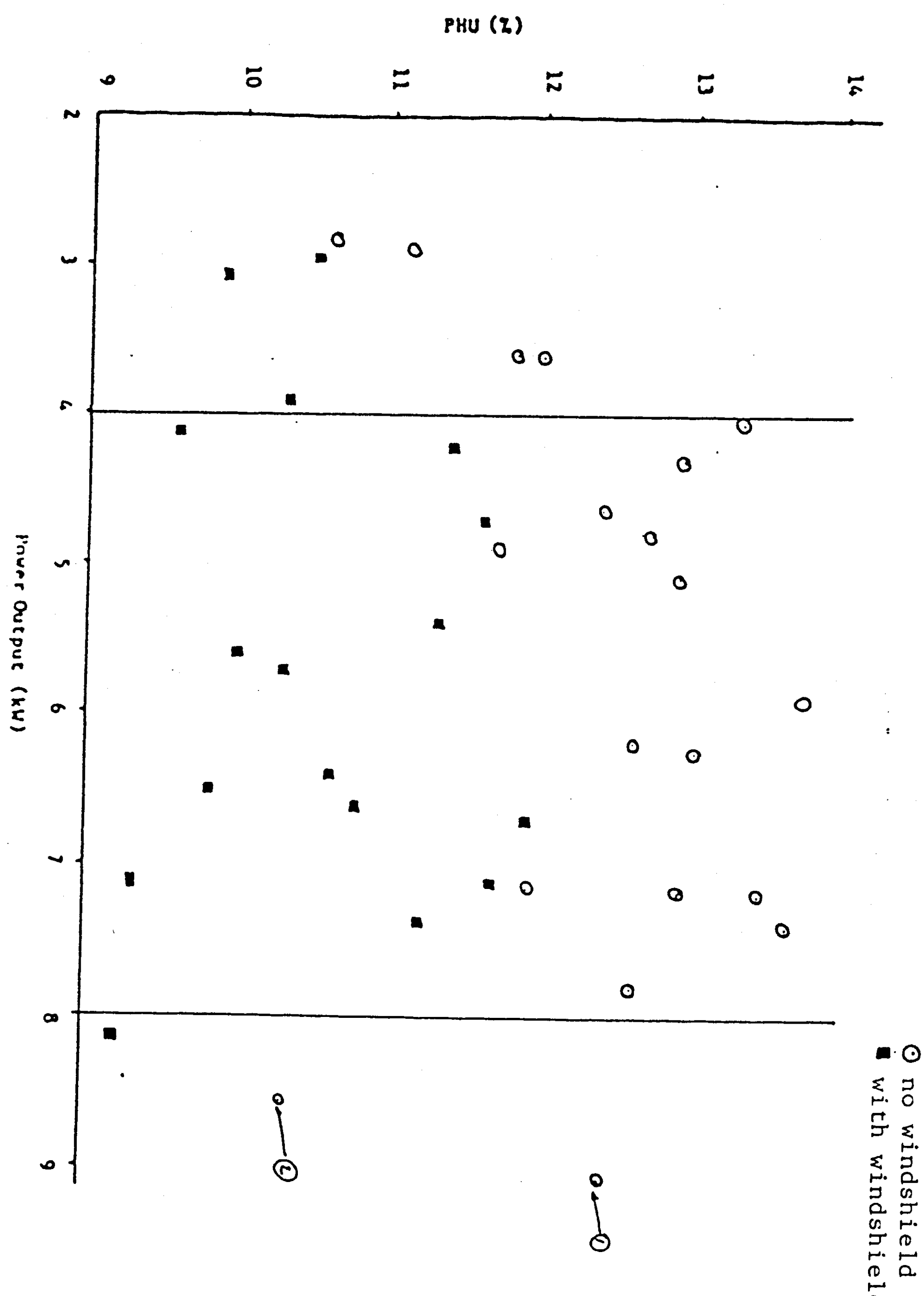
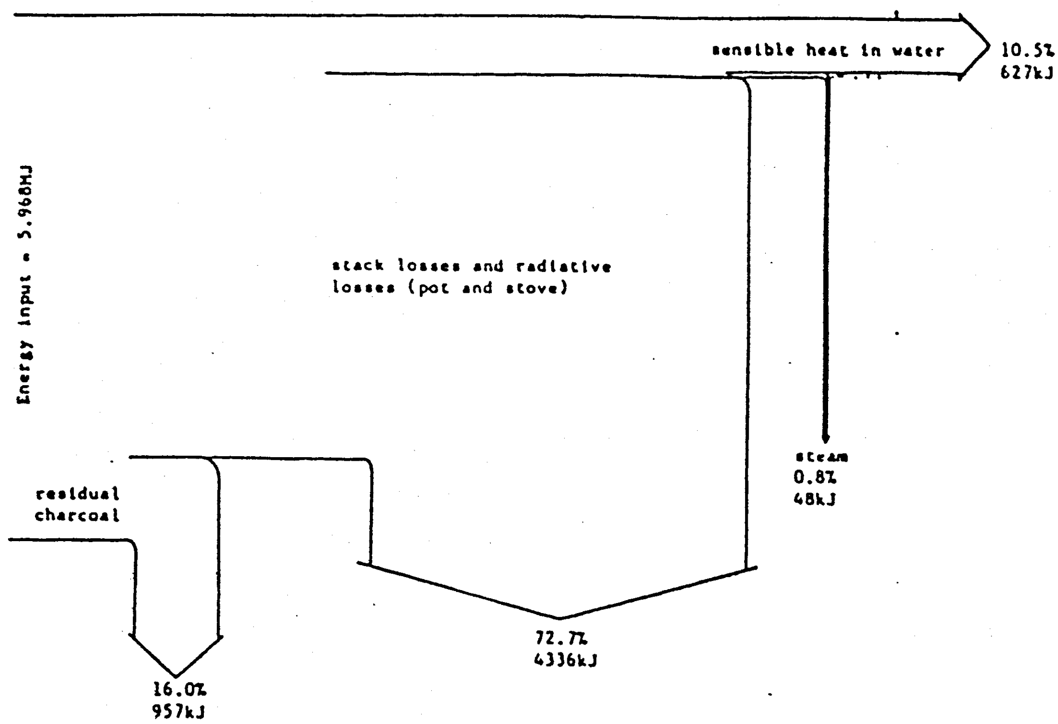
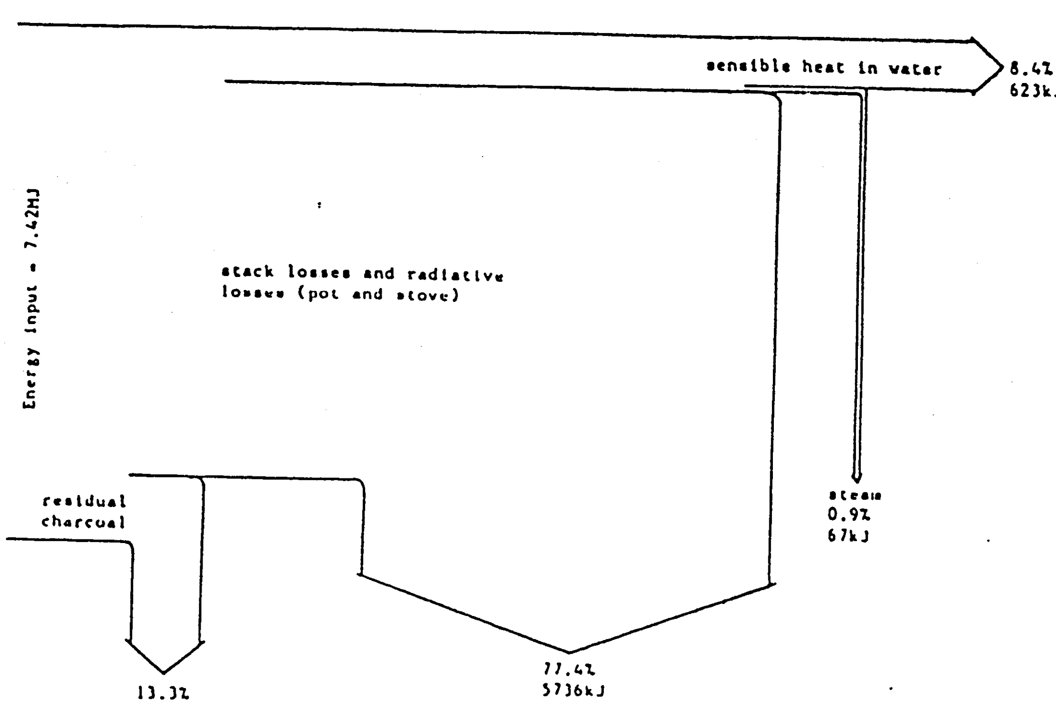


Fig 5.21 PHU vs power output for iron frame with and without windshield



(a) BP1 (power output=7.2kW)

Fig 5.22 Energy flows in iron frame without shielding



(b) BP1 (power output=6.6kW)

Fig 5.23 Energy flows in iron frame with shielding

The flames were very sensitive to cross winds with the addition of the 3 metal sides, and were continually creeping around towards the sides rather than directly underneath the pot.

(c) Energy losses

Estimated steady state energy losses at BP1 for the iron frame with and without the 3 metal sides were 0.5kW and 0.6kW respectively;

(d) Energy flows

Energy flow diagrams for the iron frame at BP1 with and without the 3 metal sides are shown in Fig 5.21 and 5.22. Energy flows are dominated by the energy lost in the hot stack gases: around three-quarters of the input energy was in the stack gases. Up to 16% of the input energy was contained in the charcoal which had formed at BP1, and hence was greater than the energy which had been absorbed by the water. Energy carried away by steam was less than 1% of the input energy.

5.2.4 Effect of wind on iron frame and McGarry stove

PHU1 at BP1 for the iron frame and McGarry stove were both around 20%. Significantly lower PHU's were obtained with both stoves with "slight" wind when the wind was blowing directly at the flames; in both cases PHU1 was around 5%. The wind had the effect of increasing the burning rate of the firewood as well as blowing away the flames from beneath the bottom of the pan. However, having a windshielded side of the McGarry stove placed in the way of the wind had the effect of doubling the PHU; PHU1 at BP1 was around 10% - the shielding was observed to have reduced

Table 5.10

iron frame and McGarry stove: PHU data

Level of wind	McGarry stove BP1 PHU1 (%)	McGarry stove BP1 PHU2 (%)	McGarry stove BP1 Po (kW)	McGarry stove BP1S10 PHU1 (%)	McGarry stove BP1S10 PHU2 (%)	McGarry stove BP1S10 Po (kW)	iron frame BP1 PHU1 (%)	iron frame BP1 PHU2 (%)	iron frame BP1 Po (kW)	iron frame BP1S10 PHU1 (%)	iron frame BP1S10 PHU2 (%)	iron frame BP1S10 Po (kW)
none	19.0	19.8	5.02	10.9	17.9	4.57	19.5	20.1	6.09	11.1	18.8	5.06
	16.9	17.6	5.17	9.5	14.7	5.00	19.1	19.9	6.30	10.5	18.2	5.36
"slight" (1m/s) (flames exposed to wind)	4.5	4.9	9.08	3.4	4.8	8.77	5.9	6.3	8.35	4.4	5.4	7.74
	5.2	5.8	9.15	3.8	5.0	8.60	5.8	6.3	7.80	4.5	5.6	7.11
(flames shielded)	10.3	11.1	6.96	7.0	9.5	4.76						
	10.1	10.8	7.27	7.6	9.8	5.56						
"Moderate" (1.5m/s) (flames shielded)	7.9	8.5	8.00	6.1	7.6	6.49						
	9.2	10.1	6.68	6.3	8.9	6.19						

Table 5.11

Iron frame and McGarry stove: heat flux, radiative* and convective heat transfers

Level of wind	McGarry stove Heat flux (W/m²)	McGarry stove Convective heat (a) transfer coefficient (W/m²K)	McGarry stove Convective heat (b) power input (W)	iron frame Heat flux (W/m²)	iron frame Convective heat (a) transfer coefficient (W/m²K)	iron frame Convective heat (b) power input (W)
none	3.2	26.5	780	3.2	26.5	780
"slight" (1 m/s)	2.3	17.5	515	1.2	5.3	155
"Moderate" (1.5m/s)	2.0	13.9	410			

* radiative heat input to the pan was calculated to be 220W in all cases

the effect of the wind on the flames. With the "moderate" wind blowing at a windshielded side of the McGarry stove, the PHU was still higher than with the unmodified iron frame; PHU1 was between 8% and 9% (Table 5.10).

A summary of the heat fluxes, convective and radiative heat transfer with the various arrangements are given in Table 5.11. Heat transfer by radiation was around 220W. Under conditions of "no wind" heat transfer by convection was dominant (around 800W), however, convective heat transfer fell as the wind blew the flames away from the pan bottom, and the total heat transfer approached the radiative component.

5.3 Discussion

5.3.1 Performance of "stoves" tested

(a) 3-stone fireplace

Values between 17% and 20% were obtained for PHU2 in bringing 2kg of water to the boiling point. These are in agreement with WBT's conducted by Joseph and Shanahan (1981).

No comparable data on PHU1 by other authors has been found. However, PHU1 falls with increasing simmering time, as the wood consumed increases.

At BP1S30, the mean value of PHU2 was 15.4% at 1.51kW for Jelutong - this is close to the expected value of 15%, according to data from Joseph and Shanahan (1981). For Iroko, the mean value of PHU2 was 13%.

Values of PHU2 at BP1S60 are much lower than reported by Brattle (1979) and, Joseph and Shanahan (1981) (see Chapter 4). In this study, once the water had been brought to boiling point, the power output of the fire was reduced to obtain gentle simmering sufficient to maintain the temperature of the water above 95°C. A higher average simmering temperature would result in a higher value for PHU2, as more water would be evaporated. Hence, these difference in PHU2 may be a result of different test conditions. Joseph and Shanahan observed that the longer the simmering time the greater the sensitivity of the PHU to the operating conditions and tending skills of the user - (see for example the differences between PHU data at BP1S60 by Brattle (1979) and Joseph and Shanahan (1981)).

(b) <u>'U' chulha</u>

PHU's of between 8% and 23% (depending on test conditions) were obtained in WBT's conducted on the 'U' chulha. This range ecompasses values obtained by other authors (e.g. NCAER, 1959; Salariya, 1978, 1983). At BP1, the optimum values of PHU were around 20%. Salariya (1978) obtained a PHU around 12% at BP1. This is not unexpected since Salariya had a greater fuelbed/pan distance for the 'U' chulha he used in his tests. PHU's obtained by the NCAER (1959) were also around 20%, which suggests that their 'U' chulha had similar values of critical parameters (e.g. fuelbed/pan distance) however this cannot be confirmed as the dimensions of the chulha tested are given.

At BP1, steady state radiative energy losses with an aluminium pan are estimated to be around 0.65kW and 0.95kW at 'low' and 'high' heights respectively. The minimum power output required to maintain simmering at BP1S60 (around 1kW) was above these values.

Heat losses from the stove and pot, after simmering for one hour, were estimated to be 39kJ and 57kJ at the "low" and "high" heights respectively; the effect of height on the PHU are discussed in more detail in the section 5.3.4. These estimates of heat losses are less than 1% of the input energy; similar values were obtained in WBT's conducted by the NCAER (1959) using metal pans on a 'U' chulha.

(c) <u>iron frame/McGarry stove</u>

Estimated energy losses due to radiation from the pan and iron frame are slightly lower than those obtained for both the 3-stone fireplace and 'U' chulha. This may be a result of differences in the thermal capacities of these stoves.

The pattern of energy flows for the iron frame are similar to those with both the 3-stones and 'U' chulha: at BP1, the energy flows with the iron frame are dominated by losses due to hot stack gases; up to three-quarters of the energy input was lost in this way. Up to 16% of the input energy was contained in the charcoal formed (some implications of this were discussed with regard to the 'U' chulha) - this is comparable to the energy transferred to the water. In Zimbabwe, however, the role of charcoal is believed to be virtually non-existent (Banks, 1980); this was confirmed in the villages visited (see Chapter 6).

With the fuelbed/pan distance set at 10cm, the PHU's for the iron frame were around 10-13%: these are much lower than those obtained in WBT's carried out on both the 3-stone fireplace and 4-stone fireplace in the field; this finding is in line with the perceptions of village women in Zimbabwe that the iron frame used considerably more fuel than their traditional 3-stone fireplace. However, decreasing the fuelbed/pan distance to 6cm increased the PHU at BP1 to around 20%. This is very close to the optimum values of PHU (at BP1) obtained for both the 3-stone fireplace and 'U' chulha (at the "low" height). This is important since it suggests that (under the same test conditions) **stoves with the same values of critical parameters, such as fuelbed/pan distance will have very similar PHU's.**

PHU's fell at the lowest and highest power outputs - a similar observation was made with the 3-stones and 'U' chulha.

Slightly lower PHU's were obtained with the addition of the 3 metal sides. This may be a consequence of the extractor fan above the iron frame, drawing air through the open side of the iron frame at a faster rate than without the windshield. In the WBT's carried out at Reading, without the presence of wind, the PHU's of both the iron frame and McGarry stove were much the same. However, the McGarry stove gives rise to significantly higher PHU's in windy conditions compared with the unmodified iron frame. Indeed with a wind speed of around 1 m/s the PHU1 of the iron frame fell from 20% (with no wind present) to 5%, whilst the PHU1 of the McGarry stove was around 10%. Observation showed the effect of wind on the flames was **reduced** by the shielding but not eliminated. This shielding was also effective at higher wind speeds. Whilst these results suggest that the McGarry stove would use considerably less fuel than the unmodified iron frame this only applies to windy conditions - with no wind the PHU's are about the same.

Under conditions of "no wind", heat transfer is primarily by convection. The effect of wind reduced the PHU by lowering the heat transfer by convection (see Table 5.9 and 5.10). As expected using a windshield reduced the effect of wind, resulting in higher PHU's (and transfer of heat by convection) than without sheltering.

Women in rural Zimbabwe tend to use the iron frame in a cooking hut (see chapter 6) hence there are likely to be very little differences in firewood consumption with the two stove types due to thermodynamic considerations alone.

Users said that headloads of firewood lasted longer with the McGarry stove compared with the iron frame. This may be a result of changes in the cooking practices of villagers (see Chapter 6): (a) it was found that villagers from one kraal in Zimbabwe only used about half their daily firewood consumption for cooking - the other half simply burned away (b) it was also noted that villagers using the iron frame were not particularly careful in ensuring that burning firewood was directly underneath the cooking pot - with the modified stove users may have to be more careful since the flames cannot be seen unless they are directly underneath the pot holes.

McGarry's statement that the modified stove used around half the firewood of the iron frame is based on rural women saying that this was the case. Obtaining such information by this method is not reliable, since villagers can often give the answers they think the questioner wants, for instance, French (1984) reports that whilst women in Malawi claimed the "improved" stoves they had been given used half the firewood of their traditional stove, physical measurements showed that there were no differences in consumption (see Chapter 3).

5.3.2 Source and magnitude of Errors

Sources of error are connected with the determination of the accuracy of the measurement of the mass of the firewood, charcoal and water. Errors due to these measurements will be very small as the mass was determined to within 1g (the error in the PHU due to an error of 1g in each of these parameters is considerably less than 1%). No significant error would have been introduced in measuring the temperature of the water with the digital thermometer which was accurate to within 0.5°C.
The major variation in measurements of PHU would be expected to arise after BP1 for the following reason: the mass of water evaporated during simmering would depend on the simmering temperature. As the vapour pressure of water increases rapidly as the temperature approaches the boiling point, small variations in the simmering temperatures would have a large influence on the mass of water evaporated. Obviously, the

longer the simmering period the larger the likely variation in the PHU.

5.3.3 Energy flows

Most of the heat energy from the firewood is lost in the escaping hot gases - this energy loss increases (both as a proportion of the total energy as well as in in absolute terms) with time.

At BP1, up to 20% of the input energy was contained in the residual charcoal - and was comparable to the value of PHU2. Whether or not this energy is "lost", depends on actual cooking practices. For example, after BP1 the power output of the burning fuel may be reduced to achieve gentle simmering, and result in a smaller quantity of charcoal left at the end of the cooking process (compare the magnitude of energy in charcoal at BP1 and BP1S60 in energy flow diagrams). In Thailand, charcoal left at the end of the cooking process is put in an air-tight tin and re-used (Dunn, 1984: pers comm). Similar practices of saving charcoal have been reported for the Gambia (Loose, 1984: pers comm). However, this practice may be a restricted to those who use charcoal burning cookers (as for example in Thailand); users of wood burning stoves may not engage in this practice.

In any case, the potential for utilizing the heat energy in the residual charcoal exists; not all this energy can be usefully employed as some energy will be lost due to incomplete combustion and the radiant energy captured by a pan will depend on the distance between the fuelbed and pot.

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5.3.4 Expected effect of power output and height

There are two major mechanisms of heat transfer from the burning wood to the cooking pot: convective transfer from the flames and radiation from the bed of char. Heat transfer from the flames will be dominant, (as generally), close to 70% of the heat energy in firewood is contained in the burning volatiles (Bussmann *et al*, 1983). However, the temperature falls rapidly with increasing distance from the tips of the flames (Bussmann *et al*, 1983).

According to Bussmann *et al* (1983), the power output, Po does not affect the *maximum* flame temperature, but simply the flame height: the flame height is proportional to the power output to the power 0.4.

For a given height, there is an optimum power output which will lead to the maximum convective heat transfer from a single flame. At other heights the temperature of the gas temperature is less, and hence also the driving power (ie temperature difference between the pot and hot gases).

Altering the power output would have the effect of changing the optimum height for maximum convective heat transfer.

The PHU at BP1 would be expected to be low at small power outputs for two reasons: firstly, the flames would be unable to reach the pan bottom, and secondly, owing to low combustion efficiency; a visual indication of combustion efficiency is given by the quantity of smoke produced. As the power output was increased the PHU would also increase reaching a maximum when the flames just touched the pan bottom, and then fall as the flames began to go around the sides of the aluminium pan.

Increasing the height should shift the PHU maxima to a higher power output (and vice versa).

In the 'U' chulha experiments, this expected variation PHU with power output was observed for Iroko at the 'high' height (data at the 'low' height is over too small a range of power outputs) and at both heights for Jelutong: low power outputs were characterized by the production of a lot of smoke (a sign of poor combustion), whilst at the higher power outputs, the flames tended to go around the sides of the pot. The latter may only have a small effect on the PHU: at power outputs greater than about 5kW at the "high" height not all the flames were directly underneath the pan. Hence, a smaller proportion of heat would be captured by the pot.

For the 'U' chulha, using Jelutong the maxima in PHU is observed at around 3kW at the "low" height setting, whilst the maxima at the high height has been shifted to a higher power output (as expected). Data at higher power outputs is required in order to determine whether a shift in PHU with respect to power output occurs with Iroko.

5.3.5 Effect of fuel

Values of PHU (whether PHU1 or PHU2) were generally lower with Iroko compared with Jelutong. This would be expected, primarily due to the signs of lower combustion of Iroko under the test conditions: Iroko was much more difficult to light and produced more smoke than Jelutong; constant blowing was required to maintain burning in some of tests. Hence, the lower values of PHU may be a consequence of a lower combustion efficiencies with Iroko. Although Bussmann et al (1983) did not observe any significant difference in the tests using different wood species (Jelutong and Iroko were among these), this may have been a result of better combustion efficiencies since they used pieces of wood that were smaller (2 x 2 x 5 cm) and oven dried, both conditions which would aid combustion.

Owing to the low power outputs obtained with Iroko, the flame lengths were smaller than with Jelutong, thereby decreasing the temperature at the pan base and lead to incomplete combustion of the volatiles - one sign of which was dark brown volatiles deposited on the bottom of the pan. This would reduce the driving power for heat transfer.

5.3.6 Pan material

The lower thermal conductivity of the clay pot compared with aluminium reduced the rate of heat transfer into the pot. In addition, a large proportion of the energy transferred to the clay pot was lost in evaporation of water: several hundred grammes of water were evaporated with the clay pot (up to 700g) compared with around 20 to 40g with the aluminium pan. There are two reasons why a large quantity of water is evaporated: firstly clay pots are highly permeable to water and secondly, because of the gaps between the pot and lid.

Both the low thermal conductivity of the clay pot and the evaporative losses means it takes much longer to bring the water to the boil, or to maintain simmering, compared to using an aluminium pan: simmering losses are higher and hence require a higher power output.

The "efficiency" (in terms of sensible heat gained by the water) of a "stove" can be changed significantly simply by substituting clay pots for metal ones (or vice versa).

5.3.7 Effect of wind

In the plots of PHU vs power output for the 'U' chulha, it was assumed that the PHU was not affected by having the wind speed at the 'low' or 'high' setting. This assumption was made on the basis of the initial analysis of the factorial design data, as well as the observation that a anemometer gave a zero reading on both wind settings. However, it is expected that changing the the wind speed would have affected the PHU in four ways: (1) By altering the burning rate (and hence the power output). (2) By altering the combustion efficiency. (3) By diplacing the flames from the optimum position underneath the pan. (4) By cooling the pan. It was assumed that changes to the PHU by both these factors were marginal; further investigation is required to determine this.

5.3.8 Use of factorial design

From the values of PHU obtained for the 16 tests in the factorial design, the effects of the four main factors (ie Fuel, Height, Pan and Wind) and interactions between any two of these factors can be determined.

As the PHU is affected by the power output, in order for the factorial analysis to be valid, tests have to be carried out at the same power output (see below) - this condition considerably weakens the use of factorially designed experiments in stove testing. In the 'U' chulha WBT's, the power output of the firewood varied from 2kW to 5kW. However, in the factorial analysis only the value of PHU for each test was used - the value of the power output was not included in the analysis, and hence, would lead to erroneous predictions.

Theoretically, it is possible to overcome this problem by employing covariate (since there are two dependent parameters, namely, PHU and the power output) analysis, but this would require more data than was obtained.

Another way of overcoming this problem would be to have a complete series of factorial tests at a number of power outputs. For example, three power levels - "low", "intermediate", and "high" - could be chosen. In a factorial design with four main factors each at two levels and one replication would involve 96 (ie 3 x 4 x 4 x 2) tests.

There may still be other problems, for example in the tests carried out it was very difficult to burn one of the species of firewood (Iroko) at power outputs beyond 4kW, whilst the other species (Jelutong) could be burnt at power outputs up to 6kW. Another problem would be in conducting tests at the same power output. This could be achieved by feeding small pieces of firewood at a known rate (e.g. Visser and Verhaart, 1980), but would be open to the criticism that it did not reflect conditions in the field, where large logs of firewood are commonly used.

5.4 Conclusions

The most important finding was that **the maximum values of the PHU** (excluding water of evaporation) **at BP1 for the 3-stone fireplace, Indian 'U' chulah, "iron frame" and McGarry stove were all around 20%.** This is not unexpected because of their similarity of geometry arrangement.

PHU's between 17% and 20% were obtained for the 3-stone fireplace at BP1 - these agree with values obtained by other authors.

A much wider range of PHU's were obtained in tests on the 'U' chulha: this wide variation ecompasses the values of "efficiency" given by other authors on tests on the 'U' chulha (e.g. NCAER, 1959; Joseph and Loose, 1982; Salariya, 1978, 1983). Differences in PHU's by other authors is due to differences in critical parameters such as fuelbed/pan distance.

Under wind-free conditions the PHU's of the iron frame and McGarry stove are about the same. The McGarry stove performs much better than the iron frame in windy conditions by shielding the flames from the wind. Cooking with either stove in a sheltered hut would give rise to similar levels of firewood consumption. The claimed savings may be due to villagers either giving the answer that they believe the questioner wanted or by changing their cooking practices.

Field based measurements during cooking (by village women) are required to establish the nature and change (if any) in firewood consumption.

For the 'U' chulah and iron frame the PHU fell at the lowest and highest power output: at low levels of power output this seems to be a consequence of low combustion efficiency. A fall in PHU at the high power outputs appears to be a result of energy losses due to the area of the fuelbed being greater than the area of the pan bottom.

PHU was affected by stove height, operating conditions, and cooking pot material. Stove "height" (ie the distance between the fuelbed and pan) and pot material were the most important parameters governing "stove efficiency". These results highlight the importance to stove performance of specifying critical parameters, as well as operating conditions (e.g. power output, pot material, length of time over which the PHU is measured), definition of "efficiency" and so on.

In all cases, energy losses were dominated by stack losses (up to four-fifths of the input energy). The potential exists to reduce these losses by increasing the combustion efficiency (e.g. by using a grate).

Steady state energy losses from the "stove" and metal pan were estimated to be between 0.5 and 0.9Kw.

In all cases, the energy associated with the residual charcoal was comparable in magnitude to the sensible energy in the water. Potentially, this charcoal could be saved and re-used (though this is debateable in the case of Zimbabwe, as charcoal does not appear to be used as a cooking fuel).

Because of the porosity of clay, the energy loss in steam with clay pots can be comparable to the energy associated with sensible heat in the water. Thus with the 'U' chulha, much lower steam losses were evident with the aluminium pots. Fuel consumption could be significantly reduced simply by substituting metal pans for clay ones. However, this may meet with resistance due to socio-cultural factors, (e.g. tradition or because of a change in the taste of the food - see for example Chapter 6).

The application of factorial analysis to stove testing is limited by the variation of PHU with power output, neccesitating covariate analysis. In practice this type of analysis may be applicable in cases where the PHU shows little scatter and is independent of power output. The most important contribution of factorial design and analysis would be in determining the importance of factor interactions (e.g. fuel type/cooking pot, stove height/fuel type, and so on); these interactions cannot be determined with the standard scientific experiments where one parameter is varied at a time. The most important factors to vary are the pan material and the distance of the pan from the fuelbed.

Chapter 6

Firewood and Cooking Stoves in Zimbabwe

6.0 Introduction

Earlier chapters have drawn together information on rural energy from a number of developing countries. It was shown that on the surface, the problem of introducing "improved stoves" seems simple, on further investigation it is much more complicated, involving:

(a) accurate experimental work;
(b) socio-cultural and anthropological studies;
(c) consideration of economic and political factors;
(d) stove design and development;
(e) diffusion of innovations into social use.

It was considered useful to examine in detail the potential for disseminating "improved" stoves by visiting a developing country - concentrating on one country would mean that factors (b) (c) and (d) above would be easier to handle. The research visit would give access to information only available in that country as well as provide contact with researchers and institutions working in the field. In addition, the situation in the field could be observed directly without having to rely just on secondary sources.

Zimbabwe was chosen as the country to be visited. The visit lasted from October 1981 to January 1982. Field data was collected from rural areas from early November to mid December (1981). The following will show that the firewood "problem" and proposed solutions in Zimbabwe parallel the analysis of the "firewood crisis" in developing countries, as discussed earlier in Chapter 1. According to various Government Departments, Forestry Commission officials, and researchers in Zimbabwe, the rural areas of the country are suffering from a shortage of firewood for cooking. This firewood shortage is expected to become more acute. Government strategies to overcome this shortage are based on the assumptions that traditional cooking stoves are very inefficient and that firewood collection is an increasing burden for the rural population; this burden falling particularly on women and children of poor families. Rural development programmes assume that cooking stoves with a high efficiency will be highly desirable to the rural poor.

This chapter gives a preliminary analysis of rural energy systems in Zimbabwe, in terms of seasonal variations as well as socio-economic and political factors; the latter will be seen to have played an important role in soil erosion, deforestation and choice of cooking stoves.

The chapter is divided into 6 parts: part 1 gives background information, the national energy profile and proposed solutions to the firewood "problem" in Zimbabwe. The aims of the field visit and methodology used are detailed in part 2. Part 3 details the field data, which are discussed in part 4. Part 5 assesses the various causes and history of deforestation in Zimbabwe. The conclusions are given in part 6.

6.1 Socio-economic and political profile of Zimbabwe

6.1.1 Background

Zimbabwe, in central Africa, (Fig 6.1) has a land area of nearly 400,000 square kilometres. Its population at the end of 1977 was estimated at

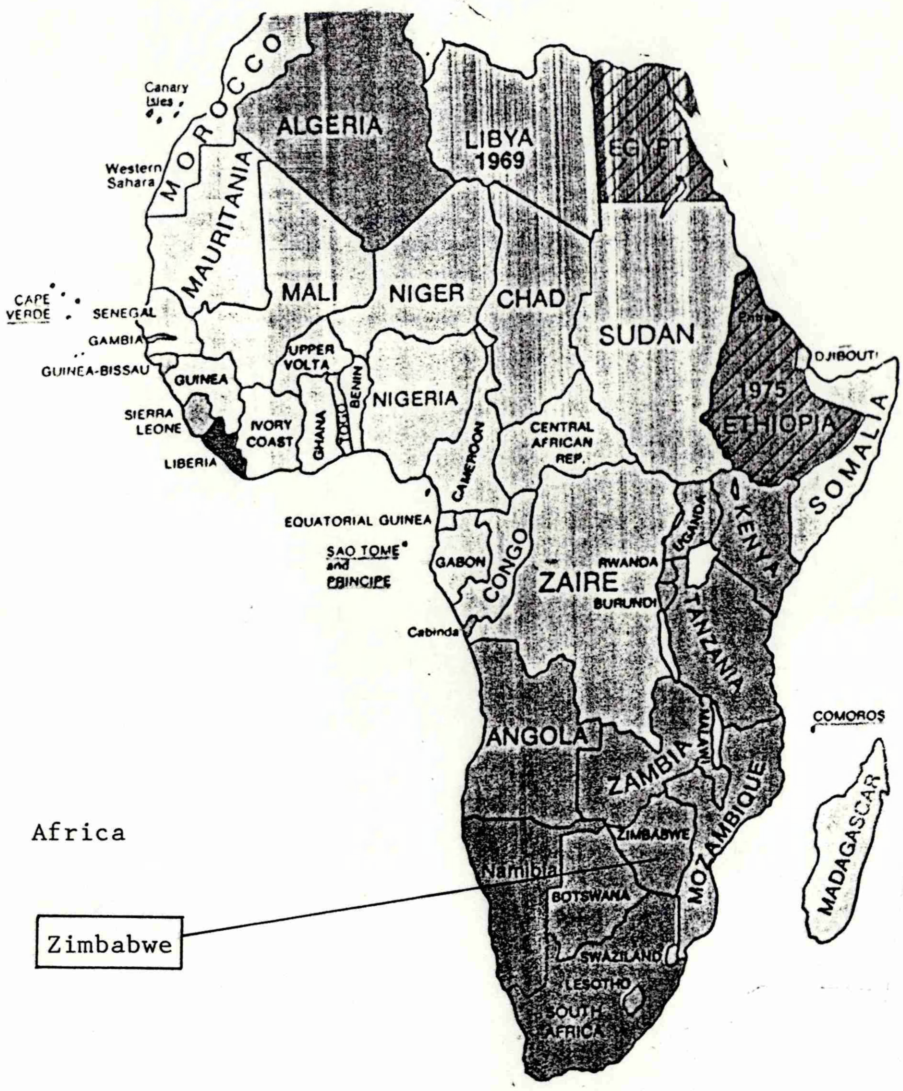


Fig 6.1 Africa

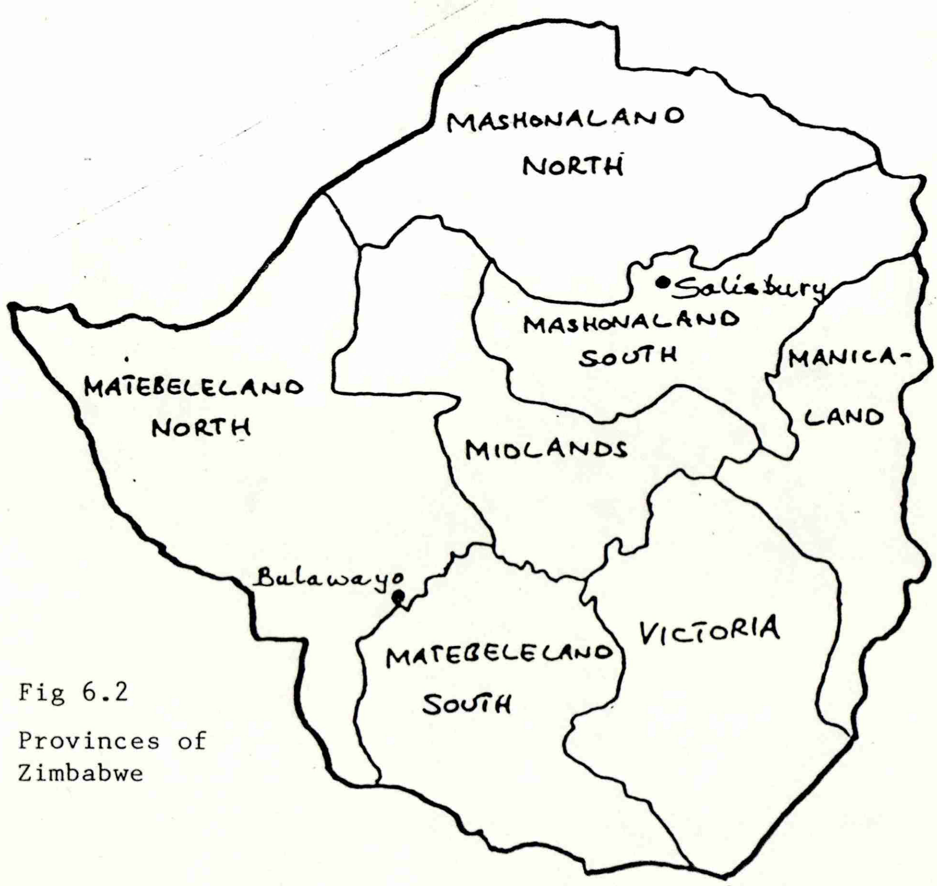


Fig 6.2

Provinces of Zimbabwe

6.86 million: the predominant groups being roughly 6.5 million Africans, 0.25 million Europeans, 10,300 Asians and 23,000 Coloureds (Ndlela, 1981).

From 1977 onwards Zimbabwe has been divided into 8 provinces (Fig 6.2): Manicaland, Mashonaland Central, East and West, Matabeleland North and South, Midlands and Victoria. Each of these provinces is further sub-divided into a total of 50 districts.

Table 6.1
Division of Land in Zimbabwe in 1973
(Ndlela, 1981)

Category	Hectares	Proportion of total land area
European Area:		
General Land	15,613,344	40.6%
Parks and Wildlife	1,744,674	4.4%
Forest Area	737,273	1.9%
Specially Designated Land	7,656	0.2%
Total European Area	18,132,947	47.2%
African Area:		
Tribal Trust Land*	18,217,705	47.4%
Purchase Area	1,486,142	3.8%
Parks and Wildlife	255,274	0.66%
Forest Area	172,000	0.44%
Specially Designated Land	121,570	0.31%
Total African Land	20,252,691	52.7%
TOTAL OF ALL LAND	38,385,638	

* now referred to as Communal Land

Land in Zimbabwe is divided into African and European areas (Table 6.1). Zimbabwe's economy has a "dual" structure (Ndlela, 1981), with a relatively highly developed "modern" sector and a stagnating "traditional" sector. This dualism is reflected in the distribution of land, labour, as well as access to agricultural credit and produce markets. One feature of this economic dualism is the high incidence of (African) male migrant labour away from the Tribal Trust Lands (rural areas) to the European urban areas and mines. This is reflected in the

African age-sex population pyramid in the Communal Lands and European areas (Fig 6.3).

6.1.2 Agriculture: past and present

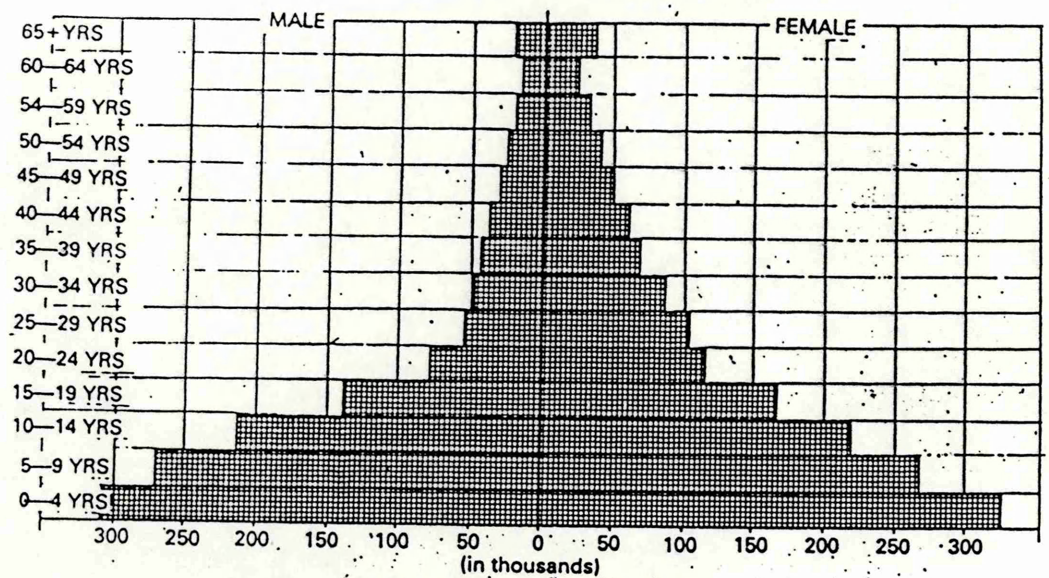
The African peasant farming population is the largest single group in the economy - 4m in 1977, primarily growing maize (the staple diet for the African population). The average income level per capita per annum was estimated to be Z$ 28 in 1977, with an average of 5% growth rate over the previous decade (Whitsun Foundation 1978). Assuming the same growth rate the average income level per year would be Z$ 38 by 1981. (In 1981 the exchange rate was approximately £1= Z$1.30).

In the early 1800's "Zimbabwe" was thinly occupied by shifting cultivators. These consisted of small settlements supported by shifting cultivation and hunting (Weinrich, 1975:5).

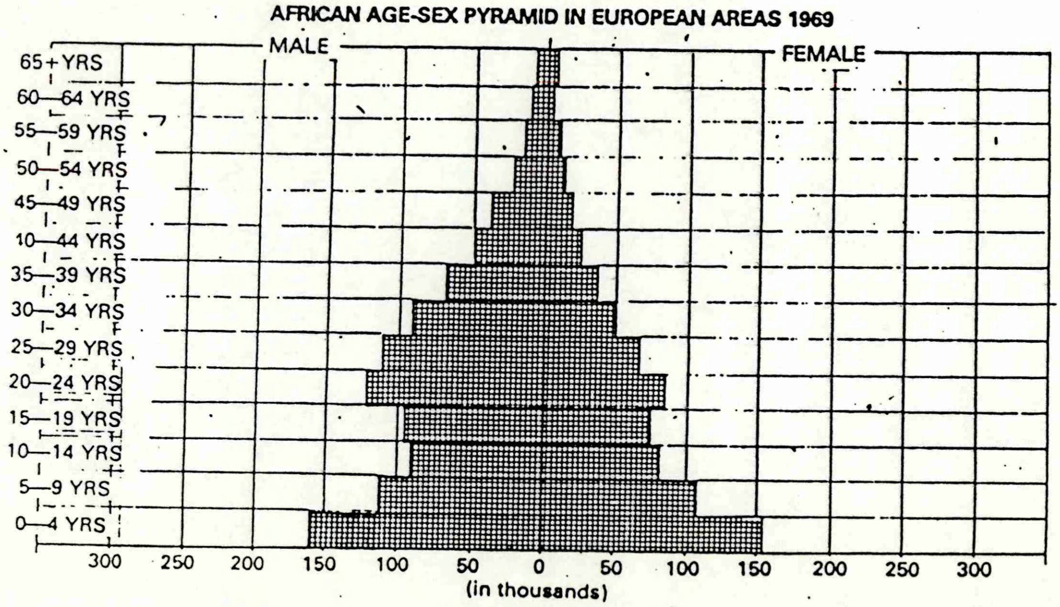
At present there are three types of African agricultural settlement, referred to as Communal Lands, Purchase Areas, and Irrigation schemes (Weinrich, 1975:4). Communal Lands before Independence in 1980 were known as Tribal Trust Lands (TTL's); TTL's are a modification of the traditional system. **Communal Lands are the most important type of peasant settlement and account for the largest number of African cultivators** (Weinrich, 1975:4).

Communal lands are based on a subsistence-type economy (Whitsun Foundation, 1978) where production is primarily for domestic consumption rather than for the market, though cash crops (e.g. groundnuts, sunflower, oriental tobacco, and cotton) are also grown. The majority of the Communal Lands are in regions which are unsuitable for cash crops

AFRICAN AGE-SEX PYRAMID IN T.T.L.'S 1969



AFRICAN AGE-SEX PYRAMID IN EUROPEAN AREAS 1969



SOURCE: 1969 CENSUS OF POPULATION:

Fig 6.3 African population distribution in Communal Land and European areas
(source: Whitsun Foundation, 1978)

and have low rainfall; yields in these areas are well below the national average (Whitsun Foundation, 1978).

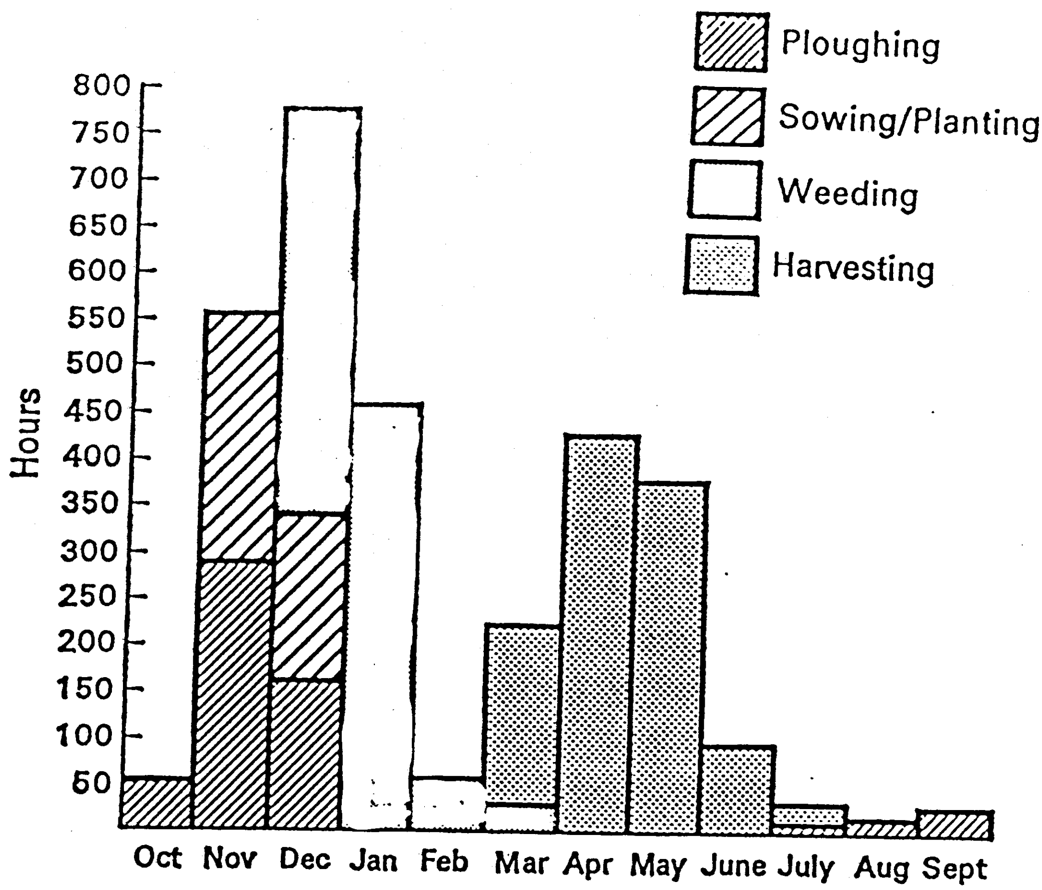
"Purchase areas" are settlements in which Africans can buy land and hence become owners of their farms. "Irrigation schemes" refer to agricultural land that is under both intensive irrigation and cultivation. These schemes are situated in Communal Lands but are highly capital intensive. Irrigation schemes were introduced by the Colonial government to "relieve the rapidly increasing pressure on tribal lands" (Weinrich, 1975:12).

There are four major seasons: **hot** (September to early November), **main rainy** (November to late March), **post rainy** (April to May when the chance of rain decreases and temperatures start to fall), and **winter** (May to August). Agricultural activity is structured around these seasons (Fig 6.4).

(a) Sexual Division of Labour

Rural women in Zimbabwe provide labour for agriculture (eg ploughing, planting and weeding) as well as domestic chores such as cooking, collecting fuel and fetching water (Weinrich, 1975; Muchena, 1977, 1981; Riddell, 1981; Gelfand, 1982)).

According to Weinrich (1975), women do not traditionally engage significantly in ploughing. Ploughing is heavy work and although Weinrich found that women in Karangaland (SE Zimbabwe) did plough, they preferred it to be done by men. In the ideal team, the man leads the plough and the women and children lead the oxen. Sowing and planting tended to be done with family labour. Whilst,



(source: Weinrich, 1975)

Season: Hot | Main Rainy | Post-Rainy | Winter | Hot

Fig 6.4 Labour input on crops in Communal Lands: peasant cultivators (and seasons) "weeding is burdensome to all peasant families. Women and children are expected to do most of this work, for men shy away from it. Some men even go off to seek urban employment, and if their wives need additional help, they are encouraged to call in work parties" (Weinrich, 1975)

Weinrich (1975) also observes that although harvesting requires much labour it is a much more pleasant activity for the following reasons: migrant labourers have returned, there is less work pressure since harvesting can be done over several months and food is plentiful.

(b) Seasonal Variation in Labour Demand

Two periods in the agricultural cycle make very high demands on labour (Weinrich, 1975) (Fig 6.4). The first period is from November to January when the sequence of events is ploughing, sowing or planting, and weeding. Ploughing takes place when the first rains fall, ie. around the end of October or early November. After this the second period of high labour demand arises when the harvest begins; high labour requirements for the harvest begin in April and trail off in July. Similar findings have been reported by other researchers (Cheater, 1974; Johnson, 1964a, 1964b: quoted in Weinrich, 1975).

Field work by Muchena (1981) further confirms these months as periods of high labour demand: longer hours were worked by villagers and the incidence of truancy amongst schoolchildren to help with agricultural tasks were both observed.

(c) Strategies to Cope with the High Labour Demand

Both early planting and weeding are important since they are critical activities which determine the agricultural output Weinrich (1975). The effect of the high demand for labour during these periods is that

> "many migrants come home in November to help their wives to prepare the fields or, if they cannot come home and if they have no relative in the village to help the family, they send some money to hire a ploughing team from neighbours" (Weinrich, 1975:91)

Other responses are to call work parties, work longer hours or withdraw children from school (Muchena, 1981).

Agricultural work is a contribution to the workload of rural women, in addition to activities such as fuel collection. If the husbands are not able to return home during this time of year, or send money to hire labour, then women have to do more work. An increase of this nature was observed in a field study by Muchena (1981), who found that more women than men were engaged in ploughing activities. This meant that some women were doing the ploughing, work which has traditionally been considered as "men's tasks".

6.1.3 Zimbabwe's Energy Profile

In 1978, firewood was estimated to supply almost one-third of national energy consumption, and as such was comparable to the energy obtained from coal or hydro-electricity (Table 6.2). Little data is available on charcoal production and transport but its consumption is believed to be virtually non-existent (Banks, 1980; Whitsun Foundation, 1981).

Table 6.2
Energy Consumption in Zimbabwe by Source
(Johnston, 1980)

Energy Source	Proportion of National Energy Supply
Hydro-electricity	33%
Coal	27%
Firewood	28%
Liquid Fuels	10%
Bagasse	2%

Overall, around 85% of the population (ie 6 million people) use wood as a primary source of energy for cooking and heating (Whitsun Foundation 1981). Firewood consumption is dominated by the rural African population: more than three-quarters of the energy from firewood was consumed in rural areas (Table 6.3) (Johnston, 1980) where it was collected by women and children.

Table 6.3
Firewood Consumption in different Sectors
(Johnston, 1980 - based on Forestry Commission Data)

Sector	Annual Firewood Consumption ($m^3 \times 10^6$)	Estimated Annual Firewood Consumption* ($kg \times 10^9$)	% Used in each Sector
Rural Areas	3.50	2.38	76.3
Commercial Farms	0.68	0.46	14.7
Mines	0.13	0.09	2.9
Urban Areas	0.28	0.19	6.1
Total	**4.59**	**3.12**	

* assuming density of indigeneous timber = 680 kg/m^3

Firewood is collected primarily in the dry seasons, with some reliance on maize cobs as a fuel supplement when available (Whitlow, 1979a) Wood is also used for construction (e.g. building huts and fences) (Whitlow, 1979a) but this is only estimated to be around 10% of wood consumption.

Average annual firewood consumption per person is estimated to be about $1m^3$ (Forestry Commission 1978). If this is air dry wood with a moisture content of 25% (Fuller, 1980), the calorific value will be 14.50 MJ/kg (using the equation derived by Bialy (1979) relating moisture content and calorific value). Assuming the density of local indigeneous timber to be 680 kg/m^3 (Johnston, 1980), then $1m^3$ represents 10 GJ consumption per year per person.

Estimates of annual per capita firewood consumption range from 370 - 1240kg (Table 6.4). There is much uncertainty about the data, (see Appendix C for a detailed analysis of these studies). Hence, the share of firewood in Zimbabwe's national energy budget may be greater than that shown in Table 6.2 which uses data from Johnston (1980).

Table 6.4
Summary of Annual Firewood Consumption Estimates
(per capita basis)

Source	mass of firewood (kg)	Annual Consumption (a) assuming Calorific Value = 14.2 MJ/kg	(b) assuming Calorific Value = 15.6 MJ/kg
Banks (1980)	502	7.1	8.0
Johnston (1980)	632	9.0	10.1
Furness (1979):			
(a) Anon, (undated)	591	8.4	9.4
(b) Anon (1978)	1244	17.7	19.8
Walsh (1979)	1131	16.1	18.0
Whitlow (1979)	371	5.3	5.9
Forestry Commission (1978):			
(a) Mondoro	580	8.2	9.2
(b) Chiwundura	625	8.9	9.9
Hosier _et al_ (1980)	1088	15.4	17.3
Mean	752	10.7	12.0
(Standard deviation)	(314)	(4.5)	(5.0)

6.1.4 Deforestation

According to the Zimbabwe Forestry Commission (e.g. Wiltshire, 1977; Banks, 1980:3; Furness, undated), and the Department of Natural Resources (e.g. Mutsiwegota, 1983) problems of deforestation have arisen because of the growing needs of agricultural land and firewood by an expanding African population. Deforestation is expected to become more acute as the African population increases further.

The Whitsun Foundation (1980) estimated that a critical firewood shortage (ie only 50% of national average consumption per head being used) had already affected 58% (2.3 million people) of the Communal Land population.

This firewood shortage has increased the firewood collection burden on rural women and children (Chavunduka, 1980, 1982; Makoni, 1983). In some cases, it is reputed that around 36kg of firewood has to be carried for distances of up to 2km (Whitlow, 1979a:9). Chavunduka (1982:289) further contends that the amount of time spent by women and children in agricultural activity has fallen in some rural areas as a result of these long firewood collection trips. According to Chavunduka (1980:3), the rural population has shifted to 'inferior' cooking fuels such as maize cobs and animal manure in order to reduce the time spent in gathering firewood. In effect, potential fertilizer would be lost, thereby depressing potential crop productivity (Chavunduka, 1980:3). Moreover, according to Chavunduka (1980:4), as shortages of firewood become more acute the village fireplaces where people sit and talk after meals will be abandoned. Hence, the traditional social functions of the village fireplace will be disrupted.

There is much concern by the Zimbabwean Government about the depletion of the supply of firewood. The Minister of Industry and Energy Development (Makoni, 1983:59), in the official opening of the SADCC (Southern African Development Coordination Conference) energy seminar, declared that, "the search for energy to meet the modest requirements of our rural population has become a burdensome and agonising chore ... the spectacle of our womenfolk travelling long distances to collect small bundles of firewood has become a common feature of our rural life"

6.1.5 Strategies for tackling the firewood problem

Solutions put forward by policy makers, researchers and government departments emphasize the need to increase the supply of firewood and/or decrease the demand for firewood.

Supply orientated strategies advocate firewood plantations (Arnold, 1980b; Whitsun Foundation, 1980) or agroforestry (Banks, 1980). Fast growing trees (e.g. various Eucalyptus species) have been promoted by the Forestry Commission, to be harvested for fuel (Furness, undated). Traditional tree species used for firewood are too slow growing to make a significant impact on forest resources in the short term (Furness, undated).

Demand orientated strategies are concerned with reducing the demand for firewood by using firewood more efficiently or by fuel substition. According to Chavunduka (1980, 1982) the traditional "open fire" is very inefficient, hence, one way of reducing firewood demand is by promoting fuel efficient stoves (Arnold, 1980b; Furness, 1980; Chavunduka, 1982:292). Other strategies advocated to decrease firewood consumption have been the promotion of fuels such as gas, paraffin and electricity (through subsidies) (e.g. Chavunduka, 1980:6; 1982:292), solar cookers and biogas plants (e.g. McGarry, 1981).

6.2 Research visit to rural areas of Zimbabwe

6.2.0 Objectives

Joseph and Shanahan (1980c) outline a design strategy to implement an "improved" stove programme in developing countries. The following is a schematic of their six stage approach:

Stage (1) An assessment of cooking practices and fuel usage.

Stage (2) Field testing of existing stoves (and collecting information to design a laboratory stove testing methodology).

Stage (3) An assessment of available stove designs (to decide whether or not alternative designs are culturally acceptable and better than indigeneous stoves).

Stage (4) Laboratory testing of available designs.

Stage (5) Field testing of stove designs chosen.

Stage (6) Large scale dissemination if stove designs are proven in stages (4) and (5).

The aim of the field work, which was carried out in the rural areas of Zimbabwe was to undertake the first two stages of the stove programme dissemination strategy outlined above, and to determine the rural women's perceptions of firewood collection.

6.2.1 Rural energy surveys

It is clear from the previous chapters that cooking stoves and fuel collection are connected to environmental, economic and sociocultural factors. Thus for example, Bhatia (1980) comments,

> "an energy survey should attempt to consider the full spectrum of energy related activities. It is not enough to examine production, distribution and consumption of traditional and commercial fuels. Rather this information needs to be seen against the social, cultural, political and ecological background"

Hence, the energy survey needs to shed light on the linkages and interrelationships between domestic energy and other parts of the village system. From this information an energy model of villages in general can be constructed. This model can then be used to determine the likely impacts of intervention strategies as well as minimize their probability of failure.

This type of approach to the issue of rural energy in developing countries is not new: work has been done in tracing energy flows within different societies (Thomas, undated). Energetic analysis of traditional agricultural systems in developing countries were reported in the mid '70s - a brief review of which is given by Schahczenski (1984). Briscoe's (1979) study of a Bangladesh village showed that the socio-economic position of villagers structured their access to fuel and cooking energy consumption. Dunn _et al_ (1983) provide insights into energy use in rice production both on and off the farm. An extremely detailed study of food and energy flows (over a period of a year) in an Indian village has also been reported (Ravindranath _et al_, 1980).

Rural energy survey methodologies described in the literature, whether in terms of the sociological aspects of forestry (Spears, 1980) or fuelwood surveys (Thomson, 1979) highlight the sheer complexity of linkages which may hold in villages in developing countries.

Survey data can be gathered by direct observation, direct measurement, the Recall Method or a combination of the previous three methods. (White (1984) examines the Recall Method, whilst Stubbs (1984) discusses the application of the "life story" method to research on rural women).

These methods can be used, for example, to obtain information on cooking fuel consumption for rural households relying on traditional fuels (see also Chapter 3).

In Zimbabwe, firewood consumption data is largely based on the methods outlined above (a number of additional methods have also been used and are included here for the sake of completeness). This data falls into five categories: (a) apparently 'anecdotal' data, (b) averaging the firewood consumption in other developing countries, (c) asking each household how long a bundle of firewood will last and extrapolating to annual consumption, (d) measuring (with a ruler) the volume of firewood in a headload and counting the number of headloads collected over a known period, (e) asking each household the quantity of firewood (either in weight or bundles) used over a specified length of time. A detailed analysis of these methods and the firewood consumption data obtained are given in Appendix C.

Data on annual consumption can be obtained by surveying households over the complete year. In order to reduce disruption to the families being surveyed, as well as survey costs, data collected for part of the year can be extrapolated to annual consumption. By using standard statistical techniques, data can be gathered by sampling and projected for the rural sector within known confidence limits.

It may not be possible to use methods relying on direct observation or measurement because of limited resources. Moreover, whilst valuable information can be obtained by direct observation or measurement, White (1984:18) warns that even 'participant-observation' can mean emerging from the study area with "information of whatsoever preconceived notions had been brought there in the first place". A systematic study based on the Recall Method can be carried out through the use of questionnaires. Questionnaire surveys may be faster (ie can collect more information on more cases in the same length of time) at lower cost than direct observation though with possible losses of accuracy. There are, however, problems with questionnaires. For example, respondents may not do what they say they do. In other cases, questionnaires may be badly worded and the questions misinterpreted. However, the accuracy of reponses obtained by questionnaires may be evaluated through direct observation and through similar studies which have relied on direct observation.

Howes (1984) undertook out a detailed analysis of a number of rural energy surveys and recommends that surveys should be carried out using a "stratified cluster" methodology. These terms are explained below (more detailed explanations are given in general texts on statistical methods in the social sciences (e.g. Goode and Hatt, 1952; Hansen et al, 1966; Yeomans, 1968).

If a population is divided into groups, a sample of groups can be drawn to represent the population. These groups serve as sampling units and are referred to as clusters. A cluster refers to a sample which is representative of the subpopulation from which it is drawn. Clustering is normally undertaken by areas (e.g. street, villages or towns) in order to decrease the area to be covered by the survey team. For example, in a rural energy survey, the developing country could be divided into areas (ie clusters) with different levels of fuel supply.

"Stratified" surveys, unlike random ones, divide the sample population into a number of categories on the basis of selected characteristics of the population as a whole. This is usually done to ensure that either a given proportion of the population can be represented in the sample or that a specific characteristic of the population can be over-represented in the sample to provide more data for analysis. In a rural energy survey, concerned with consumption of traditional fuels, the population could be stratified according to the socioeconomic grouping of the households. A stratified methodology assumes prior knowledge about the population, which is replicated into the sample. This is not a method of random sampling and the results generated are not necessarily typical of the total population.

Stratification is normally by a characteristic of the population (e.g. socio-economic grouping and gender), whereas clustering is usually undertaken in spatial terms (assuming that the characteristic under examination is representative of the population as a whole). For example, a stratified cluster methodology applied to rural energy surveys could divide the country into areas (ie clusters) of different levels of fuel scarcity and stratify the data in each cluster according to the socioeconomic position of the households.

6.2.2 Field Data Collection

Given the many objectives of the research visit (e.g. literature survey, measurement of firewood consumption, survey of attitudes to firewood collection and so on) and the limitation in resources (e.g. time, funding, personnel, etc.) a rapid rural appraisal approach was adopted;

for an assessment of such approaches to fuelwood studies see Bajracharya (1979). Research methodologies appropriate to rapid appraisal (based on two field studies in China) are discussed by Croll (1984).

Three sites in Zimbabwe (with different levels of fuel stress) were studied in the fieldwork, Inyanga North Communal Land, Inyanga Intensive Cultivation Area and Seke Communal Land. (These are detailed in section 6.2.4 and 6.2.5). Data at these sites were collected primarily in three ways: direct measurement, by means of questionnaires, and direct observation (taken to include the standard anthropological techniques of listening, observing and asking questions).

(a) Direct Measurement

At two sites (Inyanga North Communal Land and Inyanga North Intensive Cultivation Area), direct measurements were carried out for the following: daily firewood consumption, consumption of firewood over three consecutive meals, the PHU's (during food preparation) of stoves and fireplaces used, and the distance to firewood collection sources. Two traditional types of fireplace and one type of "stove" were encountered in the villages visited: the 3-stone fireplace, a "4-stone fireplace" and an "iron frame" stove; the iron frame had largely displaced the traditional 3-stone fireplace. PHU's of each of these were measured during the initial stages of cooking when water was being heated.

Firewood Consumption

The following method was used in this study to measure firewood consumption: selected households were left a weighed quantity of firewood outside their cooking hut. Each household was asked only to use this firewood for heating water and cooking from this pile. These households were selected on an opportunistic basis (see section 6.2.3). Each pile was weighed in the afternoon, (after lunch but before the evening meal). Additional firewood was added after the weighing to ensure that there was sufficient firewood till the next weighing.

It was not always possible to measure the firewood consumption over one day, hence consumption was sometimes measured over a two day period. On these occasions daily consumption was assumed to be half this consumption.

For each household a record was also made of the number of people at each meal, and the type of food cooked.

Household firewood consumption data was expressed in terms of "adult units" as well "per capita", since data on energy consumption expressed in per capita terms may be misleading as the cooking fuel requirement will be different for children than for adults. In order to take differences of food consumption for the different ages of people in the household, the United Nations Dietary Table (Table 6.5) was used to determine the number of "adult units" in the household - on the assumption that the amount of cooking fuel required was directly proportional to the quantity of food cooked.

Daily firewood consumption data (kg) was converted to units of energy by multiplying by the calorific value corrected for moisture content - according to equation 3.8 (derived in Appendix B). Projections to annual consumption were based on the reported variation in firewood consumption over the year.

Table 6.5
Scale of Coefficients on Relative Amounts of Food Energy Consumption
(League of Nations, 1932)

Age (years)	Coefficient Male	Coefficient Both	Coefficient Female
0 and 2*		0.2	
2 and 3		0.3	
4 and 5		0.4	
5 and 7		0.5	
8 and 9		0.6	
10 and 11		0.7	
12 and 13		0.8	
14 to 59	1.0		0.8
over 60		0.8	

* from birth up to and including the twenty-fourth month of age.

Firewood consumption in the cooking process was determined as follows: the pile of weighed firewood left for cooking was weighed before and after cooking had taken place for three consecutive meals (evening meal, breakfast and lunch). This firewood consumption was expressed as a fraction of the total firewood consumption over that period. These measurements were carried out once only for 1 household in Ellenvale, and 4 households in Mukweva.

Measurement of PHU and power output

PHU's of the "stoves" at the study sites were restricted to measurements during the initial heating of water in the preparation of "sadza" (the staple food comprising a paste of ground maize boiled in water). The firewood, charcoal, pots and water used were all weighed using a Salter scale (see below). A Comark digital thermometer was used to determine the temperature rise of the water. Both the thermal capacity of the ground maize and evaporated water were ignored in the calculation of the PHU (see equation 3.6). The calorific value of the firewood used by each household was corrected for moisture content (see equation 3.8), and a calorific value of 29 MJ/kg was assumed for the residual charcoal.

The average power output of the fire during cooking, was calculated from the firewood consumption and the cooking time: the initial quantity of firewood and kindling (straw) were weighed. The cooking time was measured with a Casio Fx-8100 timer. Timing was started when the kindling was lit, and stopped once the food was cooked. At the end of cooking, the charcoal and the remaining firewood were weighed separately. The energy consumption during cooking was calculated by subtracting the heat content of the fuel at the end of the cooking process from the heat energy in the initial quantity of fuel. The calorific value of the firewood was corrected for moisture content (see below); this calorific value was also used for the kindling. A calorific value of 29MJ/kg was assumed for the residual charcoal from the fire. The mean power output of the fire was calculated by dividing the heat energy consumption during cooking by the cooking time.

A Salter model 2005 scale (maximum load 5kg, 20g divisions) was used for all the above weighings.

Moisture Content of Firewood

Five samples of wood were taken from the firewood store of each household involved in the direct measurement of firewood consumption. These samples were immediately placed in plastic bags. Each sample was then weighed on a chemical balance to within 0.001g. On returning to the Harare, the firewood samples were placed in a ventilated oven at 105°C for 23 hours and reweighed. The moisture contents (dry basis) were calculated using the equation below:

$$m = \frac{\text{wood sample mass - oven dry sample mass}}{\text{oven dry sample mass}} \qquad \text{eqn 6.1}$$

Distance to firewood collection site(s)

Whenever possible a member of each household was accompanied on their firewood collection trip. The time taken and the number of steps taken (by the researcher) were recorded, as well as the time spent in the collection area. The following method was used to calculate the distance to the areas of firewood collection used by households of children at St Elim Mission: the number of steps each pupil took to walk 100m was recorded. Each pupil was then asked to walk to the source(s) of firewood and record the number of steps taken. From these two pieces of information the firewood collection distance was calculated.

(b) Questionnaire Survey

Two questionnaires (administered by the author) were used in the survey to obtain information on agricultural and domestic activities (e.g. fuel collection, cooking practices), during the year, as well as perceptions of various tasks undertaken by women. In the first study area a 4 page pilot questionnaire was used (Appendix D). (The pilot questionnaire dealt with cooking fuels, stoves, and practices in detail). Based on the answers given by villagers in the first study area, this was modified to a 2 page questionnaire (Appendix E) and used in the other study areas. The nature of the latter questionnaire was to make explicit, seasonal variations in women's (domestic and agricultural) tasks. The questionnaires served mainly two functions: firstly to obtain basic demographic and socio-cultural data. Secondly, to obtain information of any seasonal patterns in rural women's lives (e.g. cooking practices, agricultural activity, fuel collection) - changes which could not have been observed given the brief length of stay in each area. The evolution of the first questionnaire to the second is given below.

The pilot questionnaire was designed to obtain a broad view of the issues surrounding women's roles in collecting fuel and domestic activity. Hence, this questionnaire was characterized by open-ended questions. In the field, responses by women raised further questions, which were pursued. This questionnaire was found to have a number of weaknesses once it was administered in the first study area. Firstly the questionnaire assumed a large degree of invariance in womens activities over the year. (The crucial importance of women's agricultural activities in affecting domestic activity became apparent at this stage - see below). Secondly, the questionnaire was difficult to administer as it had been designed in England, based on hypothetical villages in Africa. In the field, it was found that respondents did not have the type of detailed and precise information required by the questionnaire. Thirdly, the open-ended structure of the questionnaire meant that filling in the details was time consuming.

A number of these problems were surmounted through the design of the second questionnaire which included questions on women's agricultural activity. This questionnaire structured and ranked women's responses (see below) on a number of issues (e.g. perceptions of tasks, advantages of the new "stove" adopted) as well as drawing out seasonal variations in domestic practices, fuel collection, agricultural activity and fuel consumption. Moreover, this questionnaire was much more efficient to administer, and its structure enabled it to be filled in more quickly than the pilot questionnaire, despite containing more questions. Follow-up questions were still asked when necessary.

Women who had changed from the 3-stone fireplace to other stoves were first asked the reasons for the change, secondly to rank these reasons in order of importance and thirdly the fuel consumption of the new "stove" relative to the 3stone fireplace. Women who still used the 3-stones were asked why they continued to use this traditional fireplace, the advantages they **perceived** the iron frame to have and the fuel consumption of the iron frame relative to the 3stones.

The following methodology was used to determine rural women's attitudes to firewood collection (in the context of other tasks they performed): perceptions of tasks were divided into four categories: "hard", "easy", "liked" and "disliked". A list was made of all the tasks performed by rural women (a few blank lines were left on the questionnaire so that tasks not already included could be added). Women were asked which of these tasks were the hardest, the second hardest, and so on. These answers were recorded on the questionnaire in the appropriate column by placing the number "1" against the "hardest" task, a "2" against the second hardest task, and so on. Women were then asked to identify the easiest task, then the second easiest, and so on, and the results recorded in the same way as for the "hard" tasks. Women were similarly asked to rank the tasks they "liked" and "didn't like", with the answers being recorded in the same way.

The reason for asking women to rank tasks was to locate the position of firewood collection, relative to other tasks, such as ploughing, cooking, grazing cattle, and so on. However, there are problems with the method that was used in the field. Firstly, differences between each rank may not be the same. For example, the hardest task may be regarded as being extremely hard, the second and third hardest tasks regarded as being equally as hard. Secondly, a task which is seventh "hardest" could also be regarded as being fifth "easiest" (similarly so with the categories of "liked" and "disliked"). In this case, it is more illuminating to know that a task is regarded as being neither particularly hard nor easy, than a task is seventh "hardest". These problem could be surmounted by having one scale ranging from "very hard" to "very easy", with intermediate categories such as "moderately hard", neither hard or easy, and "moderately easy".

Rural women's perceptions of seasonal variation in firewood consumption were obtained as follows: women from each household were asked the number of days a "bundle" of firewood would last; a bundle of firewood (which they had collected previously) was placed in front of them. (Whilst the size of the bundle varied between households this was not particularly important since the parameter of interest was the **relative** level of firewood consumption over the year). Recall for the women was apparently easier if they were first asked about consumption during the hottest and coldest months of the year. The data on the length of time each bundle of firewood would last was converted to absolute consumption (in "bundles") for each month for each household. For each household, this absolute consumption was divided by the level of firewood consumption in the month of November, to obtain the relative variation in firewood consumption over the year. Consumption in November was arbitrarily designated the value of unity and the results plotted for each household.

To obtain information on seasonal variation of firewood consumption, women were asked the number of firewood "bundles" collected (on average) per week during the various months of the year.

(c) Direct observation

Wherever possible answers obtained by respondents were checked by direct observation. This technique was invaluable and without which neither the seasonal variation in cooking practices nor the importance of the role of women in agriculture would have been noted: in the first study area (Inyanga North Communal Land) women said that the reason for changing from the traditional 3-stone fireplace to the iron frame was because the new stove allowed cooking to be done more quickly, since several pots could be heated simultaneously. However, when villagers were observed cooking, only one pot was being heated at a time. When asked to explain, women said that fast cooking was only required during the months when they were busy in agriculture.

6.2.3 Application of Roger's diffusion theory to new stoves

Villagers in Zimbabwe were found to have shifted from the traditional 3-stone fireplace to other types of stove. These stoves were assessed in the light of Roger's diffusion of innovations.

Roger's (1983) identifies 5 attributes of innovations which govern their rate of adoption: **relative advantage, compatibility, complexity, trialibility and visibility.**

Relative advantage is the degree to which an innovation is perceived (by the adopter) as being better than the device or idea which it replaces. Compatibility is the degree to which an innovation is congruent with existing values, past experiences and needs of potential adopters. Complexity is the degree to which an innovation is perceived as being relatively difficult to understand and use. Trialibility is the degree to which an innovation can be experimented with on a limited basis. Observability is the degree to which an innovation is visible to others.

Relative advantage, compatibility, trialibility and observability are all positively related to the rate of adoption, whilst complexity is negatively related.

6.2.4 The study sites visited

Field work was carried out **in three study areas with varying degrees of firewood scarcity:** an area where there was no reported problem with firewood (Inyange North Communal Land), one with a moderate shortage (Inyanga North Intensive Cultivation Area) and thirdly, one with an acute shortage (Seke Communal Land) (Table 6.6).

Table 6.6
Areas Surveyed in Zimbabwe

village/kraal	Agroecological Region	Firewood Situation
Mukweva and Munondo	IV	no shortage
Ellenvale and Doornhoek	III-IV	moderate shortage
Chitsvatsva	IIa	acute shortage

Selection of Areas

The three areas visited during the field work are located in Fig 6.5. It is important to point out that the study sites (and households) were chosen on an opportunistic basis and not on a random basis: contacts were known in the three areas chosen.

Given the resource constraints already mentioned above, households selected for measurement of fuel consumption were chosen such that each stove type was represented in the sample. Income levels was a sensitive issue (and difficult to determine given the nature of the rural economy) and so this was not pursued directly (average annual earnings were estimated by projecting from data from 1978). However, the type of stove used by each family could be used as a crude 'surrogate' measure of income level.

It was envisaged that 2 - 3 weeks would be spent in each area. Although, it was possible to stay 3 weeks in the first study area, Inyanga North Communal Land (I.N.C.L.), owing to lack of time, adverse weather conditions and transport it was only possible to stay for 8 days in the second area, Inyanga Intensive Cultivation Area (I.I.C.A). Direct measurement of fuel consumption was not possible in the third study site in Seke Communal Land (25km south west of the capital, Harare), in which a questionnaire survey was undertaken on a small number of households.

6.2.5 Description of Study Areas

Table 6.7 and 6.8 give an overview of the study areas and the fieldwork carried out in each.

Table 6.7
Location of Villages in Survey

village/ kraal	Latitude	Longitude	Height above sea level (m)	Annual rainfall (cm)
Mukweva/ Munondo	17°36'S	32°48'E	900	45 - 65
Ellenvale/ Doornhoek	17°57'S	31°42'E	1200	65 - 80
Chitsvatsva	18°1'S	32°7'E	1400	75 - 1000

Women in all the kraals (ie villages) visited, provided labour for agriculture (eg ploughing, planting and weeding) as well as domestic

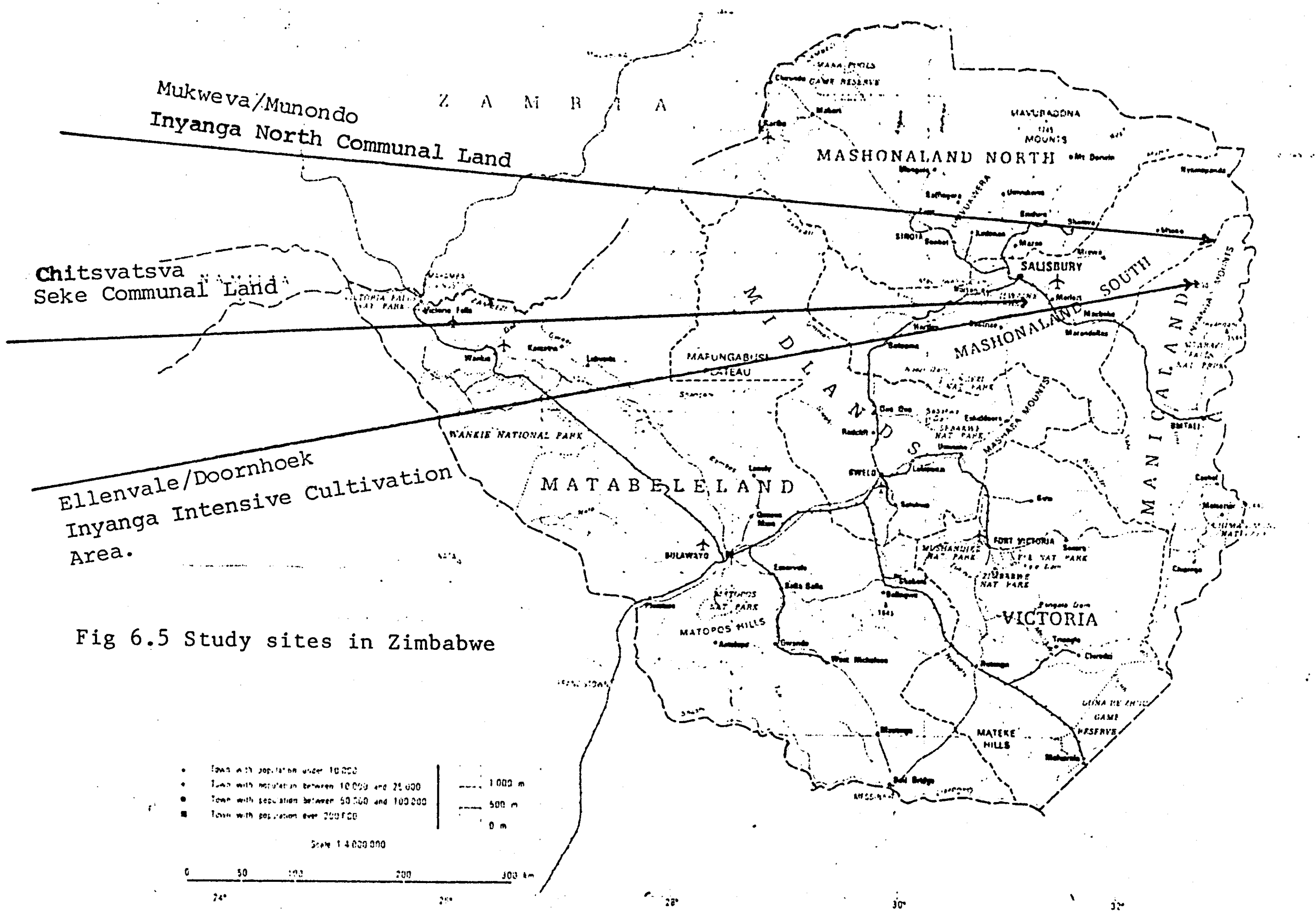


Fig 6.5 Study sites in Zimbabwe

The Atlas of Africa, p. 267, Regine Van Chi-Bonnard, Agregee d'Histoire et de Geographie, Universitie de Paris, France.

chores such as cooking, collecting fuel and fetching water. Studies by other researchers (Muchena, 1977, 1981; Riddell, 1981; Weinrich, 1975) confirm the role of women in agriculture for rural parts of Zimbabwe.

(a) Study Area A: Inyanga North Communal Land

Inyanga District is in Manicaland (east Zimbabwe) and estimated in 1980 to have a population of 66,000 people, or 8,300 families assuming an average family size of 8 people (Whitsun Foundation, 1981). The population density in Manicaland is estimated to be between 11 and $20/Km^2$ (Whitsun Foundation, 1978). The annual rainfall is between 460 and 600 mm (Vincent et al, 1961 - quoted in Ndlela, 1981).

Table 6.8
Survey Details of kraals

	Total No. of households	No. of households[1] in survey with: (a) stove type	(b) detailed questionnaire
INCL			
Mukweva[2] kraal	8	8 (43)	5 (25)
Munondo kraal	8	8 (73)	-
Households within 5km of Mission	n.a	19 (124)	-
IICA			
Ellenvale[2]	11	11 (66)	5 (21)
Doornhoek kraal	11	1 (8)	10 (72)
Seke C.L.			
Chitsvatsva kraal	n.a.	-	5 (35)

[1] figure in brackets refers to population of households surveyed
[2] firewood consumption was measured for 4 households in Mukweva and 5 households in Ellenvale

Fig 6.6 Mukweva/Munondo/St. Elim Mission and surrounding area

scale: 0 · 0.5 · 1.0 km

Two kraals - Mukweva and Munondo (Fig 6.6) - were surveyed in the first study area. The 8 households in Munondo only took part in the survey of the type of stove(s) they had inside and outside the cooking hut. A small number of local pupils (19 in total) at St. Elim Mission school took part in a survey of the stove type (Table 6.8) and distance to firewood collection sites.

Inyanga North Communal Land (the northern part of the district of Inyanga) is a Plain 800m (2600 feet), above sea level. This Plain is drained by the River Musuridzi which flows into the Matisi river to the north. Chigura mountain range runs NNW to SSW forming a barrier to the west, rising to over 1250m (4100 feet). For the survey in the first study area the author stayed at St. Elim Mission which is at the foot of this mountain range. Though the Mission is only 200km away from Harare, it took the author 10 hours by bus to get there from the Capital (Harare).

Whilst the mountains are still forested, the woodland in the Plain has been cleared for agriculture around the settlements, though fields are bounded by trees. Patches of forest remain along the river bank. On the settled parts of the plains most villages are within 2 or 3 km of uncleared undulating woodland.

Mukweva kraal is about 1.5 km from the Mission. There are two small patches of 250 metre square (ie 6Ha) of woodland within a 1km walk to the north of Mukweva. Mukweva consists of 8 households with a total population of 43 (17 adults and 25 children).

Munondo is an adjoining kraal, and consists of 8 households, with a total population of 73 (33 adults and 40 children under 16 years of age).

Migrant labour was a common feature in both these kraals: at least 4 households in both Kraals had husbands who were in urban areas as migrant labourers at the time of the survey. The status of two households in Mukewva was not known whilst in the other two the husbands were dead. In Munondo, the husband in one of the households was dead. Hence, in most cases women were running the household alone.

In the hot season the tributaries near the Mission tended to become dry. During August and September the streams close to both Mukweva and Munondo dried up necessitating a longer trip to the water tap at the Mission.

(b) Study Area B: Inyanga Intensive Cultivation Area

The author stayed at St. Mary Magdalene Mission (a Catholic school), for the survey in the second study area. Although the school is primarily for boarders, there were a small number of children from local kraal's. Two of the boarder's at the St. Mary's School acted as translators during the visits to the kraals nearby.

Two kraals (Ellenvale and Doornhoek), were surveyed in the second study area (Inyanga Intensive Cultivation Area - IICA). According to the

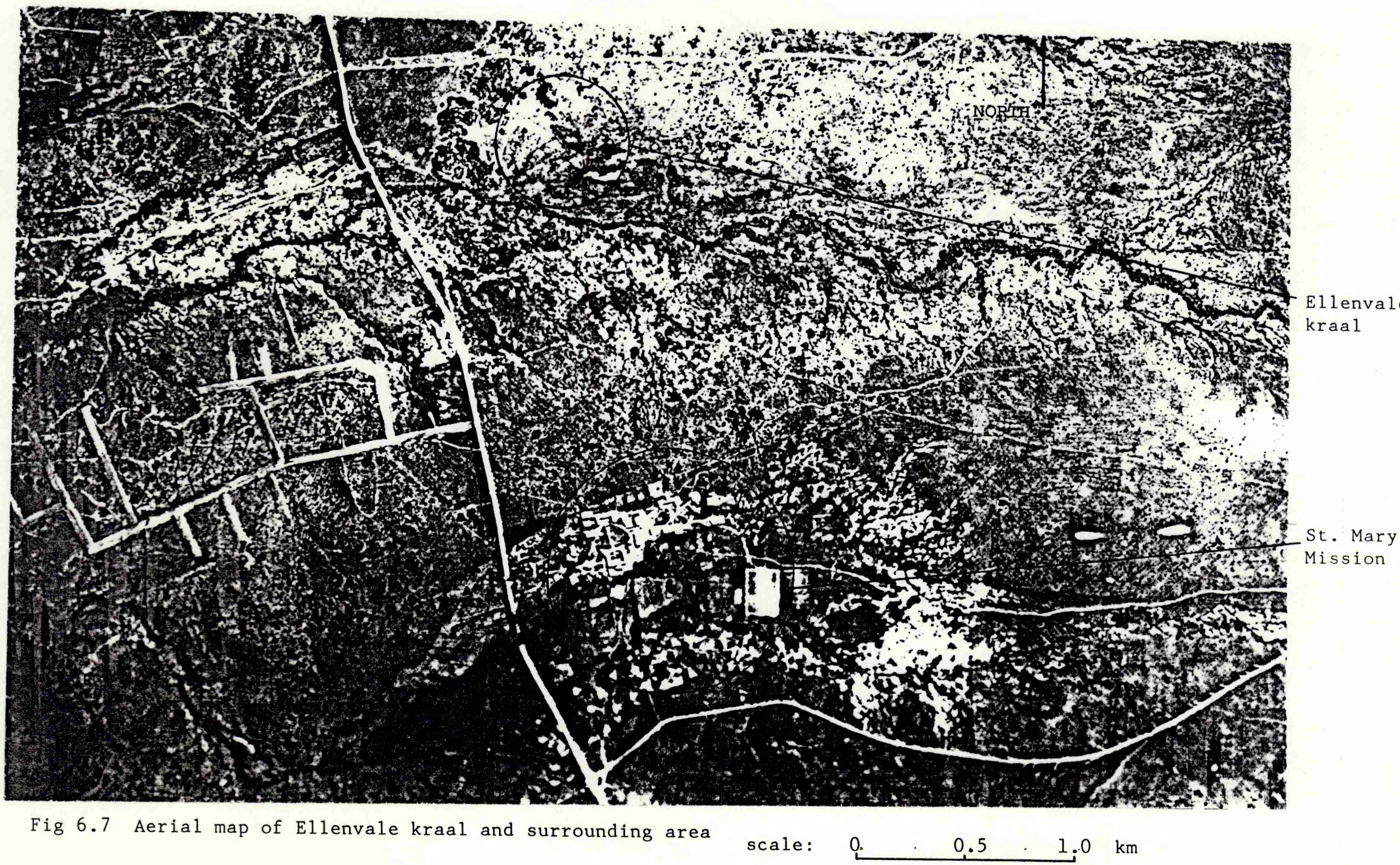


Fig 6.7 Aerial map of Ellenvale kraal and surrounding area

Whitsun Foundation (1978) the population density of IICA is between 21 and 40 persons/km^2 with an annual rainfall ranging from 460 - 700 mm (Vincent et al, 1961 - quoted in Ndlela, 1981).

Ellenvale is approximately north of St Mary's Mission (Fig 6.7), the nearest huts being about 2 km away. To the west is the main dirt track road which runs approximately north - south. Ellenvale consists of 11 households - there are 14 separate cooking huts, as three husbands each have two wives - with a total population of 66 people (26 adults and 40 children). Huts in Ellenvale are clustered close to each other in the form of a circle.

Doornhoek is a linear settlement to the South of the Mission in which the huts of the various households are scattered along the main dirt track road (Fig 6.8). A total of 11 households lived in Doornhoek with a total population of 80 (30 adults and 50 children).

The area surrounding Ellenvale, Doornhoek and the Mission School the landscape is undulating with scattered trees. Tree cover is present on hills and river banks, though this is significantly sparser than in Inyanga North Communal Land.

No concentrations of heavily wooded area were evident within 10 - 12 km of Ellenvale. The nearest sparse woodland was a strip 0.75km away, along one of the tributaries of the River Pendeke, stretching from the settlement to the east. Two scattered patches of sparse woodland lay within 1km of Ellenvale.

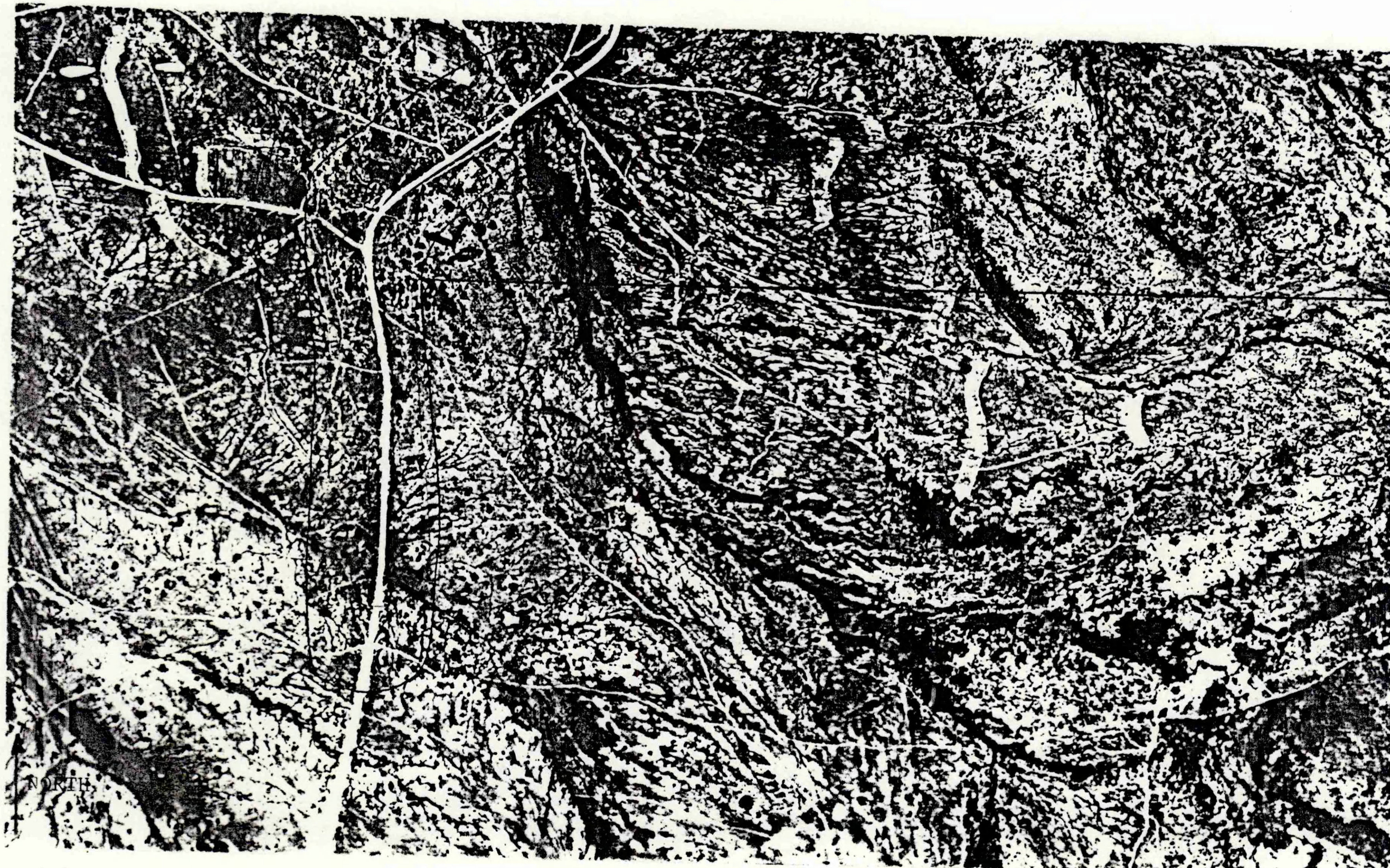


Fig 6.8 Doornhoek kraal and surrounding area scale 0 0.5 1.0 km

(c) Study Area C: Seke Communal Land

In the third study area (Seke Communal Land) the author stayed at Harare: only one kraal (Chitsvatsva) was visited. Seke has an annual rainfall ranging between 700 and 800 mm (Whitsun Foundation, 1978), and a population density of 80 persons/km^2. Despite being in a high rainfall region, the area surrounding the Chitsvatva Kraal was sandy with very sparse vegetation, giving the area a desert-like appearance. Each of the households did, however, have a tree in their compound, which provided shade from the sun.

Five of the households in Chitsvatsva were interviewed using the detailed questionnaire. The population of these five households was 35 (15 adults and 20 children).

A researcher from the University of Zimbabwe had attempted earlier in the year to introduce a "more efficient" cooking stove in response a request by villagers; these villagers were very worried about their firewood consumption. The new stove was shaped in the form of a cylinder, similar to a brazier. This had not proved to be acceptable - the major reason given was that this design allowed only one pot to be heated at a time.

6.3. Results

6.3.1 Food and agriculture

(a) Food crops

Virtually all the food eaten in Mukweva, Munondo, Ellenvale, Doornhoek and Chitsvatsva was grown by the villagers. All villagers grew crops such as maize, groundnuts, peanuts, and vegetables (pumpkin, rape, cabbage and tomatoes). Some villagers also grew potatoes, Nyemba (haricot beans), Mafunde and Munga (both local grains).

Maize was the staple food in all the kraals, and ground at the local mill. For villagers in Doornhoek and Ellenvale the local mill was about 3km away; the local mill for households in Mukweva and Munondo was between 1 and 2km away. Villagers in Chitsvatsva sometimes bought ground maize: this was necessary in years when their supply of maize was depleted (as in the previous year - 1980) owing to low crop yields.

Ground maize was used to make sadza which was eaten with a "relish" (e.g. boiled pumpkin leaves, cabbage, or meat).

Only food items which could not be supplied locally such as tea, sugar, salt, powdered milk, cooking oil, bread flour and baking soda were bought from local stores.

(b) Patterns of daily food consumption

All the villagers interviewed in Mukweva, Ellenvale, Doornhoek, and Chitsvatsva, said sadza was cooked twice a day - this was in approximate agreement with cooking practices reported during the survey period for the households in Mukweva and Ellenvale (Table 6.9).

Table 6.9
Incidence of sadza cooked for the evening and midday meal
(in Mukweva)

Household	Survey Period* (days)	No. of times Sadza cooked
A	16	29
B	16	26
C	13	21
D	12	22

* Note the maximum no. of times Sadza would be cooked is twice a day.

Sadza was prepared by heating water to about 80°C at which point a small quantity of maize meal would be added. Once the mixture started to boil more maize meal was added whilst stirring continuously for about 10 minutes. Vigorous stirring was required during the final stages of cooking sadza. Stirring the mixture was easier if the pot was stable on the stove since both hands were needed to stir the mixture; stability was a feature considered desirable by women and one reason given for changing from the 3-stone fireplace to a "iron frame" stove (see section 6.3.3). A meal for a family of five or six required about 1kg of maize meal and 3kg of water.

The vegetable "relish" took around 15 minutes to cook. Vegetables such as cabbage, rape or pumpkin leaves were cut into thin slices, and heated with a little water.

Leftover sadza from the previous evening was sometimes eaten in the morning with tea. A dilute watery mixture of ground maize was sometimes drunk in the morning, this was termed "porridge" when freshly made and "naMahewu" when prepared the previous evening.

A similar pattern of food consumption was also reported by the 19 local pupils (living within 5km) at St. Elim Mission School, and villagers surveyed in Ellenvale.

(c) Cooking pots

Three types of pot were used for cooking: three legged metal pots, enamel coated metal pans (with a flat bottom), and clay pots (with round bottoms).

Enamel coated metal and clay pots were used by villagers in all five kraals. A few villagers also had three-legged metal pots. Some villagers in Ellenvale also used paint cans (5 litres capacity). These were used for the preliminary heating of water. This water was then transferred to an enamel pan to make sadza. This extended the life of the enamel pan (an expensive investment).

Pots of different sizes were used depending on the number of people at the meal (Table 6.10).

Table 6.10
Dimensions of pots used in Mukweva

Pot type and size	height of pot (cm)	diameter of pot (cm)	Household
Three-legged pot	17.0	22.0	A
	18.0	22.0	C
Enamel pot (large)	16.5	20.5	A
	14.0	18.5	B
Enamel pot (medium)	15.0	12.5	A
	17.5	13.0	A
	15.0	11.2	B
	17.5	13.0	C
Enamel pot (small)	10.0	12.0	A
	10.0	13.5	B
	10.5	14.0	D

Lids were not used in the preparation of sadza as almost constant stirring was required. However, lids were used when simmering the relish.

Different items of food were cooked in the various pots (Table 6.11). Some villagers did not like using an enamel pot for cooking beans as they felt the long simmering time would damage the pot; one villager in Ellenvale said that it would have been difficult to replace as her husband was out of work. Others commented that beans cooked in a clay pot tasted "sweeter" or "twice as good", compared with those cooked in an metal pan. One villager said that whilst she did not notice any difference in taste with a clay or metal pan, her mother preferred the taste of food cooked in a clay pot.

Table 6.11
Food cooked in each type of pot in Mukweva

Pot Type	Food Item	Comment
3-legged pot	sadza	used when cooking for a lot of people
Enamel pot (large and medium)	sadza	
Enamel pot (small)	vegetable relish	
Clay pot (large)	heating water for washing	
Clay pot (medium and small)	sadza, relish, beans	some villagers preferred food cooked in a clay as it tasted "better"

Women were aware that cooking with clay pots used more fuel than with metal pans.

Village women said cooking beans required a lot firewood to cook, and gave three methods wherby less firewood would be required: firstly, by using metal rather than clay pots; secondly, by soaking the beans overnight; and thirdly by cooking with the addition of bicarbonate of soda. These methods were usually not used as they changed the taste of the beans: using clay pots and not soaking meant that the beans tasted "sweeter". Another reason was that they sometimes simply forgot to soak the beans.

(d) **Procedure after cooking**

The fire was not put out immediately after cooking, despite the high temperature in the cooking hut: temperatures of up to 29°C were measured. Instead, the fire was allowed to go out of its own accord. In both Mukweva and Ellenvale the fire was often observed to be smouldering. The male head of one of the households in Mukweva said that this was done because matches were expensive; whilst the cover price was 2 Zc (1.5p) per box the actual price paid was 5 Zc (3.5p). Similarly in Ellenvale, a villager explained that she did not put out the fire after cooking because her husband smoked, and matches were expensive. She put water on the firewood at the end of cooking, in order to conserve fuel, when her husband was away (working). A child in Ellenvale was observed carrying red hot embers from a neighbours cooking hut to light the fire for the evening meal.

Only one village women in Mukweva and a few women in Doornhoek, said that they usually put water on the firewood after cooking, in order to conserve wood.

In Mukweva, only about half the firewood was used directly for cooking (Table 6.12) - the rest just burned away. These figures were similar for all four households, irrespective of stove type. For the household using the 3-stone fireplace in Ellenvale around 80% of the firewood was used in cooking.

Table 6.12
Cooking energy consumption

	Mukweva				Ellenvale
Household	A	B	C	D	C
Proportion of daily energy used in cooking	47%	52%	45%	48%	80%

6.3.2 Effects of seasonal variation in demand for agricultural labour

(a) Patterns of labour in agriculture

Women were responsible for agricultural as well as domestic tasks (Table 6.13).

Table 6.13
Sexual division of labour

Agricultural tasks	Carried out by:
planting	men and women
digging/weeding	men and women
Domestic Tasks	
washing clothes/pots	women
carrying water	"
sweeping	"
cooking	"
pounding rice	"
collecting firewood	"
(by headload)	"
collecting firewood (by "scotch cart"*)	men

*see section on fuel collection

Ploughing and planting were started when the first rains fell, (usually in November) and continued till December. Weeding took place from January to March, and harvesting in May and June.

Most women said that they were busiest from November to around May or

June, and least busy from June to October (Fig 6.9). However, only the months from August to October were usually spent resting, as "winter ploughing" was done in the vegetable gardens in June and July.

```
                                            month
                                  S  O  N  D  J  F  M  A  M  J  J  A
                                                    <post>
season                            <hot><main  rainy><rainy><--cold->
firewood collection               [////]                 [////////]
busiest months for agriculture        [//////////////////]
no. of pots on iron frame*        <one><---two or three---><--one-->

* see text
```

Seasonal Variation in Agricultural and Domestic Activity
Figure 6.9

In Chitsvatsva, harvesting took place slightly earlier - from March through to April - winter ploughing was from May to July. Most villagers in Chitsvatsva also regarded the months fom November to May as the busiest; one households reported being busy all year round.

This **variation in labour demand** over the year **affected firewood collection** and **cooking practices** (Fig 6.9).

(b) Firewood collection

Firewood was collected in the agriculturally slack season when women were not busy in the fields; seasonal weather conditions also affected firewood collection (see section 6.3.6).

(c) Cooking practices

Cooking practices were affected in two ways when women were busy in agricultural labour.

Some villagers cooked in the fields at times of peak agricultural labour demand (cooking was also done outside for other reasons - see section 6.3.6).

Fast cooking was considered to be extremely useful at times of the year when the women were busy in agriculture. Village women said that the number of pots they heated simutaneously on the stove varied over the year: two or more pots were heated simultaneously when they were busy, whilst only one pot was heated at a time during the slack months (Fig 6.9).

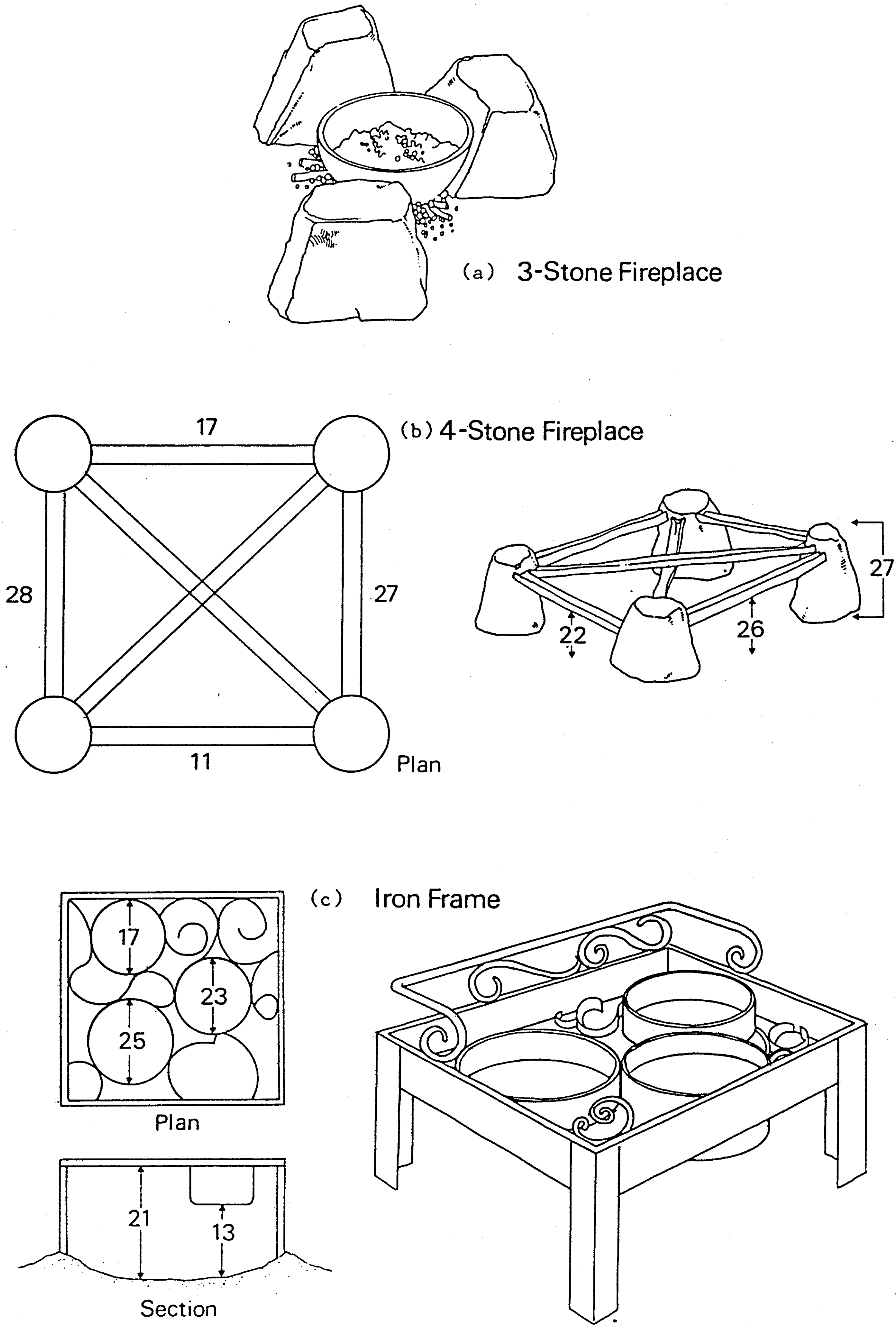
Most of the villagers had replaced their 3-stone fireplace inside the cooking hut with either a "4-stone fireplace" or "iron frame stove" (Fig 6.10). These latter stoves enable several cooking pots to be heated simultaneously, thereby reducing cooking time. This time saving feature was given as one of the most important reasons for adopting the new stoves (see also section 6.3.4).

One household in Mukweva had modified her 3-stone fireplace by placing a small additional stone (Fig 6.11), enabling her to heat two pots simultaneously - this entailed having two fires close to each other.

All other households who used 3-Stones said they always heated one pot at a time throughout the year, because it was not possible to heat more than one pot simultaneously on the traditional 3-stone fireplace.

6.3.3 Types of cooking stove

All householders interviewed in Mukweva, Munondo, Doornhoek and Chitsvatsva had a separate cooking hut. Some cooking huts in Ellenvale had still to be built: villagers in Ellenvale and Doornhoek had recently been resettled (one household in Ellenvale had arrived 4 months ago),



(measurements in cms.)

Fig 6.10 "stoves" found in rural Zimbabwe and were in the process of building their huts.

Every household in all five kraals had placed its stove at the **centre of their cooking hut.**

During cooking family members (in Mukweva and Ellenvale) were observed to gather around the central fireplace.

Three types of 'stove' were observed on the fireplace in the center of the cooking hut (Fig 6.10): 3-Stones, '4-Stones' or an "iron frame".

Households using the 3-stone fireplace sometimes placed the cooking pots directly on the burning firewood rather than the stones.

Villagers visited in Chitsvatsva had placed bricks on one side of the iron frame to act as a wind shield (Fig 6.12).

None of the stoves were higher than about 30cm; this meant that young (female) children were not prevented from cooking.

One villager in Chitsvatsva also used a "mbaura": a one pot stove, consisting of a five gallon cylinderical container with holes punched into the sides and bottom to provide air for the burning fuel. This was sometimes instead of the iron frame as the user perceived it to use slightly less fuel.

The 4-Stones fireplaces were user built and consisted of 4 pillars of clay (or termite mound) fixed to the ground. These pillars were linked by 4 metal bars in the shape of a square with two additional metal bars forming the diagonal supports: termite mound was mixed with water and

Fig 6.11 modified 3-stone fireplace

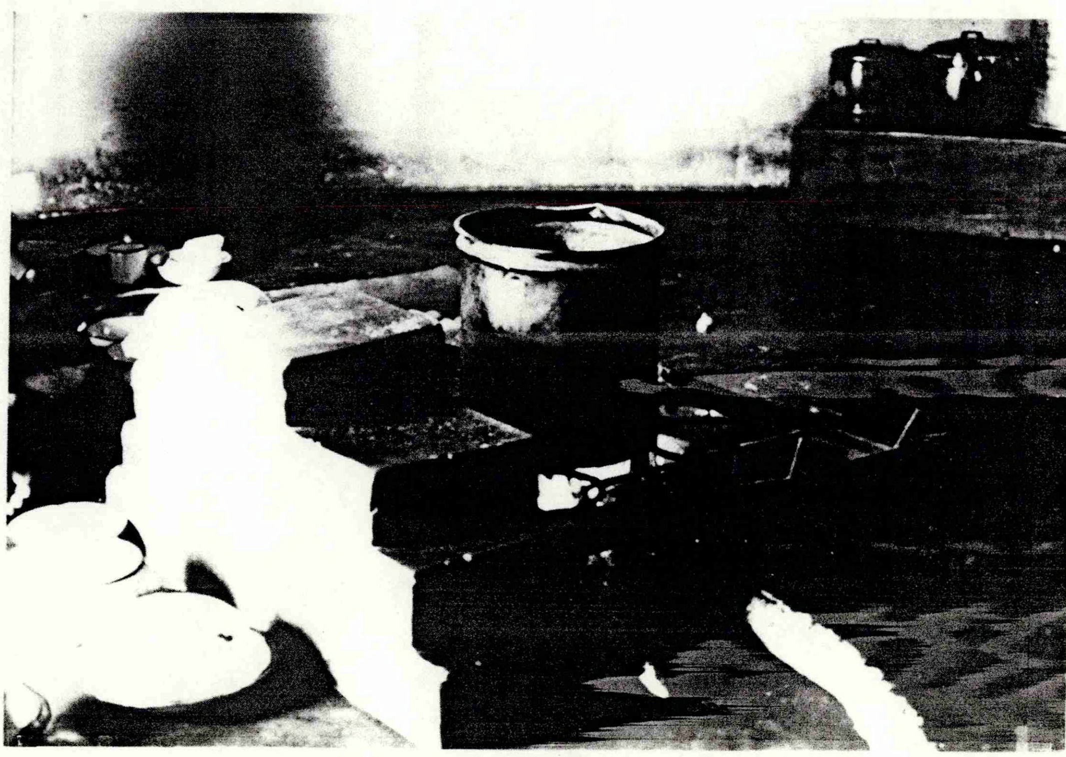


Fig 6.12 iron frame + brick windshield

formed into pillars into which metal bars were embedded. This structure was left to dry for about 10 hours. The 4-stone fireplace had to be rebuilt or repaired every 4-6 months, as it deteriorated with use (Fig 6.13).

The iron frame was made by urban artisans and available in towns: in Harare (the Capital) the iron frame cost around Z$ 4 - equivalent to nearly 5 weeks of the (estimated average) rural income in 1981.

The earliest reported purchase of the iron frame was 1961 in Doornhoek, 1965 for Chitsvatsva, 1971 for Mukweva, and 1978 for both Munondo and Ellenvale respectively (Table 6.14). Most households had purchased their iron frame in the 70's.

Most of the households in Mukweva, Munondo, Ellenvale, Doornhoek and Chitsvatsva had an iron frame stove inside their cooking hut (Table 6.15). There was a similar pattern of stove ownership in the households of 19 local children attending St Elim Mission school.

Virtually all the villagers using the iron frame or 4-Stones reported having 3-Stones inside the cooking hut prior to the change in cooking 'stove'. Following the adoption of the iron frame, the vast majority of these villagers had moved their 3-Stones outside the cooking hut, where they were sometimes used to heat water for bathing and to brew beer (a few times a year) (Fig 6.14).

Women who continued to use the traditional 3-Stones inside the cooking hut expressed a desire to change to the iron frame, but said that they could not afford to buy one.

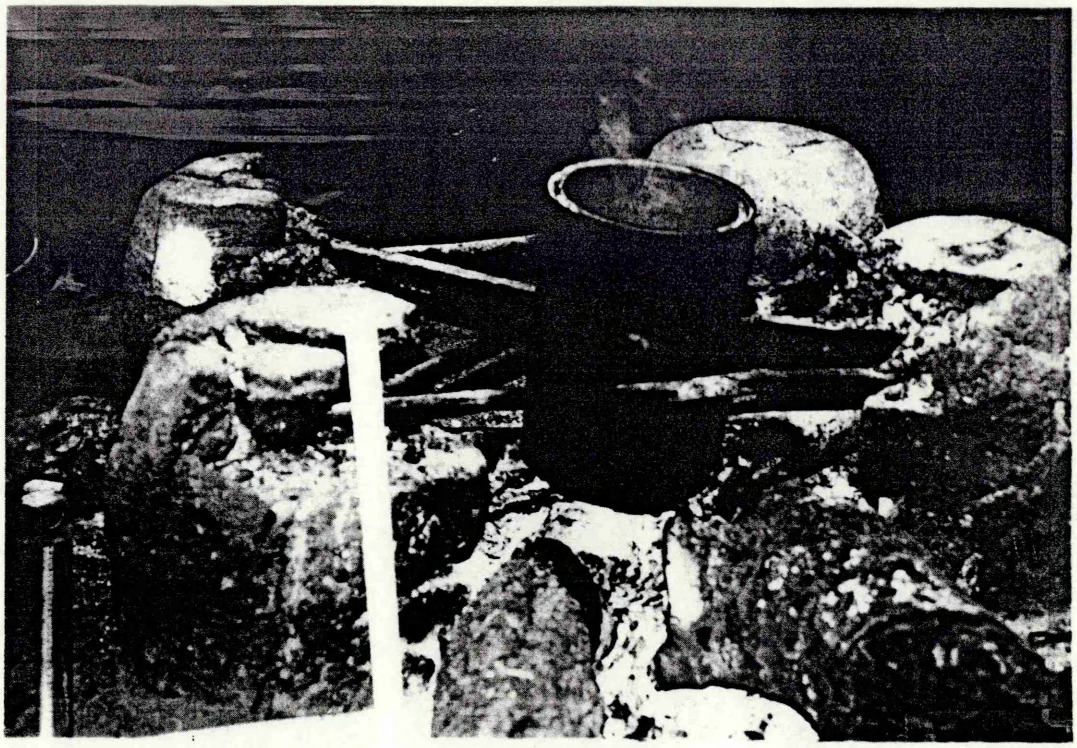


Fig 6.13 4-stone fireplace undergone deterioration

Fig 6.14 brewing beer on 3-stone fireplace

Table 6.14
Date of purchase of iron frame
and construction of 4-stone fireplace

kraal	Household[1]	Stove Inside	When bought/built[2]
Mukweva			
	A	3-stones	n.a.
	B	iron frame	1971
	C	4-stones	n.a.
	D	iron frame	n.a.
	E	3-stones	n.a.
	F	iron frame	1975
	G	4-Stones	1975
	H	iron frame	1972
Munondo	I	iron frame	1981
	J	4-Stones	1978
	K	iron frame	1978
	L	iron frame	1981
	M	iron frame	1980
	N	iron frame	1980
	O	iron frame	1981
	P	4-Stones	1981
Ellenvale[3]			
	A	iron frame	1978
	B	iron frame	1980
	C	3-Stones	
	D	iron frame	1980
	E	3-Stones	
Doornhoek			
	A	iron frame	1975/76
	B	iron frame	1979
	C	3-Stones	n.a.
	D	3-Stones	n.a.
	E	3-Stones	n.a.
	F	iron frame	1971
	G	iron frame	1979
	H	4-Stones	long ago
		iron frame	1961
	I	iron frame	1979
	J	iron frame	1972
	K	iron frame	before 1975
Chitsvatsva			
	A	iron frame	1976
	B	iron frame	1965
	C	iron frame	1979
	D	iron frame	1969
	E	"mbaura"[4]	made 3 months ago

[1] the date of purchase or construction was not known for households A, C and E.

[2]the iron frame is purchased whereas the 4-Stone fireplace is built at home

[3]the other 6 households in Ellenvale had an iron frame, but the date of purchase is not known.

[4] "mbaura" is single pot metal brazier-like stove.

Table 6.15
Cooking stove ownership

	No. of households surveyed	No. with each stove type **inside** cooking hut	No. with each stove type **outside** cooking hut
INCL			
Mukweva	8	5 - Iron Frame; 2 - "4 Stones"; 1 - "3 Stones".	6 - "3 Stones"
Munondo	8	5 - Iron Frame; 2 - "4 Stones"; 1 - "3 Stones".	6 - "3 Stones"
Households within 5km of Mission	19	19 - Iron Frame	7 - "3 Stones"
IICA			
Ellenvale	11	9 - Iron Frame; 2 - "3 Stones".	4 - "3 Stones"
Doornhoek	10	7 - Iron Frame; 1 - "4 Stones"; 3 - "3 Stones".	4 - "3 Stones"
Chitsvatsva	5	5 - Iron Frame	3 - "3 Stones" 1 - "mbaura"*

*see text

6.3.4 Villagers reasons for changing from the 3-stone fireplace

Overall, the iron frame was perceived to have a number of advantages compared with the traditional 3-stone fireplace: the ability to heat "many things" at the same time; a "modern image"; it produced less smoke; pots were more stable; it gave out more heat and bigger logs could be used. A ranked list of villagers reasons for changing or wishing to change from the 3-stone fireplace to the iron frame are given in Table 6.16. In contrast the 4-stone fireplace had only the first advantage.

A villager in Ellenvale who had a 3-stone fireplace inside her cooking

Table 6.16

Ranking of villagers reasons for changing or wishing to change from the 3-stone fireplace

kraal	Ellenvale			Doornhoek									Chitsvatsva			
Household	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
Stove type	Z	Z	X	Z	Z	X	Z	Z	Z	Z	Z	Z	Z	Z	Z	W
Cooks many things	2	3	2	1	2	1	1	2	2	2	2	1	1	1	1	1
Modernization	1	1						1	1		1		4	2		
More heat	3	4		2	3	3		3	4	3	6		3		4	2
Less Smoke	4	2	1	3	1	2	2	5	3	5	4	2		3	5	
Bigger logs							3	4		4	3	3		4		
Stable pots			3					6		1	5		2		2	3
Faster cooking				4												
Stove is portable									5							
New stove is durable											7					
Firewood can be put from all sides															3	

Key

Stove Type

W - Mbaura, X - 3-Stones, Y - 4 Stones, Z - Iron frame.

hut summarized her perceptions of the advantages of the iron frame as follows: the most important was that no (or little) smoke was produced. Another, the ability to heat several pots at the same time (in summer this meant that "many maize cobs" could be roasted - with 3-stones she was limited to 3 at a time). Finally, pots on the iron frame were more stable. In her case a lot of smoke was produced during cooking. Smoke built up inside the hut - despite the door being left open. This irritated the eyes, especially when the fire had just been started. In her view, the 3-stone fireplace had **only** the advantage of having half the fuel consumption of the iron frame.

(a) Multi-pot cooking and modern "image"

One of the most important reasons for changing from the 3-stone fireplace was that the iron frame allowed several pots to be heated at the same time: women in Mukweva gave only this reason for the change, whilst some women in Ellenvale regarded the modern "image" of the iron frame as being more important; these latter households regarded 3-stones as being "old fashioned" and by moving away from this traditional fireplace they were (literally) moving out of the "Stone Age".

Two households in Doornhoek still used the 3-stone fireplace - for them **the ability to cook food more quickly was the most important reason for wishing to acquire an iron frame.**

(b) Smoke

Cooking with 3-Stones was observed to create more smoke than with the iron frame. This was especially noticeable during the initial stages of lighting the fire. Smoke was not considered to be a problem by any of the women using the iron frame. Direct observation of the cooking process showed that little smoke was evident except during the first few minutes of lighting the fire, and when firewood was added to the fire. Nearly all the cooking huts had one or two windows. Hence, smoke tended to escape through these windows and roof of the hut. Smoke which was present was predominantly at heights above 1m from the floor. However, this was at a level above the head of a person sitting on the floor - the usual position for cooking and eating.

Smoke was a problem in two households who used the iron frame, in Mukweva, where the cooking hut had no windows - this made it expecially difficult to use fuels such as maize cobs which burnt with a lot smoke.

(c) Stability of pots

Cooking pots were fairly unstable on the 3-Stones fireplace, especially during the final stages of cooking sadza, when vigorous stirring was required. Much greater stability was apparent with the iron frame.

(d) Space heat

During winter (around June and July) the stoves were used for providing space heat as well cooking.

More heat was lost to the surroundings with the iron frame than with 3-stones. Firewood could be burnt at high rates in the iron frame - power outputs of up to 21kw were measured (see section 6.2.2). Sometimes this high power output was a problem, as the heat from the fire, in combination with the vigourous exertion required to stir the thick sadza mix, meant that the person stirring the mixture could become very uncomfortable. In response to this, some of the families in Ellenvale placed a round flat piece of metal in front of the cook, to act as a heat shield whilst stirring the sadza.

Villagers commented that the 3-Stone fireplace gave very little space heat.

(e) Size of logs

The iron frame could accomodate larger pieces of wood than three stones. Two reasons were given by villagers in Doornhoek for the desirability of being able to use large logs: a higher heat output (so food could be cooked more quickly) and that wood had to be put onto the fire less frequently.

6.3.5 Relative firewood consumption of stoves

All the women using the iron frame considered that it consumed significantly more firewood than the 3-stones: the iron frame was perceived to use between one-and-a-half to three times as much firewood as 3-stones (Table 6.17). No villager reported a decrease in fuel consumption in changing from the 3-Stones to the iron frame.

Table 6.17
Consumption of new stove relative to 3-stones
(user perceived)

kraal	Ellenvale			Doornhoek									Chitsvatsva			
Household	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
Stove type	Z	Z	X	Z	Z	X	Z	Z	Z	Z	Z	Z	Z	Z	Z	W
Consumption relative to 3-Stones	2	2		1.5	1.5			2	2	2	2	2		3	3	1

Stove Type
W - Mbaura, X - 3-Stones, Y - 4 Stones, Z - Iron frame.

Moreover, villagers observed cooking (using the iron frame) in Mukweva, Ellenvale and Chitsvatsva, did not appear to be particularly concerned about minimizing fuel consumption by ensuring that the flames were directly under the pot. In Mukweva and Ellenvale, the firewood logs were adjusted during cooking about once every 15 minutes or so.

Between 2 and 5 litres of water could be brought to the boil in 10 minutes or so with the iron frame. With a metal pan, PHU's (see section 6.2.2.) of the iron frame, varied from 8% to 10%, whilst a value of 34% was obtained for 4-Stones (Fig 6.10). Using a clay pot on the 4-Stones fireplace gave a reduced PHU of 11%. Perhaps not suprisingly, the household using the 4-stone fireplace had the smallest daily per capita firewood consumption.

The PHU has only been calculated for one household that used 3-Stones; fuel consumption data during the cooking process was incomplete for five out of the six families under observation in Ellenvale, as cooking was already underway before any measurements of the initial quantity of firewood, kindling, temperature of the water heated and so on, could be made. Repeat measurements would have inconvenienced these housholds. PHU's of 15% and 19% were obtained in heating water on the 3-Stones (Table 6.18).

For comparison, in laboratory, values of PHU (excluding water of evaporation) of up to 20% and 13% were obtained in laboratory tests on the 3-stone fireplace and iron frame stove respectively (see Chapter 5).

Despite the relatively higher fuel consumption, none of the women using the iron frame or 4-stone fireplace thought that having a 3-stone fireplace inside the cooking hut had any advantages. In addition, all

the women who still had 3-stones inside their cooking hut expressed a desire to have an iron frame but were prevented from purchasing one for lack of money.

Table 6.18
Percentage heat utilization data

House-hold	T_f (^oC)	T_i (^oC)	Time to T_f (min)	M_w (Kg)	P_o (kW)	Pan	PHU (%)	Stove
Mukweva								
A	80.0	27.5	9.7	4.95	21.2	metal	8.8	Iron frame
B	87.5	28.5	11.0	2.56	9.3	metal	10.3	Iron frame
C	93.5	29.1	9.0	2.68	4.2	metal	33.8	4-Stones
	92.2	25.2	22.5	2.68	5.1	clay	11.0	"
D	81.6	24.6	11.8	4.48	15.8	metal	9.6	Iron frame
	97.0	23.4	10.9	2.10	12.0	metal	8.2	" "
Ellenvale								
C	96.6	21.0	14.2	1.98	4.4	paint can	18.9	3-Stones
	96.6	24.0	14.4	2.57	6.1	paint can	14.9	"

Key
T_f - final temperature of water;
T_i - initial temperature of water;
M_w - mass of water being heated;
P_o - power output of burning fuel;
PHU - percentage heat utilization excluding energy associated with evaporated water (see Chapter 3).

6.3.6 Effects related to seasonal and climatic variations in weather

(a) Cooking out of doors

One villager in Mukweva said she cooked outside on her 3-Stones from May till July, whilst she was drying maize inside the cooking hut. It was possible to cook outside during this time as the rains stopped in April.

Some villagers in Doornhoek and Mukweva cooked outside on a 3-stones fireplace in the hot season (ie August to October). Three out of the five households in Chitsvatsva cooked outside in the hot season when using animal manure, since it burnt with an unpleasant smell and a lot of smoke.

(b) Fuels used for cooking

Firewood and maize cobs were used as cooking fuels in four kraals (Mukweva, Ellenvale, Doornhoek and Chitsvatsva). Three households in Mukweva did not use maize cobs because they produced "too much smoke" and burned "too quickly"; there were no windows in the cooking huts of two of these households in which the level of smoke built up very quickly (see also section 6.3.4).

Firewood consisted of tree branches and logs varying from 0.5 - 1m in length and 2 - 10 cm in thickness. The quality of the firewood was not the same for all the kraals: whilst villagers in Mukweva, Ellenvale and Doornhoek used tree branches, villagers in Chitsvatsva also dug up tree roots. Some villagers said that they preferred thick logs as they required less attention and did not have to be replaced so often during the cooking process (see also section 6.3.4).

Average moisture contents (dry basis) of the firewood samples (see section 6.2.2) obtained from households in Mukweva and Ellenvale, ranged from 10% to 37% (Table 6.19).

Table 6.19
Moisture content of firewood samples

	Mukweva				Ellenvale				
Household	A	B	C	D	A	B	C	D	E
Firewood moisture content (%) -dry basis	10.0	10.5	37.0	12.5	10.7	27.1	12.5	16.8	21.6
standard deviation	2.6	3.3	11.0	1.3	1.0	4.4	1.3	2.6	8.1

Sun dried cattle manure was used as a fuel only in Chitsvatsva. This was collected and burnt in the (3-stone) fireplace outside the cooking hut during the post-rainy and hot season: manure could not be collected during the rainy season as it was washed away by the rain. **Only manure that was found outside these kraals was burnt as cooking fuel;** villagers said that manure from the cattle kraal - the enclosure where cattle were kept - was needed as fertilizer. Some villagers said that they had insufficient cattle manure to use as fertilizer.

None of the villagers reported using paraffin or charcoal as cooking fuels. In Chitsvatsva villagers said that they did not cook with charcoal because it produced a "bad atmosphere" ie carbon monoxide.

Both animal manure and charcoal were used for non-cooking activities: in Mukweva, Ellenvale and Doornhoek cattle manure was principally used as a fertilizer. One villager in Doornhoek also used manure as a polish for the floor of two huts (three times a week); another preferred to use mud as a floor polish as she did not like the smell of manure. A few villagers in Doornhoek and Ellenvale reported saving charcoal from the fire to use in their clothes iron's; ironing was done between one and three times a week.

(c) Patterns of fuel collection

Firewood was collected in all the kraals by women and girls and carried as headloads, or by men and boys and carried by cart (Fig 6.15). In Mukweva, the weight of firewood per headload ranged from 12kg to 36kg; the larger amounts being carried by young women whilst the older women carried much less. The weight of firewood collected by scotch cart (measured on only one occasion) was just over 170kg.

Firewood was reported to be collected from June till October - the agriculturally slack season: during the rainy season, women were busy

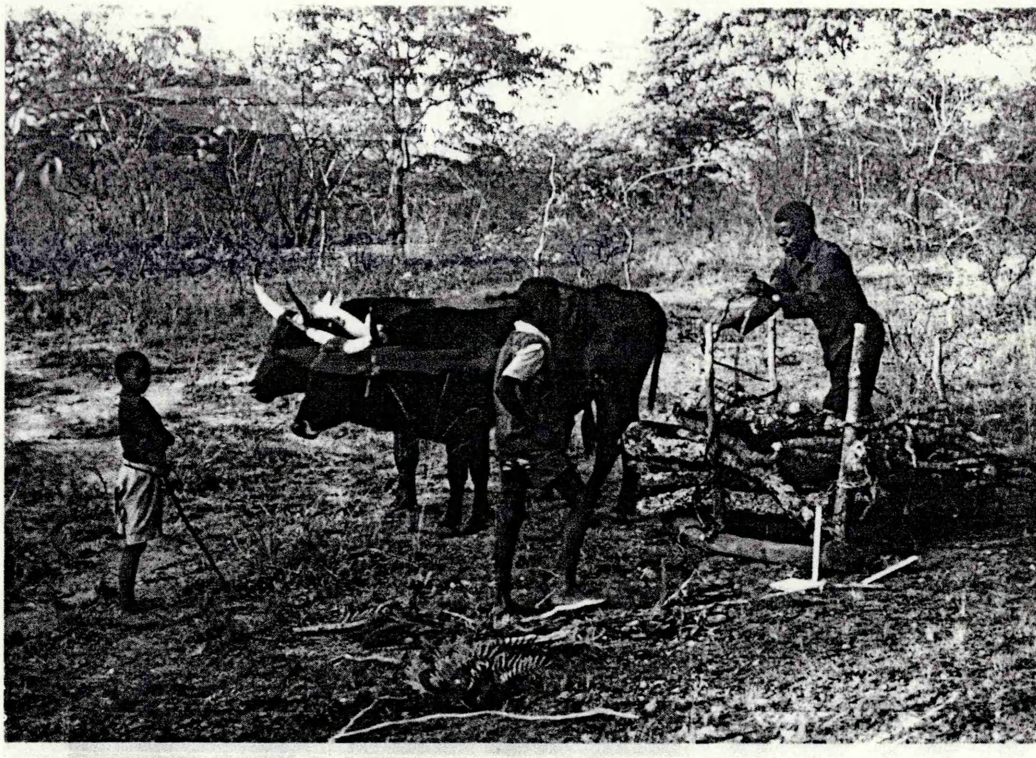


Fig 6.15 loading firewood onto "scotch" cart

Fig 6.16 firewood store of household in Ellenvale

with agricultural work (see section 6.3.2). Moreover, wet wood was "very heavy" and "difficult to burn". The usual practice was to collect enough firewood during the dry months (and store it in a pile) to last through to the end of the rains (Fig 6.16 - 6.18).

Some villagers in Ellenvale were observed to have continued to gather firewood during **December.** However, the rains had been delayed and did not arrive till mid-December. Women questioned about this said that they preferred to use as little as possible of their stored firewood, which they would need during the rainy season.

Villagers in Chitsvatsva started collecting firewood a few months earlier than in Ellenvale, Doornhoek and Mukweva.

Firewood was used all year round by every household questioned in Mukweva, Ellenvale and Doornhoek, and three households in Chitsvatsva.

Two households in Chitsvatsva said they were only able to use firewood during the rainy season, as their store of firewood lasted about half the year entailing the use of animal manure for the rest of the year; firewood stockpiles in Chitsvatsva were generally considerably smaller than those in the other two study areas (Fig 6.16 - 6.18). These households bought firewood: one said that she was too ill to collect firewood, and so bought all the firewood she used over the year; the other bought firewood to supplement the firewood she had collected.

Maize cobs were generally collected and burnt during August and September in all kraals, though, one of the households in Chitsvatsva reported using maize cobs from June to August.

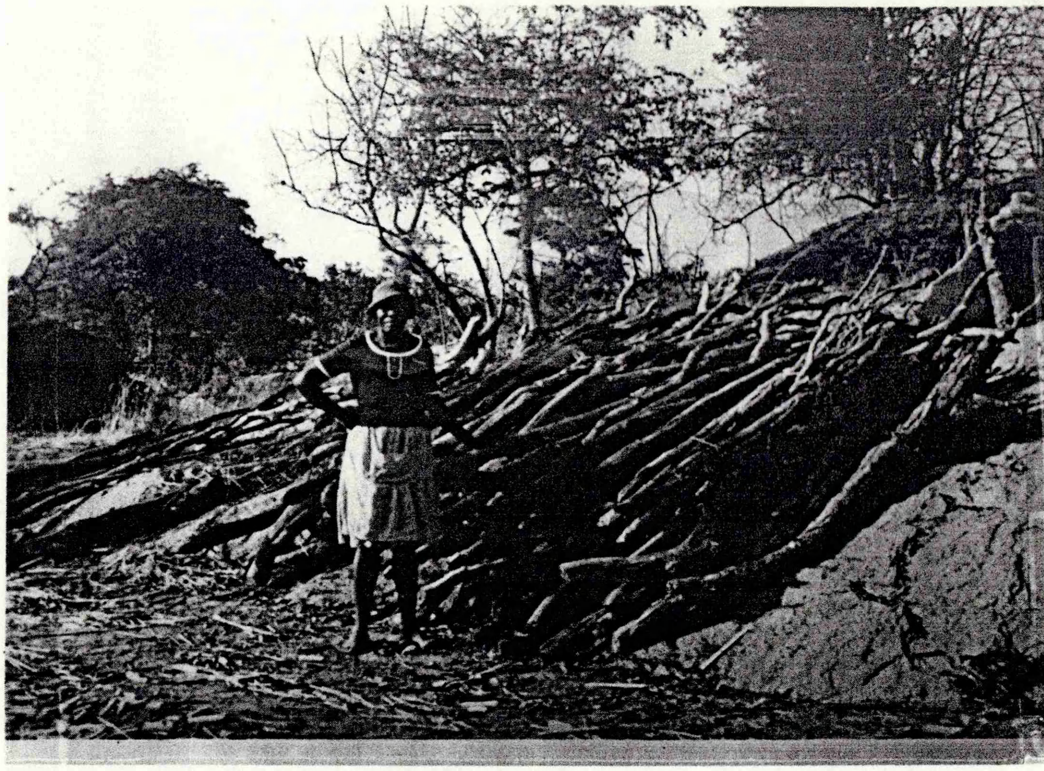


Fig 6.17 firewood store of household in Mukweva

Fig 6.18 firewood store of household in Chitsvatsva

(d) Variation in firewood consumption over the year

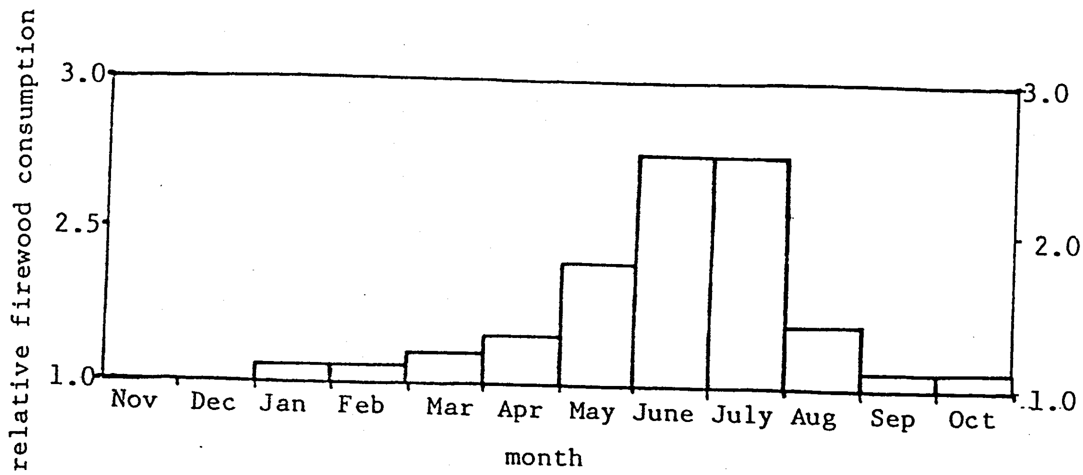
All the villagers said that their level of firewood consumption **varied over the year**, mainly as a result of requirements for space heat in winter; for villagers in Chitsvatsva, firewood consumption fell due to the substitution of animal manure for firewood for part of the year. As noted in section 6.3.4, one reason given by villagers for changing to the iron frame stove was its better space heat capability compared with the 3-stones.

The mean variation (relative to the level of consumption in November) for each kraal is shown in Fig 6.19 (see section 6.2.2). Some villagers also said that firewood consumption increased after harvesting as more food was available for cooking.

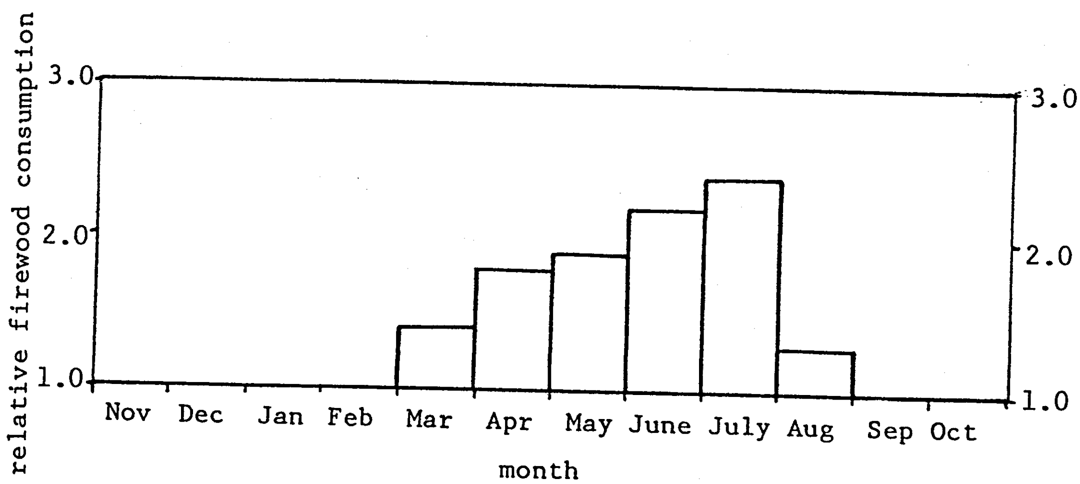
In Mukweva, fuel consumption during the cold months of June and July was said to be one-and-a-half to twice as high as the rest of the year.

In Ellenvale and Doornhoek firewood consumption was perceived to increase from around the beginning of March and peaking in the winter of June and July. After July, the relative consumption fell and remained fairly constant from September to February. According to respondents, fuel consumption was between one-and-half to three times as high in these cold months as the other months. On the basis of these estimates of consumption, the average level of consumption in winter was calculated to be about two-and-a-half times the consumption during the months from September to December (Fig 6.19).

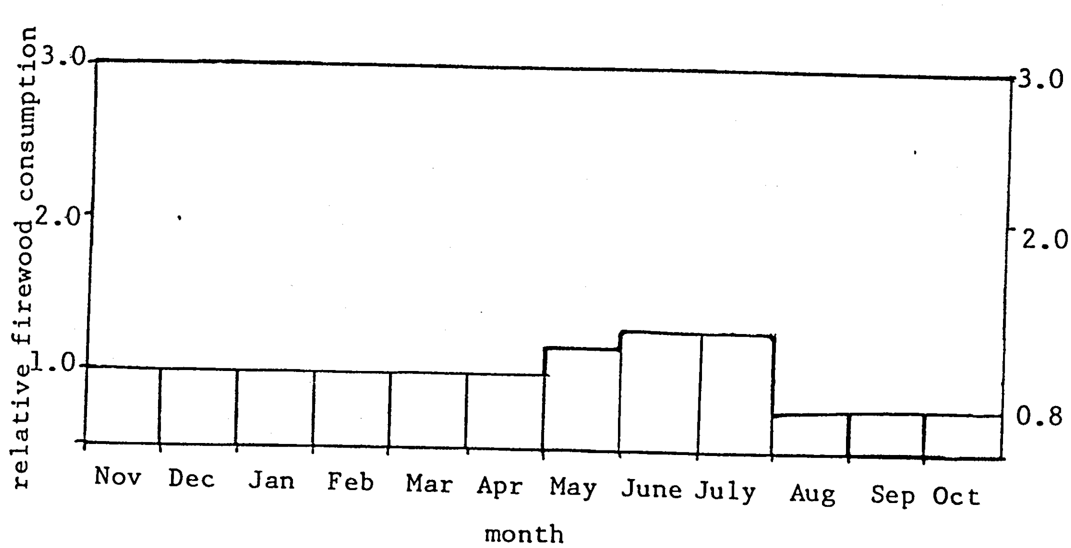
In Chitsvatsva, the mean consumption of firewood was fairly constant till July, after which it **fell** to about two-thirds of the value during



(a) Ellenvale



(b) Doornhoek



(c) Chitsvatsva

Fig 6.19 Perceived variation in firewood consumption over the year (data normalized such that consumption in November = 1.0) the months from August through to October. Firewood consumption was perceived to increase for two of the households around winter. Two other households reported a fall in consumption: in one case, no firewood was reported to be consumed during April to October, whilst for the other, firewood consumption was half its usual value. Both these villagers said that **firewood consumption during these months fell as animal manure was being substituted for firewood.**

6.3.7 Firewood collection site(s)

All five households surveyed in Mukweva said they went to the same firewood collection source (about a 10 minute walk away). On two occasions that village women were accompanied on their firewood collection trip, around 10 minutes were spent in the collection area itself. Dry branches of wood were gathered: these had been cut earlier in the year and left to dry out. A total of 30 minutes was taken in going to the collection area, collecting the wood, and bringing it back as a headload. Firewood was collected on these trips by individual women rather than in groups - it is not known whether this is the norm or not.

The firewood source was 30 minutes away for an observed trip to collect firewood with a Scotch cart. Only a few minutes were spent in loading the cart since the firewood had been put in a pile on a previous trip.

All the households in Mukweva reported cutting firewood and leaving to dry for a few months before coming to collect it - there were no reports of others taking this firewood.

Additional data on the distance to firewood collection areas obtained in

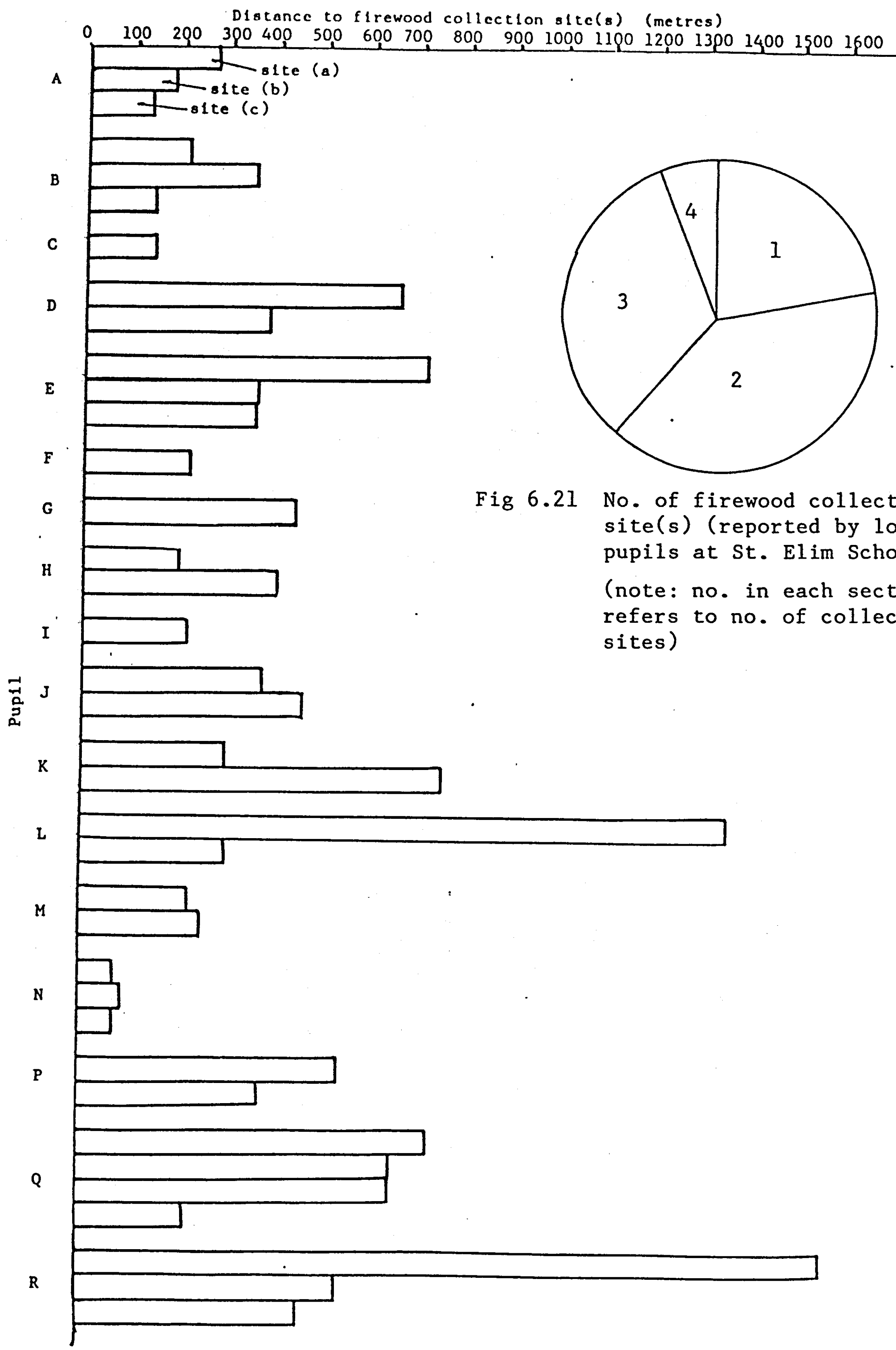


Fig 6.21 No. of firewood collection site(s) (reported by local pupils at St. Elim School)

(note: no. in each sector refers to no. of collection sites)

Fig 6.20 Distance to firewood collection site(s) (reported by local pupils at St. Elim School) the questionnaire from 19 local children who attended St Elim Mission school is shown in Fig 6.20; **around three quarters of these households had more than one firewood collection source** (Fig 6.21). The distance to firewood collection areas was in the range 70 - 1500m.

In Ellenvale, the surrounding area was sparsely populated by trees. There were very few trees at the nearest collection point (about a 15 minute away). The main collection area was a 20 to 25 minutes walk away (ie between 2000-2500m) and took the form of a linear trail along the nearby river's bank to the east. Another forested area was evident to the west. All the villagers interviewed in Ellenvale said that firewood was collected from the trees along the river bank.

A few villagers in Doornhoek who were questioned collection sources said that they went to the mountain range (about 3km away) for firewood.

Villagers in Chitsvatva were not asked about distance to sources of firewood collection, however, very few trees could be seen from the village.

Overall, the larger distance to firewood collection sites in Ellenvale compared to Mukweva supports the view that Ellenvale is in an area of greater fuel stress than Mukweva. The tree-less landscape around Chitsvatsva further confirms this village to be in an area with an acute shortage of firewood.

6.3.8 Perceptions of fuel collection vis a vis other tasks

Women's perceptions of tasks they regarded as being "hard", "easy", "liked" and "disliked" are summarized in Fig 6.22 - 6.25; data from the women in Mukweva is only for the tasks they regarded as being hard or easy. Whilst all villagers regarded at least one activity as being hard, easy or liked, some villagers gave the response that there was nothing that was disliked.

(a) Agricultural tasks

All the women surveyed in Mukweva, Ellenvale, Doornhoek and Chitsvatsva, felt that ploughing was hard.

Ploughing was regarded as being the hardest activity as there was little time to rest: villagers woke up at 4am and worked till about 10am, and then from 4pm till 6pm, as it was too hot to work late morning and early afternoon. One household in Chitsvatsva only had 2 cattle - ideally 4 cattle were required. In another case, the wife had to do the ploughing as the husband was working.

Other agricultural tasks (harvesting, weeding and planting) were also felt to be hard by nearly all the women surveyed.

In Doornhoek, 9 out of the 10 women interviewed felt grazing cattle was hard.

Some villagers liked harvesting and ploughing. In Doornhoek, 9 out of the 10 households interviewed liked ploughing, despite it being the hardest task. To explain liking the hardest task, all these villagers said that "we have to like it [ploughing], because if we don't plough we won't survive".

In Doornhoek, 7 out of the 10 households disliked taking cattle to the

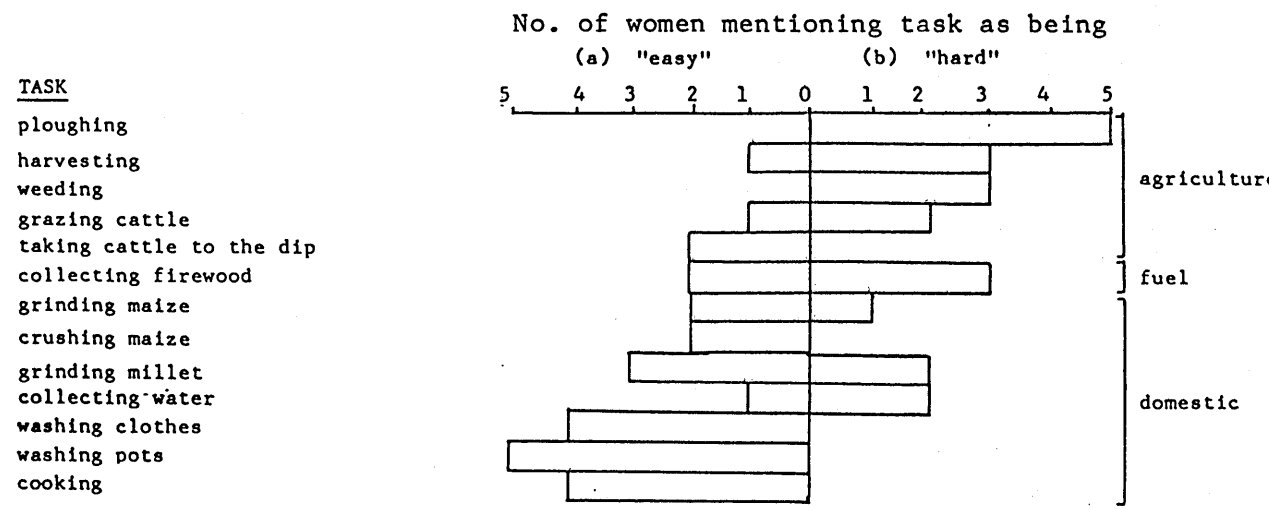


Fig 6.22 Women's perceptions of tasks in Mukweva
(kraal in area with no fuel stress)
(sample size = 5 households)

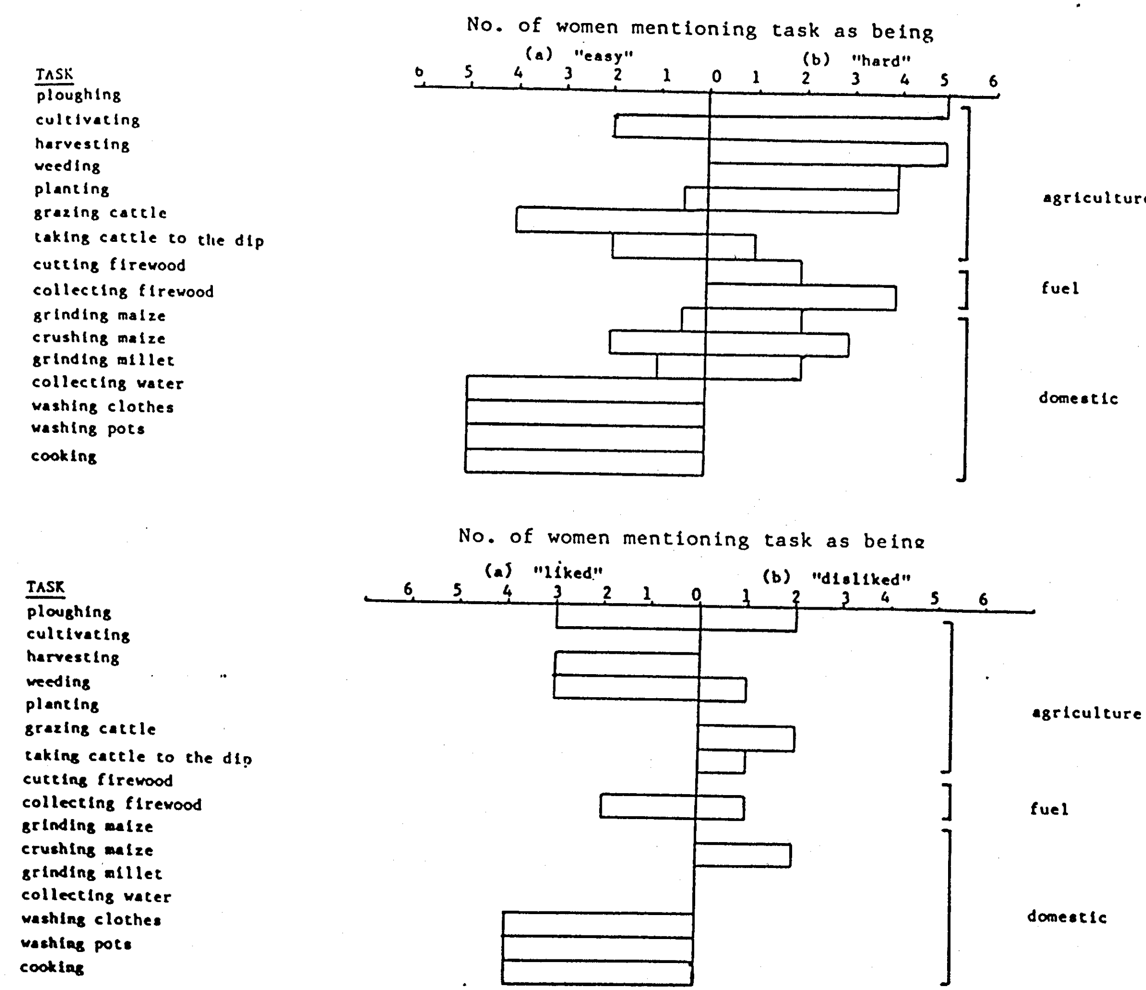


Fig 6.23 Women's perceptions of tasks in Ellenvale
(kraal in area of moderate fuel stress)
(sample size = 5 households)

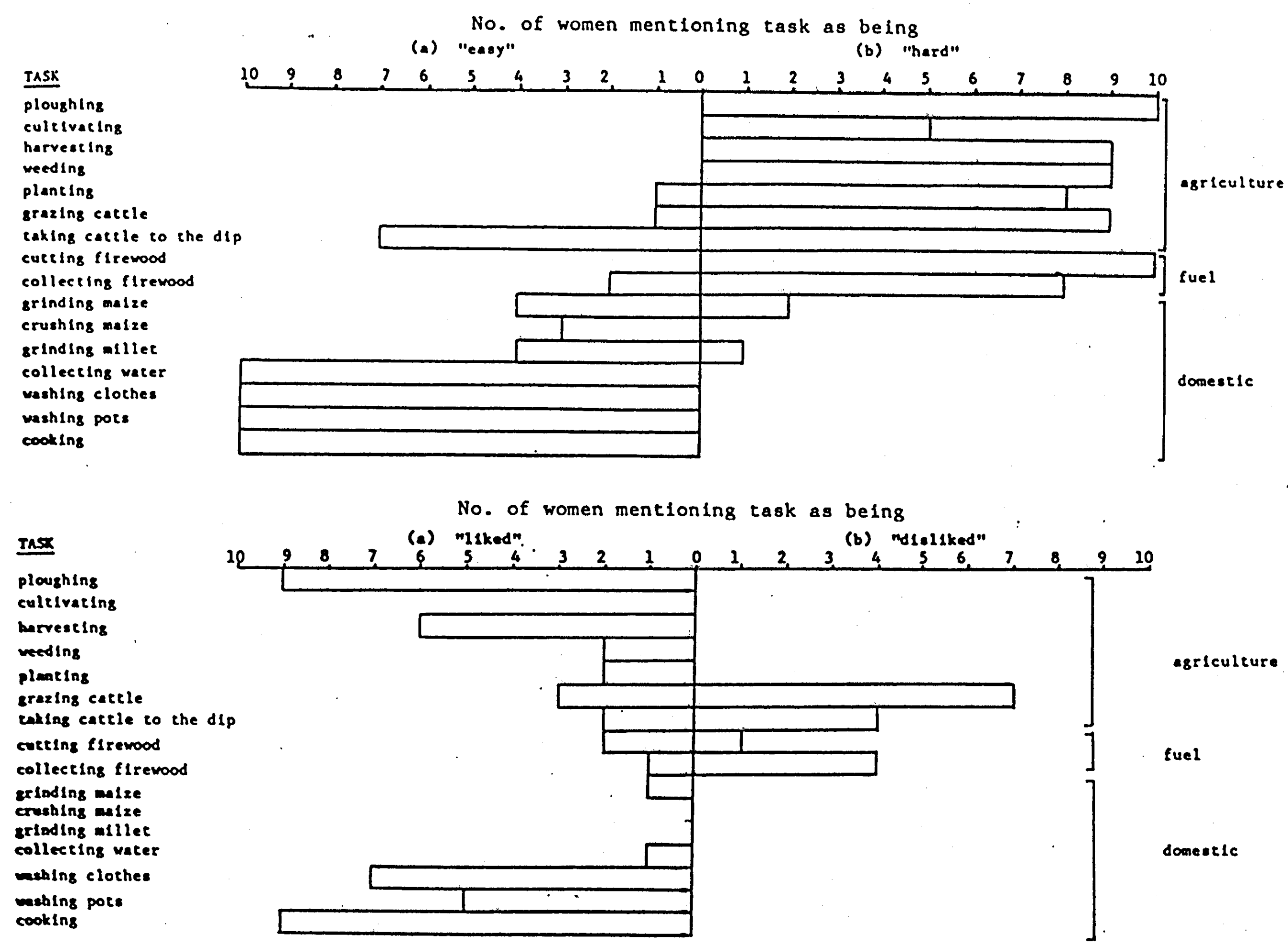


Fig 6.24 Women's perceptions in Doornhoek
(kraal in area of moderate fuel shortage)
(sample size = 10 households)

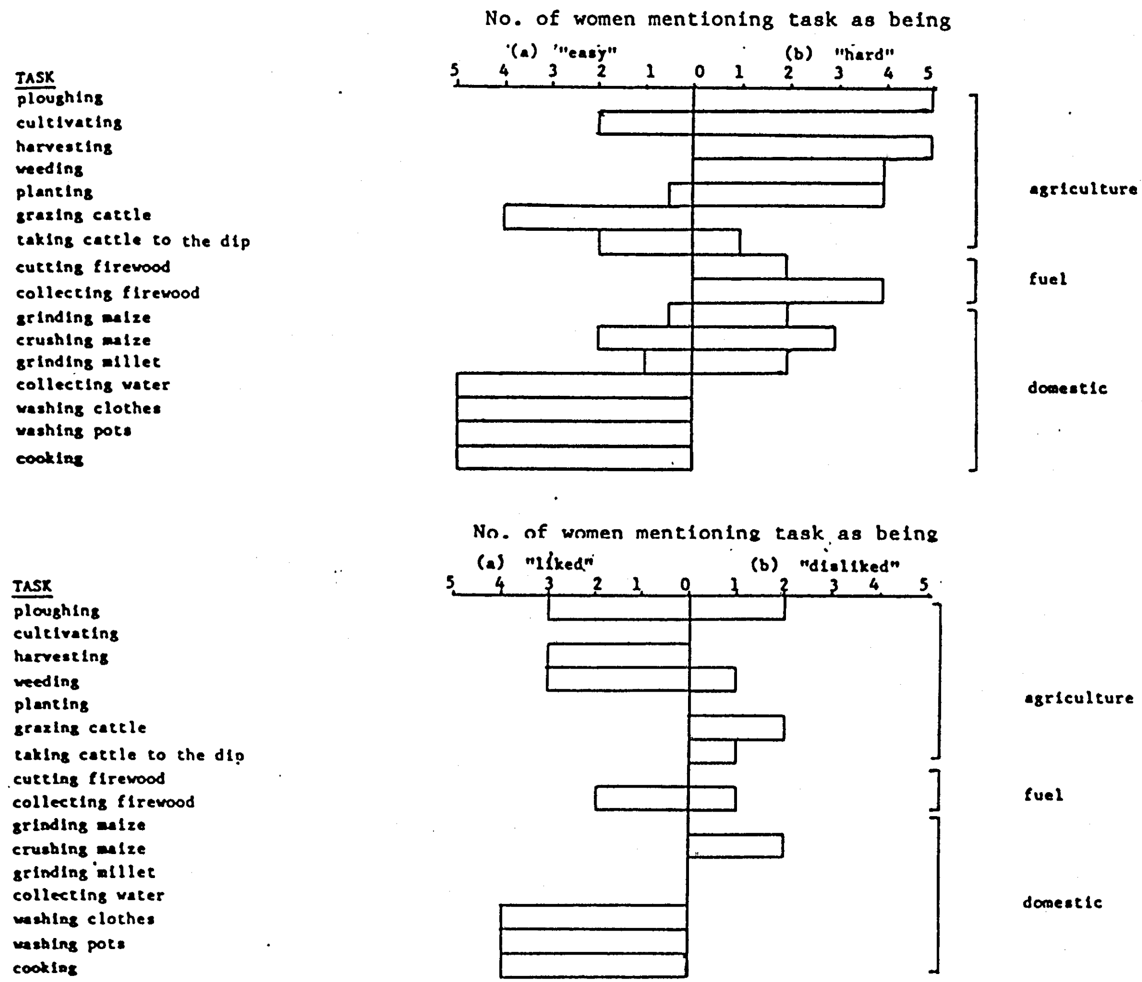


Fig 6.25 Women's perceptions of tasks in Chitsvatsva
(kraal in area of acute fuel stress)
(sample size = 5 households)

dip.

(b) Collecting fuel

Cutting and collecting firewood was likewise considered to be a hard task by most of the women surveyed. All the women in Doornhoek found cutting firewood hard. Three households (out of the five surveyed) in Mukweva felt firewood collection was very hard: two were grandmothers, whilst the third said collecting firewood was hard because her children were too young to help her.

One women in Ellenvale (who had only one small child) said that cutting and collecting firewood was difficult, as she had to bring back the wood on her head; she would have preferred collection via cattle and cart. Other women in Ellenvale said that although firewood collection was hard they had grown used to it.

Some women in Chitsvatsva said they found it hard to dig for roots.

In Doornhoek, women in 4 households disliked collecting firewood.

(c) Domestic tasks

All the villagers regarded domestic tasks such as washing pots, washing clothes and cooking as being easy. However, one villager in Doornhoek did not find cooking very easy because the cooking process had to be carefully watched in order to minimize fuel consumption.

Domestic tasks such as cooking, washing pots and clothes were liked by nearly all the villagers.

6.3.9 Magnitude of daily firewood consumption

Data from two households were discarded: one in Mukweva owing to a very large variation in the moisture content of the wood samples taken; the other in Ellenvale as measurements were taken for only two days.

Daily firewood consumption measured over survey period ranged from 1 - 3kg per capita (or 1.5 - 4kg per adult unit). Generally, slightly less firewood was consumed for the households monitored in Ellenvale compared with Mukweva. Details of the daily firewood consumption (in terms of energy) for all the households surveyed in Mukweva and Ellenvale are given in Appendix F. The highest firewood consumption was generally recorded when beans or meat had been cooked.

The household with the 4-stone fireplace consumed the least firewood per day (the highest PHU was also recorded for the 4-Stone fireplace - see section 6.3.5).

6.3.10 Projected annual cooking energy consumption

Projections of annual energy consumption have been made for households in Mukweva and Ellenvale on the basis of their perceived variation in firewood consumption over the year: firewood consumption was measured by the author in November for Mukweva and December for Ellenvale (see section 6.2.2). Any contribution to cooking fuel by maize cobs was neglected in these projections.

Per capita annual firewood consumption ranged from 450 - 1050kg (700 - 1800 kg per adult unit) in Mukweva (Table 6.20). Annual per capita consumption in Ellenvale ranged from 600 - 1500kg (1200 - 2100kg per adult unit) (Table 6.21).

Table 6.20
Firewood consumption in Mukweva

Household	A	B	C	D
No. of adults*	3	1	2	3
No. of children	3	5	4	3
No. of "adult units" (AU)	4.7	3.3	3.8	4.3
No. of days firewood consumption measured	17	15	13	15
Mean daily firewood consumption (kg)	14.8	11.8	6.3	18.1
Mean daily " " (per capita, kg)	2.5	2.0	1.1	3.0
Mean daily " " (per AU, kg)	3.1	3.6	1.7	4.3
Projected annual firewood consumption (kg)	6302	5025	2683	7708
" " " " (per capita, kg)	1050	838	447	1285
" " " " (per AU, kg)	1341	1523	706	1793
Calorific Value (C.V.) of firewood (MJ/kg)	16.8	16.7	13.0	16.4
Per capita annual energy consumption (GJ)	17.6	14.1	5.8	21.1
Annual energy consumption (per AU) (GJ)	22.5	25.6	9.2	29.4
Stove Type Inside Cooking Hut	IF	IF	4S	IF

KEY:
* persons over the age of 16.
Stove Type - IF: iron frame; 4S: 4-Stones.

Calculations based on this data of annual (per capita) energy consumption for cooking, range from 6 to 22 GJ (Table 6.20 - 6.21). On the whole most of these figures are substantially higher than the average figure of 10GJ per capita calculated using the data from other researchers. Projections of annual energy consumption per "adult unit" range from 10 to 30GJ (Table 6.20 - 6.21).

Table 6.21
Firewood consumption in Ellenvale

Household	A	B	C	D	E
No. of adults*	2	2	1	2	1
No. of children	3	1	4	3	2
No. of "adult units" (AU)	3.5	2.2	3.8	4.4	1.7
No. of days firewood consumption measured	4	8	8	6	5
Mean daily firewood consumption (kg)	10.7	6.5	10.0	10.1	5.0
Mean daily " " (per capita, kg)	2.1	2.2	2.0	2.0	1.7
Mean daily " " (per AU, kg)	3.1	3.0	2.6	2.3	2.9
Projected annual firewood consumption (kg)	5858	4626	5080	4147	1931
" " " " (per capita, kg)	1171	1541	1016	829	644
" " " " (per AU, kg)	1673	2102	1337	1155	1136
Calorific Value (C.V.) of firewood (MJ/kg)	16.7	14.2	16.4	15.7	15.0
Per capita annual energy consumption (GJ)	19.6	21.9	16.7	13.0	9.7
Annual energy consumption (per AU) (GJ)	27.9	29.9	21.9	14.8	9.7
Stove Type Inside Cooking Hut	IF	3S	IF	IF	IF

KEY:
* persons over the age of 16.
Stove Type - IF: iron frame; 4S: 4-Stones; 3S: 3-Stones.

6.4 Discussion

6.4.1 Fuel Situation in the kraals visited

(a) Mukweva kraal

Mukweva appears to be in an area with the least fuel stress. Firewood was reported to be used in all the months of the year by the villagers, whom the author visited. Moreover, the largest stockpiles of firewood (of all the kraals visited) were in Mukweva. Firewood was supplemented by maize cobs when they were available. Animal manure was not used as a cooking fuel, and the maximum reported distance to firewood collection was a 30 minute walk.

(b) Ellenvale and Doornhoek kraals

Ellenvale and Doornhoek appear to be under slightly greater fuel stress: tree cover was sparser, and the size of firewood piles were smaller than those observed in Mukweva. There was no acute shortage - no shift to animal manure had been reported. Firewood was said to be used all year round, and hence, was the major source of cooking fuel. Maize cobs were used as a fuel supplement during August and September, as in Mukweva.

(c) Chitsvatsva kraal

There are a large number indicators that suggest that Chitsvatsva is in an area with an acute shortage of firewood. The area surrounding the kraal had very sparse vegetation; villagers were searching for tree roots as a fuel not just tree branches; animal manure was used as a cooking fuel; and the firewood piles for use in the rainy season were considerably smaller than those observed in Mukweva, Ellenvale or Doornhoek. In addition, some villagers did not have enough firewood to last them through the year. Two (out of the five households surveyed) bought firewood; one bought all the wood required whilst the second bought wood to supplement firewood that had been collected. These purchases means that in Chitsvatsva firewood can no longer be regarded as a "non-commercial" fuel.

Animal manure was used by all the households in Chitsvatsva as a cooking fuel for a minimum of 3 months of the year and in some households up to 7 months (this may be an upper limit owing to the incidence of rain). Villagers were prepared to use manure as a fuel despite their dislike of the smoke and smell of burning manure.

6.4.2 Change in types of cooking stove used by villagers

The most important finding is that in Mukweva, Munondo, Ellenvale and Doornhoek there has been **a major shift from the traditional 3-Stone fireplace either to a user built '4-Stones' or to an iron frame 'stove',** with the vast majority of the villagers adopting the iron frame. This shift has also taken place in Chitsvatsva and the kraals close to St. Elim Mission.

It is **culturally significant** that **both the iron frame and 4-Stones were placed on the traditional fireplace at the centre of the cooking hut. Hence the social aspect of gathering around a fire had been retained.** In addition, the height of both these types of new stove was similar to that of the traditional 3-stone fireplace - **the transfer to new stoves has thus taken place without displacing traditional cooking postures.**

The iron frame may be based on the 4-stone fireplace: the earliest report of the iron frame being purchased was 1961, whilst the 4-stone fireplace had been in use for many years previously.

Villagers changed to these types of cooking 'stove' despite additional costs involved: 4-Stones require a morning or so to construct, and then have to be repaired every four to six months, while the iron frame stove costs Z$3-5. The cost of the iron frame represents around 13-20% of the average (estimated) per capita rural income of Z$ 38 per year.

According to women in Ellenvale, Doornhoek, and Chitsvatsva with whom the author spoke, changing to the new stoves meant an increase in fuel consumption: the 4-Stones was estimated to use one-and-a-half to twice as much firewood as 3-Stones, whilst the iron frame was said to use between 1.5 to 3 times as much firewood as 3-Stones. It would not be unreasonable to expect the women concerned to be aware of such significant increases in cooking fuel consumption. In addition, the PHU measurements suggest that the iron frame consumed more firewood than the 3-stone fireplace, but enabled food to be cooked more quickly, owing to the higher burning rates of the wood.

Despite its relative fuel efficiency none of the villagers thought that the 3-Stones had any advantages: the primary reason why the two women in Doornhoek continued to use 3-Stones was lack of money to purchase an iron frame.

6.4.3 PHU's of stoves: field measurements

Field measurements gave PHU's of around 10% for the iron frame. Follow-up water boiling tests in the laboratory undertaken at the Open

University on the iron frame with a fuelbed/pan distance of 10cm gave maximum PHU's around 14%. In the field, the distance between the fuelbed and pan for the iron frame was larger and hence its PHU would be lower. Given this geometrical arrangement the iron frame would have a higher fuel consumption than the 3-stone fireplace. An additional finding was that the iron frame is extremely sensitive to side winds resulting in the flames moving from under the pot and reducing the heat transfer to the pot (see Chapter 5).

In the field, PHU's (excluding evaporated water at BP1) of 15% and 19% were obtained for the 3-stone fireplace. Laboratory tests by Brattle (1979), Joseph and Shanahan (1981) and Prasad (1980) have indicated efficiencies ranging from 12 - 30 %, for the 3-stone fireplace, depending on factors such as wind speed, size of the firewood, height of the pot above the fire, and so on (see also chapter 4). Data from tests in the field would be expected to be lower, and is not inconsistent with that obtained from laboratory tests.

The highest values of heat utilization measured by the author in the field , viz 34%, was obtained with the 4-stone fireplace, which fell to 11% when a clay pot was used instead of a metal pan and took two-and-a-half times as long to heat the water. However, this would not be unexpected since clay is not as good a conductor of heat as a metal, and substantially more water would be evaporated during heating; the energy associated with evaporated water was ignored in the calculation of heat utilization. Both these would increase the time to heat the water (compared with the metal pan) and reduce the calculated value of heat utilization. The value of the PHU measured with the 4-stones is not in agreement with the perceptions of the villagers in Doornhoek. This requires further investigation.

6.4.4 Villagers rationale for adopting new types of cooking stove

Village women in Chitsvatsva perceived a **tripling in fuel consumption for the iron frame compared to the 3-Stones.** As discussed earlier, the costs of fuel collection in Chitsvatsva were high (villagers burnt animal manure and were involved in digging for roots). Therefore, it is suprising that these users were willing to sacrifice fuel economy and bear the especially high labour cost for the benefits of the iron frame.

It will be argued that the reasons for the change from the 3-Stone fireplace are as follows: Zimbabwean women provide labour for agriculture as well as for cooking and fuel collection. As agricultural labour demand varies over the year, increases in this workload is felt more acutely during the period of peak labour demand. The busiest time of year is from November to April when the women prefer to cook quickly and have transferred to the iron frame or 4-stone fireplace.

Though time is saved because cooking can be done more quickly, this has to be offset against the additional labour time spent in fuel collection owing to the relatively higher fuel consumption of the iron frame. However, since fuel is collected during the slack season whilst fast cooking is required in the peak agricultural season, higher fuel consumption costs incurred are affordable, because they are borne during the part of the year when labour is not in high demand. It is crucial to note that the villagers are able to do this because they can collect and store sufficient firewood during the slack season to last them through the busy months.

One effect of this increased workload would be to decrease the amount time available for day to day activities such as cooking. A stove which enabled cooking to be done more quickly would, under these conditions be highly desirable.

Since agricultural labour demand varies over the year, increases in the workload of women would be felt most acutely during the period of peak labour demand. The busiest time of year is from November to around April: in these months women were able to save time by heating several pots simultaneously rather than one pot at a time. This has resulted in transferring to the iron frame (or 4-Stones) even in an kraal with an acute fuel shortage. This correlates with the major reason given for changing to 4-Stones or the iron frame, namely the change enabled the users to cook many things at a time (ie faster meal preparation): for the iron frame wood was calculated to be burnt at power outputs of up to 21kW; this would contribute to a speedier cooking time.

Other additional user perceived benefits brought about by the change to the iron frame were less smoke, a modern 'image', more space heat and stable pots, which no doubt added to its attraction.

6.4.5 Innovation diffusion

In terms of Roger's (1983) theory of the diffusion of innovations, 4 out of the 5 elements governing diffusion were favourable for both the iron frame and 4-stone fireplace. As the iron frame was perceived to have a many more advantages than the 4-stone fireplace it would be expected to have a higher level of diffusion - this was borne out in the villages visited.

In terms of **relative advantage**, the iron frame had a number of advantages compared with the traditional 3-stone fireplace (e.g. faster cooking, status, greater space heat); the 4-stone fireplace was perceived only to have the advantage of allowing several pots to be heated simultaneously. However, both the iron frame and the 4-stone had disadvantages: the iron frame cost Z$4 and used more fuel; the 4-stone fireplace took half a day or so to construct and then had to be repaired every 6 months or so.

Both the new stoves were **compatible** with existing values and practices: the technical and social functions of the 3-stones had been retained whilst, traditional cooking postures had not been disrupted.

A low level of **complexity** was evident for both the new stoves as they were simple to use and did not have any baffles or complicated controls.

Both the 4-stones and iron frame had a high degree of **visibility:** the iron frame was regarded by a number of village women as conferring a modern image hence a visibility would be desirable.

The iron frame has been observed to be very widely disseminated in Zimbabwe (Ascough, 1981:pers comm; McGarry, 1982:pers comm): the high level of ownership of the iron frame in these three kraals is not unrepresentative of the rest of Zimbabwe. This is not unexpected as migrant labour and the division of labour in villages are not restricted simply to the kraals visited. Additional survey work needs to be carried out to document the exact extent of the dissemination of new stoves and the users perceptions of benefits.

In summary, fuel efficiency does not appear to be the main determinant of choice of cooking method in these villages, hence stove designs are more likely to be acceptable to users if they also take into account factors such as convenience, 'image', provision for space heat etc.

6.4.6 Applicability of the findings to other countries

Changes in rural agricultural labour demand through the year which affected domestic activity are not restricted to Zimbawe.

Using survey data from 25 African villages Schofield (1974) found that as more female labour is spent in the agricultural work there is a decrease in time spent in domestic activity. This had several other consequences:

> "**cooking practices change,** especially where quick easy-to-prepare meals (usually of the nutritionally poorer staples such as cassava) are produced once a day or in bulk and vitamins are destroyed by food kept simmering in the pot. Intra-family distribution of food is affected, where children are asleep before the daily meal has been prepared and women have no time to either prepare special foods or effect the proper distribution of foods. Food gathering may be inhibited so that some types of food (e.g.green leafy vegetables) are suddenly excluded from the diet. House cleaning, essential in overcrowded and insanitary conditions, may be inhibited. **Fuel and water collection is constrained by lack of time.** Finally mothers devote less time to the care of their children who are left in the charge of other siblings or elderly grandparents (Schofield, 1973) (emphasis added)

In a field study in highland Peru, Skar (1982:74) found that as the time spent by women in gathering fuel increased, they spent less time in cooking.

The finding that stove users rated features such as faster cooking and convenience as more important than fuel savings has also been reported in Indonesia and Sri Lanka (Joseph 1982 pers comm), and in Senegal (Evans 1982 pers comm). This may be a result of the increasing burden on rural women. These findings suggest that **stove programmes** in Zimbabwe (and possibly in other developing countries) will **have to take into account the perceived needs of users. This is of crucial importance since 'improved' stove programmes tend to emphasize fuel savings and reduction in smoke above all else.**

6.4.7 Patterns of fuel collection and consumption

(a) Fuels gathered

Firewood is the main source of cooking fuel in all the kraals visited; maize cobs are used as a fuel supplement when available. In addition, use of charcoal as a cooking fuel is non existent. This is in agreement with the field findings of other researchers (e.g. Whitlow, 1979a; Hosier et al, 1982) for other parts of Zimbabwe. Hosier et al found that around 40% of the total of 194 rural households surveyed (in 10 Communal Lands) said they used "crop residues", whilst Whitlow reports a total of 24 out of 30 households surveyed (in 2 Communal Lands) used maize cobs.

Fuel collection in the kraals visited is predominantly done by women and girls collecting by headload, whilst men and boys use cattle drawn "scotch carts". Similar survey findings have been reported for other parts of Zimbabwe (Hosier et al, 1982).

(b) **Fuel collection**

Firewood collection is structured by seasonal variations in agricultural labour demand and weather conditions.

A similar seasonality of firewood collection in 5 Communal Lands is reported by Whitlow (1979a): collection in the dry season took place in order to stockpile wood for use during the rainy season. According to Whitlow (1979), though firewood collection took place in the rainy season, much less time was spent in gathering - a few hours per week, compared with a few days per week in the dry season.

Whitlow's study suggests that whilst the villagers in the present study said they did not collect firewood in the rainy season, some limited gathering is likely to have taken place - this is supported by villagers in Ellenvale observed bringing firewood during the November.

Overall, these patterns of collection means that firewood collected in the slack season had to be sufficient to last through the rainy season.

The patterns of fuel collection in all the kraals are similar, with the exception of the use of animal manure as a cooking fuel in Chitsvatsva.

(c) **Women's perception of fuel gathering vis-a-vis other activities**

Concern with the increasing burden on rural women has focussed on their role in gathering cooking fuel. This perception of women's role in

Zimbabwe is one-dimensional and ignores the multi-faceted nature of womens work. Since one of the major reasons given for the change by rural women interviewed in the survey for changing to stoves which allow faster cooking (despite the perceived increase in fuel consumption which would mean more time spent in gathering fuel) it is informative to look at the reasons that the workload of village women may have increased (see also Fig 6.26).

Muchena (1981) argues that this increase in burden has occurred primarily for three reasons:

Firstly, the effect of migrant labour owing to men going away to work in towns or mines. According to field research in two Communal Lands, carried out by Muchena (1981), out of a sample of 90 women, 44% of the women were the head of the household for the whole or part of the year. In addition, 51 out of 90 (i.e. 57%) women interviewed in the research undertaken in one of the Communal Lands said they were ploughing by themselves using hoes, whilst in the other more women were involved in ploughing activities than men. Hence, **women were doing work traditionally regarded as being "men's tasks".**

Weinrich (1975) observed that women provided 40% of the labour force amongst peasant cultivators, as men were away working in urban areas.

Muchena (1981) found that women's main problems with ploughing were

> "the lack of adequate or proper implements, **lack of time,** and **sheer physical effort in the field** using hoes or pushing ox-ploughs" (emphasis added)

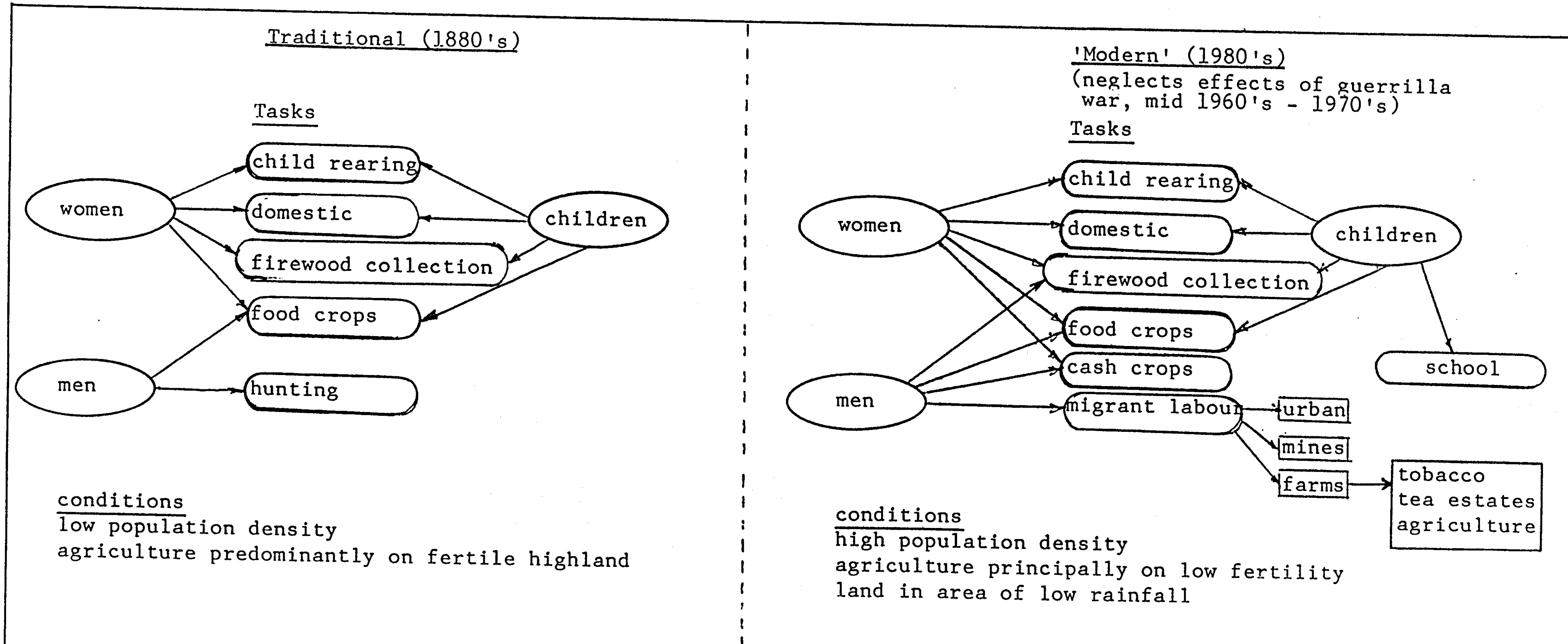


Fig 6.26 Division of labour of African population in rural Zimbabwe (a historical perspective) (adapted from Weinrich, 1975; Kay, 1975; Palmer, 1977; Ndlela, 1981)

In addition, women consistently mentioned the time and the **"back breaking effort"** required in weeding. At the time of Muchena's survey the workload of these tasks was accentuated as the survey was carried out during the first year of free primary education for children.

Around half the respondents in Doornhoek said that ploughing was the activity they disliked the most, the other half said it was the one they liked the most. The reason given for liking ploughing was that villagers <u>had to like it</u>, because if they did not plough they would not survive. Hence, a sense of fatalism may have developed. Some women said that they regarded fuel collection as being hard, but they were used to it; perhaps displaying a similar sense of fatalism.

Most of the women in Doornhoek did not like grazing cattle. This may be because this activity places an additional strain on women during the time of peak labour demand: Weinrich (1975) observed that herding duties are seasonally distributed, and four-fifths of the total time in herding occurs between October and May" when workers are ugently needed in the fields". Whilst herding is traditionally undertaken by men and boys almost one-third of the time spent in herding was provided by women as men were away as migrant labourers whilst children were at school.

Secondly, as a result of the introduction of cash crops which not only increased the agricultural workload of women but also reduced their status: women are traditionally concerned with food crops and the routine aspects of agriculture eg. planting, weeding, harvesting and processing. These tasks are also done by women for cash crops, even though these crops are owned by men. Cash crops were prestigious since they generated income, relied on new farming methods, hybrid seeds and so on.

Thirdly, rural women were constrained by the lack of agricultural information which could be given by extension workers leading to increases in their productivity and lessening their workload: in the Communal Lands extension services are directed at Master Farmers, and women Master Farmers are an exception (Weinrich, 1977). Muchena (1981) argues that this neglect was primarily due to social values whereby planners regarded women

> "essentially as domestic workers, whose primary responsibility should be in the home and not in the fields" (Lele, 1975, quoted in Muchena, 1981).

Perceptions of the difficulty of gathering firewood in Mukweva are not coherent. Firewood collection was regarded as being "hard" by women in 3 households, and "easy" by women in 2 households. Of the 3 who had problems, one found firewood collection hard as her children were too young to help her: this villager said that she tried to save fuel by putting water on the firewood at the end of cooking.

Possibly because Mukweva is in an area under less fuel stress than the other two sites, women in Mukweva are not particularly careful about conserving fuel: it is startling to note that for all four households only half the total firewood consumed was utilized in cooking (Table 6.12), the other half simply burned away! This is a cause for concern, since these measurements were taken in the hot season when space heat would not be required. Further work needs to be done to confirm this, as these measurements were only conducted once for each household.

In Doornhoek, 8 out of 10 respondents found firewood collection hard, as did 4 out of 5 respondents in Ellenvale.

Firewood gathering is not generally disliked: in Doornhoek and Ellenvale **more that half the women did not mention firewood collection at all** in this respect. Only 5 out of the 11 households were interviewed in Ellenvale, hence these findings may be atypical; though the perceptions in terms of attitudes to firewood collection are not disimilar, to those in the nearby kraal (Doornhoek) where 10 out ot the 11 households were interviewed.

In Chitsvatsva, no household disliked firewood collection despite it being hard and only one villager said she disliked collecting animal manure for fuel. Agricultural tasks such as ploughing, weeding, and planting were disliked more. This is unexpected since firewood collection is difficult. Again though the sample size is small these perceptions are not disimilar to those found in the other two kraals.

In general, activities which were the hard were disliked, whilst those regarded as the easiest were liked. Cooking, washing pots and clothes were generally regarded as being the easiest and also the most liked, whilst, activities such as ploughing and weeding were the most disliked.

Hosier et al (1982) also report that village women have a number of burdens, and not simply those related to fuel collection. Hosier asked a number of households to rank the difficulty of obtaining "seven fundamental necessities": housing, education, health care, food, fuel, and transport. Tranport, fuel and health care were regarded as being the three most difficult needs to obtain, by half the respondents - Hosier points out that some respondents "tended to give answers biassed toward the fuel alternative on a fuel supply questionnaire".

6.4.8 Fuel consumption and projected levels of annual consumption

One source of error in energy surveys is the very act of measuring fuel consumption, since the monitoring would be expected to draw attention of the households to their fuel use. It is not clear whether this would increase or decrease fuel consumption.

In a fuel survey conducted in Burkina Faso (formerly Upper Volta) (Wood, 1981, 1982) it was observed that the average consumption fell by 6% in the second week of observation (after a weeks gap) - the total variation ranged from an increase of 11% to a decrease of 25%. This variation may simply have been a reflection of different quantities or types of food being cooked. In Mukweva, data on the number of people and food being cooked was gathered during the survey period, hence, variations due to these factors can be taken into account.

As most of the firewood is collected during the dry (slack) season any methodology attempting to determine the annual **firewood consumption** by only measuring the **firewood collected** for part of the year could be open to considerable error. The methodology used in this study to determine daily firewood consumption measured the depletion per day of a known quantity of firewood left outside the cooking hut. Errors would be introduced if wood from elsewhere was used for cooking, or if another household used wood from this pile. The latter is believed to be unlikely as each of the households (in Mukweva and Ellenvale) had large firewood piles of their own.

Errors would be introduced in projections to annual consumption if the **variation of firewood consumption over the different seasons** is not taken into account.

As measurements of firewood consumption were carried out during hot weather, very little consumption owing to space heat requirements would be reflected in these data.

Projected levels of annual (per capita) firewood consumption range from 450- 1540kg (Table 6.4). The highest figures are outside the range obtained by other researchers. The sample size (and data taken in Ellenvale) are too small to enable meaningful comparisons between the level of firewood consumption in Ellenvale and Mukweva.

In energy terms, projections of the daily firewood consumption give figures of annual energy consumption per capita ranging from 6 to 22 GJ. The mean annual projection of cooking energy consumption for Ellenvale was 16 GJ per capita.

Recent work by Hosier _et al_ (1982) gives annual energy consumption as 1.5 m^3 (equivalent to 15 GJ per capita). This is close to the figure of 16 GJ obtained in this study, and suggests that the commonly used estimate of 10 GJ may be an underestimate of the true consumption of firewood.

A study on the required afforestation in Zimbabwe (Whitsun Foundation, 1980) calculated that 27 out of the 50 districts in Zimbabwe had an acute deficit of firewood i.e. a deficit of more than 4.0 m^3 per family (of 8 people) per annum, and 13 districts were in the situation of a firewood surplus. This was based on population data and the assumption that annual per capita firewood consumption was 1.0 m^3 and wood growth at between 0.8 and 1.0 m^3. If data from the present study is used, i.e. firewood consumption is 16 GJ (1.6m^3) then only 3 districts have a firewood surplus.

6.4.9 Practices affecting fuel consumption

The following findings are based on measurements of firewood consumption in cooking three consecutive meals on only one occasion for one household in Ellenvale and four households in Mukweva. In effect, considerable caution has to be exercised in generalizing from this data. **However, if these measurements are representative of cooking practices** there are important consequences for strategies to reduce firewood consumption. These findings suggest that **it may be possible to make considerable savings in firewood consumption simply by altering cooking practices.** In Mukweva, around half the firewood consumed was simply allowed to burn away. This practice may have served a social function, with the family eating around the fire. In Ellenvale (an area of greater fuel stress) only **one-fifth** of the firewood was consumed after the cooking had been done.

It is likely that villagers would reduce the amount of firewood "wasted" by tending the fire with more care in response to a growing shortage of firewood: villagers under fuel stress put water on the burning firewood at the end of the cooking.

A low cash income appears to be another factor which can affect fuel consumption. Some villagers in Ellenvale went without breakfast because they could not afford to buy tea. Conversely, the villager who cooked sadza and relish in the morning in response to this would consume more fuel than if she was simply boiling water for tea. The practice of leaving the fire burning at the end of a meal in order to conserve matches would also increase fuel consumption.

6.5 Deforestation in Zimbabwe

6.5.1 Impact of agricultural practices on deforestation

Kay (1972, 1975) and Whitlow (1979b) argue that rural deforestation has arisen due to changes in land use patterns by a growing African population engaged in subsistence agriculture:

> "as the population increases so the area under cultivation is extended to produce more food ... prolonged cultivation (will result) in declining yields , and so the area under cropping is extended at the expense of the grazing lands. The areas taken over for cropping ... are likely to be characterized by less fertile soils and steeper slopes, that is marginal lands" (Whitlow, 1979b)

Vicious cycle effects are brought into play as the ensuing deforestation and shortage of firewood decrease crop productivity further. Firstly, deforestation will contribute to soil erosion as it is associated with an increased incidence of floods. Secondly, through the diversion of animal manure as a fertilizer from the fields to be burnt as a cooking fuel.

An indication of the pressure on agricultural land was obtained from an analysis of aerial photographs of Zimbabwe for the period 1972-1977 (Whitlow, 1979b): in nearly one-fifth of the Communal Lands the proportion of cultivation was **greater than half** the available land. Using the data from these photographs to calculate the cultivated area per person and compare with estimates for 1900 - the latter data is estimated for the whole population of Zimbabwe since the present day Tribal Trust Lands were in their inchoate form - he concludes that

> "there has been a considerable extension in the area under cultivation...but more significantly, this has involved an increase in area of land cropped per person, a feature which is symptomatic of a subsistence cultivation system under pressure and attempting to maintain production levels in the face of declining soil fertility." (Whitlow, 1979b)

6.5.2 Political factors

In order to understand how the problems of soil erosion and deforestation arose in Zimbabwe it is necessary to adopt a historical approach. A detailed study of this nature is outside the scope of this thesis. However, much has already been written which sheds light on the root causes of these ecological problems (e.g. Arrighi, 1966, 1970; Loney, 1975; Moyana, 1975; Ndlela, 1981; Palmer, 1977; Riddell, 1978), and summarized below:

Lands occupied by a growing African population were forcibly seized by European settlers in the late 1890's. Land assigned to the African population (initially termed "Reserves", then "Tribal Trust Lands" - or TTL's - and now "Communal Lands") was of low quality and signs of soil erosion were evident as far back as the very early 1900's (Palmer, 1977). Successive Colonial Governments systematically neglected conditions in African areas, forcing Africans to enter the cash economy, primarily as migrant labourers to work in the mines and towns (Ndlela, 1981; Palmer, 1977) - one result of the increased burden on African women left behind in the rural areas has been their receptivity to cooking stoves which enable cooking to be done more quickly than their traditional 3-Stone fireplace even at the cost of higher fuel consumption.

By the 1920's and 30's signs of serious land degradation were becoming increasingly apparent in many African areas (Ndlela, 1981:194). Whilst pressure on land due to the African population in the reserves increased in the 40's (Ndlela, 1981), in the European areas almost two-thirds of the best land in the country was left unused (Riddell, 1978): "by 1943 63% of the reserves were classified as 'overpopulated' and 50% were carrying excessive cattle stock" (Ndlela, 1981; Arrighi, 1970). Needless to say, the situation in the "TTL's" became even more acute by the 60's and 70's (Cross, 1977): by this time successive Land Apportionement Acts had effectively allocated 47% of the land set aside for farming to the Europeans (4% of the population) and 57% to the Africans (96% of the population) (Ndlela, 1981).

Based on an analysis of changes in woody vegetation from aerial maps (1963 - 1977), it was observed that there had been **no overall change** in the extent of woody vegetation cover (Whitlow, 1980). Extensive tracts of woodland remained. However, these were confined to areas of "steeply sloping, inaccessible terrain and/or sparsely populated regions". In addition, decreases in woody vegetation were mainly recorded in areas of "high to moderate population densities" particularly in the Communal Lands.

In effect, peri-urban deforestation has occurred as a result of demand for firewood by urban Africans. Most importantly, Whitlow (1980) concludes that rural deforestation since the early 60's had resulted from demand for agricultural land, not firewood gathering activities: shortages of firewood being a consequence of deforestation.

In summary, these studies highlight the political and economic roots of deforestation and soil erosion, hence intervention strategies need to address themselves to issues beyond technical fixes. In addition, different responses to rural and urban deforestation will be required, as the major causes are different. Programmes of afforestation and reduction of demand for firewood are more likely to be successful in urban areas than in rural areas where forest land may come under pressure to grow crops. Strategies designed to cope with rural deforestation will need to consider the dynamics of demand for agricultural land rather than just simply growing more trees or reducing the demand for firewood.

6.6 Conclusions

According to villagers in the study sites visited there are seasonal variations in cooking practices, the provision of food, and fuel collection and the level of consumption of traditional cooking fuels. These effects appear to be a result of seasonal variation in demand for agricultural labour, and changes in both climate and weather over the year.

During the months of peak agricultural labour demand there is less time for other tasks; less time is spent in cooking during these months using the iron frame or 4-stone fireplace. In addition, firewood is generally not collected owing to the heavy agricultural workload, (as well as the difficulties of carrying and burning wet wood). Firewood is collected predominantly in the agriculturally slack season (and stockpiled for use in the rainy season) and supplemented by maize cobs (when available); firewood and maize cobs were used in all the kraals visited even though they had varying levels of firewood scarcity. Cooking is done at a more leisurely pace during the slack months.

Climatic changes affect both the level of fuel consumption and the type of fuel that can be used. In the cold months, firewood consumption increases because of the need for space heat. Sun dried animal manure was used in the kraal in an acute firewood shortage, but restricted to the months when the manure was not washed away by the rain.

Animal manure burnt for cooking was not taken from the cattle enclosure but collected from around the homestead. This suggest that manure which previously had marginal utility was burnt. However, if firewood supplies become further depleted, these villagers may have to increase both their consumption of manure and level of firewood purchases.

In all the villages visited there has been a significant shift from the traditional 3-stone fireplace either an iron frame stove or 4-stone fireplace; the vast majority of villagers having adopted the iron frame. A similar shift in cooking stove has been reported for other parts of Zimbabwe. These changes appear to have taken place despite the extra costs involved: 4-stones take about half a day to construct and then repaired every 6 months or so; the iron frame costs around Z$4 and was perceived to use significantly more fuel than 3-stones. The major reason for this is the greater fuelbed/pan distance of the iron frame. The fuel consumption of the iron frame could be reduced by decreasing the distance between the fuelbed and cooking pot.

The major reason for the change to new cooking stoves appear to be the desire to cook quickly when rural women are busy in agriculture; Zimbabwean women provide labour for agriculture as well as for cooking and fuel collection. One prediction of these findings is that both solar cookers and hay boxes will meet with resistance from the rural African population owing to the slow cooking speed of these devices.

Historically, a number of factors have served to increase the workload of rural women (e.g. the introduction of cash crops, the provision of formal education for children and male migrant labour away from the rural areas). These changes are rooted in the colonization of Zimbabwe, initiated in the 1890's, whereby a growing African population was forcibly removed from the fertile highlands and moved onto marginal land. Consequent requirements for food produced in African areas led to soil erosion and the destruction of forest cover. Hence rural deforestation has its origins in the colonial political economy.

Forestry programmes per se initiated in the African areas are likely to fail for two reasons. Firstly, it will only be a matter of time before land used for growing trees will come under pressure for agriculture. Secondly, the labour requirements of tree species such as Eucalyptus (promoted by the Forestry Commission in Zimbabwe) compete with agricultural labour. Since women in these areas already appear to be very busy in agriculture and have adopted time-saving stoves, it is unlikely that any spare labour capacity exists for them to take part in planting and tending tree crops.

The above analysis suggests that intervention strategies to cope with deforestation in rural areas involves more than the introduction of fuel efficient stoves and forestry schemes, but have to be part of a broad based rural development package. A three-fold strategy to tackle rural deforestation consisting of increasing agricultural productivity, forestry programmes and reducing firewood consumption is detailed below.

Agricultural productivity can be increased in Communal Lands through investment in technical inputs (e.g. increased use of fertilizer, irrigation, increased commerical energy inputs). Employing female agricultural extension agents would facilitate communication with village women. Another way of increasing productivity is by resettling villagers onto fertile land. Though, resettlement may initially mean stress on forests, since wood is required to build huts. These measures may reduce the incidence of male migrant labour to the urban areas, mines and European farms and so further aid productivity in the rural areas as well as lessen the workload on village women.

Forestry programes need to take into account the competition between labour required for food and fuel production. Schemes incorporating agroforestry are more likely to be successful than reforestation alone. Involvement of the villagers could usefully aid these programmes of rural development by identifying desired tree species as well as articulating user needs: village women in Kenya were interested in multi-purpose trees (e.g fruit, firewood, medicinal) rather than just for firewood (Thrupp, 1982, 1983). In addition, seedlings were requested by women and bought by tree nurseries for planting in arid areas - this programme had the added advantage of allowing the rural poor to usefully engage in income generating activity.

Firewood consumption can be reduced in a number of ways: shifting from clay to metal pans; subsidizing matches; increasing fuel consciousness of villagers. Another method would be to design and promote fuel efficient stoves. However, fuel economy did not appear to be the main determinant of choice of cooking method in the villages visited. Hence, stove designs are more likely to be acceptable to users if they also take into account the key features identified from the measurements of PHU (such as the ability to bring 2-5 litres to boiling point in about 10 minutes), fuel efficiency and the following:

- allow up to 4 pots to be heated simultaneously;
- provide space heat (only required a few months of the year);
- produce little smoke;
- have a long lifetime;
- not cost more than about Z$4;
- and have a modern "image".

Given the scale of the problem of food and fuel, it would be expected that the rural development programme described above would first be carried out in areas with an acute shortage of firewood.

Chapter 7

Conclusions and Future Work

Chapter 1 detailed six propositions which were examined in this thesis. These propositions, the conclusions reached, and further work which is required are presented in this chapter.

(a) there is a shortage of cooking fuels in rural areas of developing countries

There appears to be a shortage of traditional cooking fuels in a number of developing countries. However, the level of this shortage varies considerably between and within developing countries. Further work (especially micro level surveys) needs to be carried out to provide detailed evidence of cooking fuel scarcity and adaptations in developing countries.

(b) deforestation is caused by the rural population in using fuelwood for cooking and exacerbated by population growth

In developing countries population pressure is believed to have placed increasing stress on agricultural land and forests to meet the dual needs of food and firewood. However, when examining deforestation in detail, it is apparent that there are a number of other contributions to the destruction of forest cover, e.g. timber exports, road construction, not just the demand for agricultural land or the collection of traditional cooking fuels.

A historical analysis is invaluable in understanding the dynamics of land degradation as well as to highlight the complexity of issues involved. In Zimbabwe, the processes of land degradation, deforestation and the ensuing shortage of firewood were set in motion as far back as the late 1890's when the Africans who had settled on the fertile highveld were pushed onto marginal land to eke out a meagre existence and provide labour for the Colonial economy. Pressure for food production on poor land has led to the clearance of forest and marginal land for agriculture. Further pressure on Zimbabwean forest cover has arisen because of the shift from the traditional 3-stone fireplace to the iron frame stove; the latter because of its greater fuelbed/pan distance is a much less efficient cooking device. Elements of a successful rural intervention strategy must encompass broader issues such as land tenure, inputs to increase crop productivity, as well as questionning the role of migrant labour in the economy.

(c) traditional stoves and fireplaces are highly inefficient; (d) traditional stoves and fireplaces are causes of ill health because of smoke production

Traditional stoves and fireplaces are widely believed to be inefficient as modes of cooking, and unhealthy because of the smoke they produce inside the kitchen. Designing and promoting stoves that are highly efficient (and often smokeless) were believed to hold the promise of reducing firewood consumption considerably.

Defining and measuring the "efficiency" of cooking using firewood is beset with difficulties. Most stove testing has involved heating water to simulate cooking. PHU's obtained depended on parameters such as the fuelbed/pan distance, moisture content of the wood, fuel type (e.g. firewood, crop residues or animal manure), wind, and the power output.

Fuel consumption in the field depends not only on the "hardware" (ie stove, fuel type, cooking pot material) but also on the "software" such as the skill of the cook and cooking practices. Hence, cooking is a system involving a number of components all of which have to be considered in reducing fuel consumption rather than just the "stove".

Other contributions to fuel consumption arise from villagers using the stove (or fireplace) for space heat or as a social focus. These manifold functions of traditional designs have yet to be integrated into "improved" stove designs.

In areas of fuel stress, villagers would be expected to reduce their fuel consumption by changing their cooking practices, e.g. leaving beans to soak before cooking, or being more careful with the process of cooking. These areas would be regarded as prime targets for fuel efficient stoves. However, introducing more efficient modes of cooking in these areas may not save much fuel, as users may simply revert to less fuel conscious practices.

However, traditional stoves and fireplaces are not inherently inefficient, (as has been widely claimed in the literature). Moreover, traditional designs are not necessarily designed for maximum cooking efficiency: firstly because other practical features are considered desirable (e.g. ability to use different fuels, provision of space heat, fast cooking; and secondly because of other non-technical functions of traditional stoves (e.g. social focus and symbolic value).

(e) the low thermal efficiency of traditional stoves and fireplaces aggravates the burden of fuel collection

As outlined above, traditional stoves and fireplaces are not inherently inefficient. Moreover, the task of fuel collection is not universally regarded as a burden. In the case of Zimbabwe (see below) the situation is much more complicated than considered by many observers, and rural womens workload has a number of contributions.

(f) technical interventions will solve the problem of fuelwood energy

The review of field and laboratory testing has shown that not all "improved" stoves were more efficient for cooking than traditional designs, because of poor design. Some improved mud stoves did use less firewood than traditional designs. However, a number of these improved mud stoves deteriorated with use and their firewood consumption increased. Interest has shifted to the production and dissemination of improved ceramic designs. These can be made in large quantities much more quickly and accurately by skilled potters at low cost. It is too early to say whether or not these stoves will displace traditional designs - this will become clearer by 1985/6.

Working with rural women and identifying user needs would aid dissemination. Designing stoves based on traditional stoves is likely to minimize sociocultural resistance. In addition, a high cooking efficiency is only one of a number of features that is considered desirable by stove users. Women in a number of developing countries are especially keen on stoves which allow cooking to be done quickly - in Zimbabwe, women were prepared to sacrifice fuel economy for benefits such as fast cooking, even in areas with an acute firewood shortage.

The collection and consumption of cooking fuel has to be seen as an integral part of the rural energy system.

This thesis highlights the importance of studying the existing situation in depth before embarking on technical solutions. One of the most important ways in which this can be done is to carry out multi-disciplinary research in the field. Desk-based studies (whether in developing or developed countries) in themselves are insufficient. In the research visit to Zimbabwe, the questionnaire designed whilst in the U.K. was found to be of limited value in the villages surveyed: answers by villagers raised further questions which were usefully encompassed in the second questionnaire. It was also found that there was conflict between declared and observed cooking practices: in the first village visited, women said that they had adoped the new stove because it allowed them to "cook many things" simultaneously. However, villagers were observed to be cooking items of food sequentially. When asked to explain, villagers said that fast cooking was only required during the time they were busy in agriculture. This explanation made explicit the labour linkage of women's role in agriculture and domestic work, and the structure imposed in village life by the changing seasons.

It is clear that the introduction of fuel efficient stoves in rural areas are unlikely to have much impact on deforestation on their own. Given also the field experience of improved stove programmes, the manifold functions of traditional stoves, and the desirability of stoves allowing fast cooking by rural women, there is a need to reassess the design characteristics of "improved" stoves and the rationale for their introduction.

Moreover, the analysis of rural energy in developing countries needs to include the multiple role of women in the rural economy, and the variation in their labour in agriculture, fuel collection and domestic activities over the year.

In this thesis data was gathered from parts of rural Zimbabwe. An intensive study of two small sites to an extensive survey requires that sampling is carried out in stratified clusters; review work on rural energy methodologies was done recently by Howes (1984). Further questionnaire surveys are needed in Zimbabwe. One low cost method would be to administer the questionnaires to schoolchildren and students from rural areas to fill out for their home village and surrounding villages.

Further work needs to be done in measuring fuel consumption (using the sampling techniques above) in areas with different levels of fuel scarcity. Data on observed (and villagers perceptions of) seasonal variations in consumption of firewood and other cooking fuels e.g. maize cobs and animal manure, would usefully contribute to a database on rural energy.

To summarize, the probability of successful intervention in developing countries in the field of rural energy would be aided by the following: user participation in defining needs; adoption of a multi-disciplinary systems approach; gathering data (and living) in villages as well as gathering data from the country under study; awareness of the limitation of purely technical solutions; a historical analysis of the "problem"; and finally the realization that both the "problem" and "solution" has more than one dimension.

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APPENDIX A

Moisture content in wood

A.1 Introduction

Water is an essential component of living trees. Variation in water content occurs between trees of the same species, during different seasons, as well as in different parts of the same tree. This water content can be expressed as a percentage of the total mass of the wood, and is termed the 'moisture content'. The moisture content, m, can be defined in two ways:

$$Mw \text{ (wet basis)} = \frac{\text{original mass} - \text{dry mass}}{\text{original mass}} \times 100\ \% \qquad \text{(eqn A.1)}$$

$$M \text{ (dry basis)} = \frac{\text{original mass} - \text{dry mass}}{\text{dry mass}} \times 100\ \% \qquad \text{(eqn A.2)}$$

The wet basis is used by heating engineers, whilst most foresters and wood technologists use the dry basis, (Curtis, 1976). However, it is fairly straightforward to go from the wet to the dry basis (and vice versa):

$$Mw = \frac{m}{1 + m} \qquad \text{(eqn A.3)}$$

(where m and Mw are the moisture contents at dry and wet bases respectively).

The moisture content, on the dry basis, can exceed 100%. The water content of a freshly cut tree is also referred to as the 'green ' moisture content. As this green wood is exposed to air, it will dry, and its moisture content will change until it is in dynamic equilibrium with the surrounding atmosphere. The moisture content attained is termed the 'equilibrium moisture content', (EMC). The value of the EMC depends on factors such as the relative humidity, temperature, presence of mechanical stress, and the previous sorption history of the wood. Of these, the single most important factor, is the relative humidity of the surroundings.

Wood which has been cut into planks and stacked, (usually in the open air), is referred to as 'air dried'. The time period for this drying process is of the order of six months to one year. Moisture contents of air dried wood (dry basis) vary from about 20% to 30%. Wood can be further dried under conditions of elevated temperatures, and fast air circulation - this is termed kiln drying. With kiln drying it is possible to acheive any desired moisture content, (Forest Products Laboratory, 1974:14-6). However, it must be borne in mind that wood is a hygroscopic material and will spontaneously absorb moisture from the atmosphere, (or lose moisture), until dynamic equilibrium is reached.

A.2 Measurement of moisture content by oven drying

From the definition of moisture content, it follows that the basic method involved in its measurement is gravimetric. There are a variety of methods for determining the moisture content of wood. According to Kollman and Hockele (1962), there are up to fifteen. Skaar (1972:32) describes a few additional methods not mentioned by Kollman and Hockele (1962).

The simplest method involves recording the moist and dry mass of each wood sample.

According to the Forest Products Laboratory (U.S. Department of Agriculture),

> "oven drying has been the most universally accepted method for determining moisture content, but it is slow and necessitates cutting the wood" (Forest Products Laboratory, 1974:14-2).

The American Standard (ASTM D2016, 1977) recommends oven drying at 100°C (plus or minus 2°C), until constant mass is attained. However, ovenight drying is usually sufficient, although this depends on the size of the sample, viz. the larger the surface are to volume ratio, the faster drying will occur. This method relies on introducing a sample into an environment with a relative vapour pressure very close to zero, and allowing the sample to attain an equilibrium moisture content. However, the precise value of the moisture content may not be attained owing to:

(a) the relative vapour pressure departing significantly from zero;

(b) possible effects of previous sorption history;

(c) volatile compounds other than water evaporating during oven drying.

Effects of relative vapour pressure

According to Skaar (1972:32),

> "the dry weights of thirty - eight different woods native to Venezuela were 0.42 per cent lower on average when dried in an oven in Syracuse, New York in January compared with their oven dry weight in Merida, Venezuela. The difference in retained moisture is attributed to the higher ambient vapout pressure in Venezuela compared with Syracuse, in the middle of winter".

These differences are negligible. However, the effects of room conditions can be reduced considerably by use of a vaccuum oven, (there is also the added advantage that lower oven temperatures can be used). Another method, is to use a strong dessicant such as phosphorous pentoxide, which will produce a very low relative humidity environment - however, in this, much longer 'drying' times are required, (typically of the order of days).

Previous sorption history

The relative vapour pressure of the surrounding atmosphere is the single major factor which affects the equilibrium moisture content of the wood. However, the previous sorpton history of the sample is important, as the relationship between EMC and the relative humidity (rh) shows hysteresis (Skaar, 1972).

Non water volatilization

According to the Forest Products Laboratory (1974:14-2),

> "(oven drying)...gives values slightly higher the true moisture content with woods containing volatile extractives"

Moreover,

> "oven drying and vacuum drying yield correct results only with woods which in addition to water do not contain any volatile constituents like resins, oils fats or volatile preservatives like creosote" (Kollman and Cote ,1968:181).

If non water constituents are evaporated during oven drying, this will lead to an overestimation of the moisture content.

> "at high temperatures volatilization of organic compounds and various chemical changes such as protein denaturation can occur which would lead to underestimates of calorific value" (Woodland, 1972:23).

Since, the moisture content affects the net heat of the wood, this will lead to inaccuracies in the measured calorific value of the firewood used (see Appendix B).

APPENDIX B

Heat Values

This work draws heavily on a report by Bialy (1979) and British Standard 526 (1961).

Heat is released when any organic fuel is burnt in oxygen. The quantity of heat released per unit mass depends on both the chemical composition of the fuel and the conditions under which combustion takes place. Hence, for the purposes of comparison, the heat values of fuels have to be defined under standard conditions. These conditions define the temperature at which combustion takes place, and are either performed at constant pressure or constant volume.

Water may be present at the end of the combustion process: firstly, because any hydrogen in the fuel will oxidize to water; secondly, because the fuel may contain water. In either case, the water at the end of the combustion process can (in the extremes) be in the form of liquid or gas. If all the water is condensed, then any heat it absorbed during vapourization will be re-released. The total quantity of heat released under this condition is termed the **gross or high heat value.** If all the water at the end of combustion is in the form of vapour, then the total heat released will be less than in the former case by the amount of heat required to vapourize the water. Under these conditions, the heat output is termed the **net or low heat value.** Heat values, where the water is in an intermediate state, (e.g. partly liquid and partly vapour), are not defined.

Since, heat values are defined under conditions of constant pressure or volume, this leads to four different heat values being defined for any solid or liquid fuel:

Hhv - High heat value (constant volume)
Hlv - Low heat value (constant pressure)
Hhp - High heat value (constant pressure)
Hlp - High heat value (constant pressure)

In practice only one of these heat values is experimentally measured, the others are then calculated from this value. For solids and liquids, the value normally measured is the high heat value at constant volume since it is much easier to maintain the volume constant rather than the pressure during controlled combustion. According to BS 526 (1961), combustion should take place isothermally, under an initial pressure of 25 to 37 atmospheres of oxygen.

Hhp will not be the same as Hhv for any given fuel if the number of moles of gas are not the same at the end of combustion as at the beginning. Under conditions of constant pressure an increase or decrease in the volume, will lead to work being done - this will absorb or emit heat energy. If the volume change is positive, then work will be done on the surroundings by the system, and vice versa. Usually for solids and liquids, the volume of the products is less than the volume of the reactants.

$$\text{work done} = PdV + VdP \qquad \text{(eqn B.1)}$$

V - volume;
P - pressure;
dV - change in volume;
dp - change in pressure.

Under conditions of constant pressure, $dp = 0$, hence,

$$\text{work done} = Pdv \qquad \text{(eqn B.2)}$$

$$= nRT \qquad \text{(eqn B.3)}$$

n - change in number of moles of gas per unit mass of fuel
R - universal gas constant
T - temperature

Many organic fuels commonly contain carbon, sulphur, hydrogen and oxygen. The oxidation reactions for these are:

$$C(s) + O_2\ (g) = CO\ (g) \quad dn = 0 \qquad \text{(eqn B.4)}$$

$$S(s) + O_2\ (g) = SO_2\ (g) \quad dn = 0 \qquad \text{(eqn B.5)}$$

$$C(s) + \tfrac{1}{2}O_2\ (g) = CO \quad dn = +\tfrac{1}{2} \qquad \text{(eqn B.6)}$$

$$CO(g) + \tfrac{1}{2}O_2\ (g) = CO\ (g) \quad dn = -\tfrac{1}{2} \qquad \text{(eqn B.7)}$$

$$dn = 0$$

For the above reactons, there is no change in volume. Now consider the oxidation for hydrogen:

$$H_2(s) + \tfrac{1}{2}O_2 = H_2O \quad dn = \tfrac{1}{2} \qquad \text{(eqn B.8)}$$

(As this is the high heat value liquid water is formed)

From the above, one mole of hydrogen reacts with half a mole of oxygen for complete oxidation. Work is done since there is a net change of volume in this process. There is half a mole change in volume for every mole of hydrogen in the fuel. If the fuel contains H percent hydrogen, by mass, then the molar concentration of hydrogen is

$$\frac{H \times 0.01}{2.016} \qquad \text{(eqn B.9)}$$

The net change in volume is half of this:

$$n = 0.5 \times H \times 0.01/2.016 \qquad \text{(eqn B.10)}$$

$$\begin{aligned} \text{work done} &= nRT \\ &= 0.01 \times RT \times (0.5H/2.016) \end{aligned} \qquad \text{(eqn B.11)}$$

If the material contains oxygen, then less molecular oxygen will be required to react with the hydrogen. This will mean a smaller change in volume. For a material with P % oxygen (by mass), the amount of oxygen required will be less by the amount equal to:

$$= 0.01 \times P/32.00 \qquad \text{(eqn B.12)}$$

Hence, the net change in the number of moles during combustion will be

$$dn = \left(0.01 \times \frac{0.5H}{2.016}\right) - \left(0.01 \times \frac{P}{32}\right) \qquad \text{(eqn B.13)}$$

$$= 0.01\ (0.5H/2.016 - P/32.00) \qquad \text{(eqn B.14)}$$

(but as the work done)

$$\begin{aligned} &= nRT \\ &= 0.01\ RT\ (0.5H/2.016 - P/32.00) \end{aligned} \qquad \text{(eqn B.15)}$$

The work done, in this case is the difference between the high and low heat values at constant pressure, ie

$$Hhp - Hlp = 0.01RT\ (0.5H/2.016 - 0/32.00) \qquad \text{(eqn B.16)}$$

for a material with H% hydrogen and P% oxygen (by mass). The difference between the high and low heat values simply relates to the latent heat of vapourization of the water produced in the combustion process, at the reference temperature of 298K.

For water at 25°C, its latent heat at both constant pressure and volume is 2.30 MJ/kg (44.0 kJ/Mol), and 2.44 MJ/kg (41.5 kJ/Mol) respectively. The water produced by a fuel containing H% hydrogen (by mass) is

$$0.01 \times H/2.016 \ \text{moles per unit mass of fuel} \qquad \text{(eqn B.17)}$$

If the fuel also contains W% moisture (by mass) then an additional quantity of water produced will be given by

$$0.01 \times W/18.016 \ \text{(moles/unit mass of fuel)} \qquad \text{(eqn B.18)}$$

Total no. of moles produced = $0.01(H/2.016 + W/18.016)$ mol/kg

(eqn B.19)

Heat required to vapourize this quantity of water

$$= 0.01L(H/2.016 + W/18.016) \ \text{kJ/kg}$$

(eqn B.20)

L - molar latent heat of water; L = 44.00 kJ/Mol
H - percentage by mass of hydrogen in the dry fuel;
W - percentage by mass of water in fuel;

Hence,

$$\begin{aligned} Hhp - Hlp &= 0.01 \times 44 \times 1000\ (H/2.016 + W/18.016) \ \text{kJ/kg} \\ &= 218.25H + 24.42\ W \ \text{kJ/kg.} \\ &\simeq 218H + 24W \qquad \text{(eqn B.21)} \end{aligned}$$

If a fuel contains water the high heat value will have a lower value, as not all the material is fuel; the water will not make any contribution to the calorific value. Hence, the high heat value is directly proportional to the quantity of dry fuel per unit mass of material. If the moisture content of the fuel m% (dry basis), then the proportion which is dry fuel is

$$100/(100 + m) \qquad \text{(see Appendix A)}$$

If the high heat value of the dry fuel is E MJ/kg, then the high heat value of the same fuel with a moisture content m% (dry basis) will be given by

$$Hhp(m) = [100/(100 + m)]\ E \quad MJ/kg \qquad \text{(eqn B.22)}$$

The moisture content W is expressed as a percentage of the total mass of fuel and moisture. Now,

$$W \text{ (wet basis)} = m \text{ (dry basis)} \times [100/(100 + m)]$$
$$W = 100m/(100 + m) \qquad \text{(eqn B.23)}$$

If the hydrogen content of the dry fuel is h percent. Then the hydrogen content of the fuel and moisture,

$$H = [100/(100 + m)]\ h \qquad \text{(eqn B.24)}$$

since,

$[100/(100 + m)]$ = fraction per unit mass which is dry fuel.

and (as calculated earlier)

$$Hhp - Hlp = 218H + 24\ W \quad kJ/kg \qquad \text{(eqn B.21)}$$
$$Hlp = Hhp - (218H + 24W) \qquad \text{(eqn B.25)}$$

Substituting for Hhp (eqn B.22), H (eqn B.24) and W (eqn B.23),

$$Hlp = \frac{100E - 21.8h - 2.4m}{100 + m} \quad MJ/kg \qquad \text{(eqn B.26)}$$

In the case of wood, the value of E and h are approximately 20MJ/kg and 6% respectively (Bialy, 1979), whence:

$$Hlp \text{ (wood)} = 2.4\,\frac{(780 - m)}{(100 + m)} \quad MJ/kg \qquad \text{(eqn B.27)}$$

APPENDIX C

Firewood consumption data in Zimbabwe

Data on firewood consumption in Zimbabwe falls into five categories:

(1) those in which the figures of consumption are apparently anecdotal.

Banks (1980) assumes that firewood consumption in rural areas of Zimbabwe is 0.85 m^3, but gives no literature source for this figure.

(2) Using data on firewood consumption from other developing countries.

Johnston (1980) estimated firewood consumption to be 0.93 m^3 (632 kg) per capita per annum using "comparative data from other countries" - the conversion of volume of wood to mass, uses Johnston's assumption that the density of local timber is 680 kg/m^3. This estimate is based on a previous study, though Johnston does not quote the source. In support of this figure, Johnston quotes a comparable figure of 0.83 m^3 (564 kg) obtained by the Forestry Commission - though again no literature source is given.

(3) Asking each household how long one bundle will last.

According to Furness (1979)

> "One of the first recorded assessments of firewood consumption was made by finding out from tribespeople how long an average headload of firewood would last. This was given as three days, and with the average headload estimated at 34 kg, the yearly consumption worked out at 4147 kg"

However, repeating this calculation (assuming 365 days per year) gives a figure for annual consumption of 4137kg, but this is insignificant relative to the ommission of other information: the number and size of the households surveyed, where and when the survey took place, and moisture content of the firewood are not given.

To convert this to **per capita** consumption requires the **household size.** According to Furness (1979), whilst early studies of firewood consumption in Zimbabwe assumed an average household size of 5 people, the "latest evidence" suggested 5.5 people would be more accurate.

However, both these seem to be underestimates since an earlier study by the Forestry Commission (1978) obtained values as high as 8.4 people per household (Table C.1). More recently data from 200 households in 10 Communal Lands (Hosier et al, 1982) gave a mean value of 6.8 people per household (the standard deviation was not given). This figure is very close to 6.9 obtained in the present study. The mean household size for all the studies is 7.0 people.

Table C.1
Household Size Obtained in Studies of Firewood Consumption

author	village/area surveyed	population of survey	mean household size
Forestry Commission (1978)	Mondoro	54	7.7
	Chiwundura	84	8.4
Anon (quoted in Furness, 1979)	Inyati C.L.[a]	45	9.0
Hosier *et al* (1982)	(see Table C.3)	1360	6.8[b]
			6.9[c]
Total		1799	7.0[d]

Key
[a]C.L. - Communal Land
[b]mean household size for all 10 areas surveyed
[c]mean for all 5 villages surveyed
[d]Weighted mean for all studies

Assuming that the mean household size is 5.0, 5.5 and 7.0 gives the annual per capita firewood consumption as 827kg, 752kg, and 591kg respectively. Assuming the moisture content of the firewood is 27.5 % gives per capita energy consumption of 11.7GJ, 10.7GJ and 8.4GJ, respectively.

(4) Measuring the <u>volume of firewood</u> in a headload and counting the number of headloads collected over a known period.

Two studies fall into this category (Anon, undated quoted in Furness, 1979; Forestry Commission, 1978).

Furness (1979) quotes the results of the measurement of firewood collected in Inyati Communal Land for a period of four weeks by a scholar at the University of Zimbabwe in July 1978: all the firewood collected by 5 households (with a mean size of 9 persons) was measured. The mean annual volume of firewood sticks collected per capita was estimated at 2.1 m^3 (1244 kg). Furness regards this as overestimating actual consumption as the measurements took place during the cold months.

Firewood consumption collected under the auspices of the Forestry Commission (1978) was obtained for one village in Mondoro Communal Land and another in Chiwundura Communal Land. The survey took place from December 5th 1977 to February 14th 1978 and December 18th 1977 to February 12th 1978 in Mondoro and Chiwundura, respectively.

Mondoro and Chiwundura are in areas of "great land pressure" and "extreme land pressure" respectively (Whitsun Foundation, 1981). According to the Whitsun Foundation (1981) the population density in

Mondoro is 38 persons/km^2 and 24 persons/km^2 in Chiwundura.

The magnitude of firewood consumption were 0.984 m^3 (581kg) and 1.059 m^3 (625kg) per capita for Mondoro and Chiwundura respectively. In energy terms the annual projections for firewood consumption range from 8.3 GJ per capita for Mondoro and 8.9 GJ per capita for Chiwundura (assuming a moisture content of 27.5% for the firewood.

The methodologies employed to measure the firewood consumption in the two areas were similar: firewood brought into the village by scotch cart, wheelbarrow or as individual logs were **"measured"** to give data on the volume of wood. However, in **Mondoro** only the headloads were **"weighed"**; no measurements were made of the firewood piles. Hence, it had to be assumed that there was no net change in the firewood piles during the period of the survey.

As firewood is stored so that it can be used during the rainy season when villagers are busy, casts doubt on the validity of the assumption that there is no net change in the firewood pile - this would lead to an underestimate for the data on Mondoro.

Moreover, even "measuring" the firewood piles would have been fraught with problems, such as how to take into account the different packing densities, uneveness of the pile, and the moisture content of the different pieces of firewood.

Another source of error is that the projections of annual firewood consumption in **both villages** take no account of variations in the level of firewood consumption over the year.

It is likely that these values understate the actual level of annual firewood consumption.

(5) Asking each household the quantity of firewood (either in weight or bundles) over a known period, for example 1 day (Hosier et al, 1982; Hosier, 1983 pers comm; Walsh, 1978) or 1 week. This can be further refined by taking into account any variation over different seasons, for example summer and winter (e.g. Whitlow, 1979).

Walsh (1978) undertook measurements of firewood consumption in Chikwaka Communal Land for a total of 216 families. Measurements of the **volume of firewood** each family estimated it would use the following day were carried out by 6 agricultural extension workers in the course of their work in January and February of 1978. Walsh does not seem to have gathered any information on the size of the households visited - whereby he has to rely on an earlier study (Walsh, 1977) to convert the data on household consumption to per capita consumption. The mean daily household consumption was calculated to be 0.042 m^3 with a standard deviation of 0.035 m^3 ! Projected to annual per capita consumption (assuming the mean household size is 8 persons (Walsh, 1977)) gives a value of 1.916 m^3 (1131 kg) - Walsh quotes a figure of 1.825 m^3 caused by rounding the daily per capita consumption **before** extrapolating to annual consumption.

Walsh estimates for the standing crop and annual increment are 11,564 m^3 and 6107 m^3, respectively. Using the estimate of the total population of Chikwaka he obtains a figure of 26,709 m^3 which is rejected as it is higher than the standing crop and annual increment ! Even assuming annual firewood use of 0.62 m^3 and 0.98 m^3 per capita, leads to total annual consumption of 9,073 m^3 and 14,342 m^3 respectively - both comparable to the estimate of standing crop.

Owing to the discrepancy between the total estimated consumption and other estimates, Walsh recommends that this methodology of firewood consumption is not used.

Whitlow's (1979) study involved students from the University of Zimbabwe (formerly University of Rhodesia). Five areas were chosen for the questionnaire based survey and corresponded to the home areas of the students: Mangwende, Nuanetsi, Ndanga, Que Que and Matoba. Using this method gave a range of projections of annual consumption per capita from 0.268 m^3 (158 kg) to 1.638 m^3 (966 kg) with a mean of 0.629 m^3 (371 kg) (Table C.2)

Table C.2
Annual firewood consumption in five study areas
(adapted from Whitlow, 1979)

Study Area	Whitlow's data (kg)	assuming bundle size = 16.5kg (kg)	(A)	(B)	assuming bundle size = 36kg (kg)	(A)	(B)
Nuanetsi	378	173	2.5	2.8	378	5.4	6.0
Que Que	286	286	4.1	4.4	624	8.9	9.9
Ndanga	158	158	2.2	2.5	344	4.9	5.5
Matoba	966	444	6.3	7.1	966	13.7	15.4
Mrewa	565	260	3.7	4.1	565	8.0	9.0
Mean	371	264	3.7	4.2	576	8.2	9.2

(A) - calorific value of firewood = 14.2 MJ/kg
(B) - " " " " = 15.6 MJ/kg

Estimates of firewood consumption were based on the frequency of collection of firewood "bundles" by the households in the survey.

A further refinement was added by asking the household of the frequency of collection over the "winter period" (May to August) and "summer period" (September to April). From this information on the total number of bundles collected over the year could be calculated. Multiplying by the mass of the average bundle in each study area would give a figure for the annual firewood consumption. But, the major weakness of the study methodology is that **no measurements were undertaken on the mass of bundles collected in any of these areas.**

In order to circumvent this problem, data of the mean bundle size was obtained from an earlier study of the firewood consumption in two villages by the Forestry Commission (1978). Unfortunately the mean bundle size in one village was 0.061 m^3 and 0.028 m^3 in the other ie differing by a factor of 2! This difference in mean bundle size was taken in to account by classifying each area according to which of the villages each was thought to be most similar: Mangwende, Nuanetsi and Ndanga were equated with the village with the higher bundle size, with Que Que and Matoba equated with the area with the lower bundle size.

Assuming that the average bundle in all the areas is 16.5 kg and 36kg gives rise to a mean firewood consumption of 371 kg (0.629) and 576 kg (0.976 m^3) per capita, respectively.

Whilst, Whitlow has collated useful data from a number of areas, his methodology has two weaknesses: a failure to determine the "bundle" sizes for the different households and the moisture content of the firewood.

In a later study by Hosier et al (1982) 1360 people (20 households in each of 10 Communal Lands - see Table C.3) were surveyed using a questionnaire. Firewood consumption data from rural areas was collected in December 1981 (cf November and early December 1981 in the present study).

Table C.3
Areas surveyed by Hosier et al (1982)

(1) Inyanga North	(6) Zaka (Marimira)
(2) Old Umatali	(7) Chiwundura
(3) Rugoyi	(8) Zimuto
(4) Chibi Mahangove	(9) Zvimba
(5) Gutu	(10) Zaka (Jichidza)

A range of values for different income levels were obtained (6800kg to 7800kg per household per annum), with a mean of 7400kg per household per annum; Hosier points out that these differences are not statistically significant. Since the mean household size is given as 6.8 the mean annual per capita energy consumption is 1058kg. In energy terms the mean annual consumption of firewood per household is 15.4GJ per capita, assuming the moisture content of the firewood is 27.5%.

In each area the household was asked to put in a pile the quantity of firewood that would be consumed in one day (Hosier, 1983, pers comm): this pile of firewood was then weighed, though no indication is given of the accuracy of the weighings.

In addition, no mention is made of any seasonal variation in firewood consumption over the year - since firewood consumption would be expected to vary over the year (being higher in the cold than in the hot months) data which is collected in the the hotter months and projected to annual consumption without taking these variations into account will underestimate the actual consumption.

In conclusion, data commonly quoted in the literature in Zimbabwe (a summary of firewood consumption is given in Table C.4) is likely to underestimate actual firewood consumption.

Table C.4

Summary of annual firewood consumption obtained in studies
(per capita basis)

Source	mass of firewood	Annual firewood consumption: calorific value (= 14.2 MJ/kg) (GJ)	calorific value (= 15.6 MJ/kg) (GJ)
Banks (1980)	502	7.1	8.0
Johnston (1980)	632	9.0	10.1
Furness (1979)			
(a) Anon, undated	591	8.4	9.4
(b) Anon (1978)	1244	17.7	19.8
Walsh (1978)	1131	16.1	18.0
Whitlow (1979)			
(a) bundle size=16.5kg	264	3.7	4.2
(b) Whitlow's data	371	5.3	5.9
(c) bundle size=36kg	576	8.2	9.2
Forestry Commission			
(a) Mondoro	580	8.2	9.2
(b) Chiwundura	625	8.9	9.9
Hosier *et al* (1980)	1088	15.4	17.3

APPENDIX D

COOKING SURVEY

This survey is attempting to find the cooking patterns, (primarily in rural areas) in order to help design more efficient stoves. The person who normally does the cooking would probably be able to answer the question best.

Note

Use diagrams wherever you think necessary, however all questions marked with an * indicate that a diagram would be especially useful. Label the diagram with dimensions if possible. If there is not enough room by the question, draw the diagram on page 4.

Stove

What do you normally use to cook on ?

* Sketch this stove and label it on page 4. Include its main dimensions eg height.

What is the stove made from ?

Was the stove bought from someone or home built ?

If it was homemade:

Who built it ?

How long did it take to build ?

How much did the materials cost ?

Where did the materials come from ?

Where is the stove normally used eg. inside, outside ?

Is it sometimes used elsewhere ? Yes/No. Why is that ?

How long does the stove last before it needs replacing ? (If only part of it needs replacing, say what it is).

What do you like about the stove ?

What are the things you do not like about the stove ?

Fuel

What are the main fuels used for cooking ?

Describe the fuels giving its shape and size.

* If each of the fuels is usually used in a standard shape and size, sketch on page 4 of this survey, indicating the dimensions.

Is anything done to the fuels before they are used, eg chopped up, dried ?

Are any of the fuels bought ? Yes/No. If so, what are they, and how much do they cost ?

Fuel	Cost per week

Which fuels are collected, if any ?

If any are collected:

Who collects each of these fuels ?

How many people in your family collect each fuel ?

How much time is spent by each person in collecting fuel per week ?

Does the amount of time spent in collecting fuel vary over the year ? If so, how does it vary ?

At what time of day is each fuel normally collected ?

Is any of it stored ?

What do people like about collecting fuels ?

What are the things disliked about collecting fuels ?

What are the main advantages of the fuels you use ?

What are the main disadvantages of the fuels that you use ?

What is the best fuel for cooking ?

Why is this ?

If you do not use this fuel, why not ?

Besides cooking what else do you use fuel for ?

	How much fuel per week used.	What fuel?
heating bathwater		
boiling drinking water		
heating water		
other		

Cooking

How many people do you cook for regularly ?

How many of these are adults ?

Who does the cooking ?

* How is the cooking done ? eg standing up, sitting down on a stool ... ? If possible sketch on other side of the paper, showing stove, cooking pot(s) and person cooking.

What meals are usually cooked each day ?

What time is each meal cooked ?

What is cooked for each of the meals ?

How many cooking pots are normally used for each of the meals ?

Do any of these pots have lids ?

What, if anything is cooked in a pot plus lid ?

What materials are the pots made from ?

Were the pots made at home or bought ?

* Sketch the shapes of the cooking pots and indicate the materials they are made from, as well as the main dimensions (eg height, diameter) on the other side of this page.

Additional information, write or draw here anything which you think is relevant but has not been asked

Thank you for your help.

Jas Gill, Energy Research Group, The Open University, Walton Hall, Milton Keynes MK7 6AA, England.

APPENDIX E

QUESTIONNAIRE

for school pupils

NAME		FORM	AGE
HOME ADDRESS	ELLENVALE, INYANGA INTENSIVE CULTIVATION AREA		
NO. OF PEOPLE IN HOUSEHOLD	4	ADULTS 2	
CHILDREN	2 (ages: 4 - girl; 2 - girl)		

MONTHS	J	F	M	A	M	J	J	A	S	O	N	D
1. CROPS ✓	W	W	W	W C	E	D H	H	Resting	Pd	Pd	Pd-P	Pd-P
MAIZE ✓												
MILLET												
RAPOKO ✓												
WHEAT												
RICE ✓												
GROUNDNUTS ✓												
PEANUTS												
CORN												
NYEMBA ✓												
MAFUNDE ✓												
MUNGE ✓												
2 VEGETABLES ✓												
POTATOES ✓												
PUMPKIN ✓												
RAPE ✓												
CABBAGE ✓												
TOMATOES ✓												
COLLECTION (firewood)					✓	✓	✓	✓	✓	✓		
USE (NO. OF DAYS)	3	3	3	3	3	2	2	2½	3½	3	3	
POTS ON 'STOVE'	2	2	2	1	1	1	1	1	1	1	2	
COOKING (INSIDE/OUTSIDE)	I	I	I	I	I	I	I	I	I	I	I	
BUSIEST MONTHS	✓	✓	✓	✓							✓	
LEAST BUSIEST					✓	✓	✓	✓	✓	✓		

*Advantages of new stove

① modern image

② less smoke

③ cooking many things

④ more heat

(3-stones no advantages)

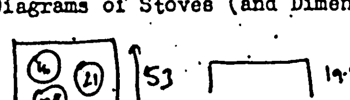
Firewood -No. of Bundles
-No. of days 1 bundle will last.

P - PLANTED C-CULTIVATED E-EATEN S-STORED D-DRIED
H - HARVESTED W- WEEDED Pd - PLOUGHED R-RESTING

KEY FOR CROP/VEGETABLES

	STOVE	WHEN BOUGHT?	USED FOR
INSIDE	iron frame	1980	Cooking, space heat, heating water
OUTSIDE			

Diagrams of Stoves (and Dimensions)



Reason(s) for changing to different 'stove' (in order of importance).

*Advantages Relative Fuel consumption.

3 Stones	4 Stones	Iron Stove
x	n.a.	2x

These questions to be answered by the ~~female~~ members of the household

TASKS	Hard	Easy	Liked	Not Liked
Ploughing	2		1	
Cultivating	4			
Weeding	3		4	
Planting		5		
Grinding Mealie Meal				
" Millet				
" Maize				
Crushing Maize	6			1
Cutting Firewood	5			3
Carrying Firewood				
Carrying Water		4		
Washing Clothes		3	2	
Washing Pots		2	3	
Cooking		1		
Grazing Mombe				2
Taking Mombe to Dip	1			

Cooking fuels	Firewood	Mealie Cobs	Manure	Paraffin
D	✓			
N	✓			
O	✓			
S	✓	✓		
A	✓	✓		
J	✓			
J	✓			
M	✓			
A	✓			
M	✓			
F	✓			
J	✓			

Use a '✓' in the boxes above.

Cooking -Household

Best Wood msasa

2nd Best mukowe

3rd Best muuku

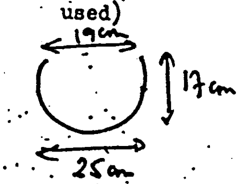
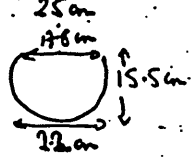
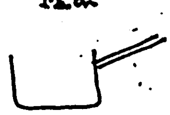
Which ones do you use? mutowe mutara

Which fuel(s) would you like to use? firewood

Is firewood bought-collected.. collected

No. of times Sadza eaten in one month? (Assume month = 30 days). 60

How is cooking done (sitting on floor/standing)? sitting/kneeling (prefers sitting)

Cooking Pots Diagram & Dimensions (Draw in lid if used)	Material (e.g. Clay)	Food Usually Cooked in Pot
	clay	
	clay	meat
	enamel coated metal	sadza

Food Purchased.

Tea, salt, bread, flour, sugar

Additional information.

Firewood Collection

Now. difficult

1 Year ago
5 Years ago
10 Years ago. } always been difficult but used to it.

		Number
Mombe	- Adults-Male	
	-Female	
	Calves-Male	
	Female	
Goats Yes/No		
Chickens Yes/No.		

APPENDIX F

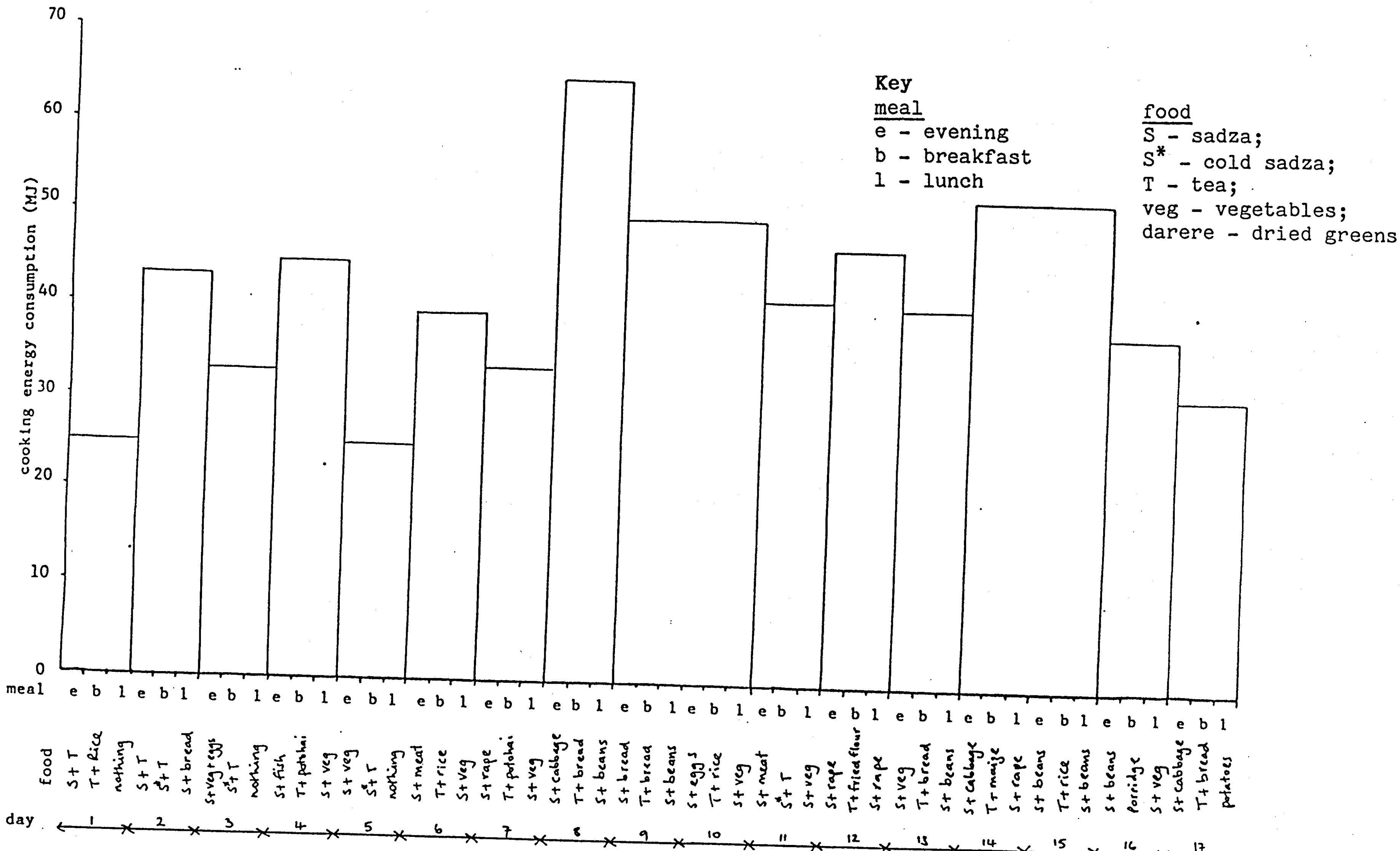


Fig F.1 Daily cooking energy consumption (per capita) and food cooked in Mukweva (household A)

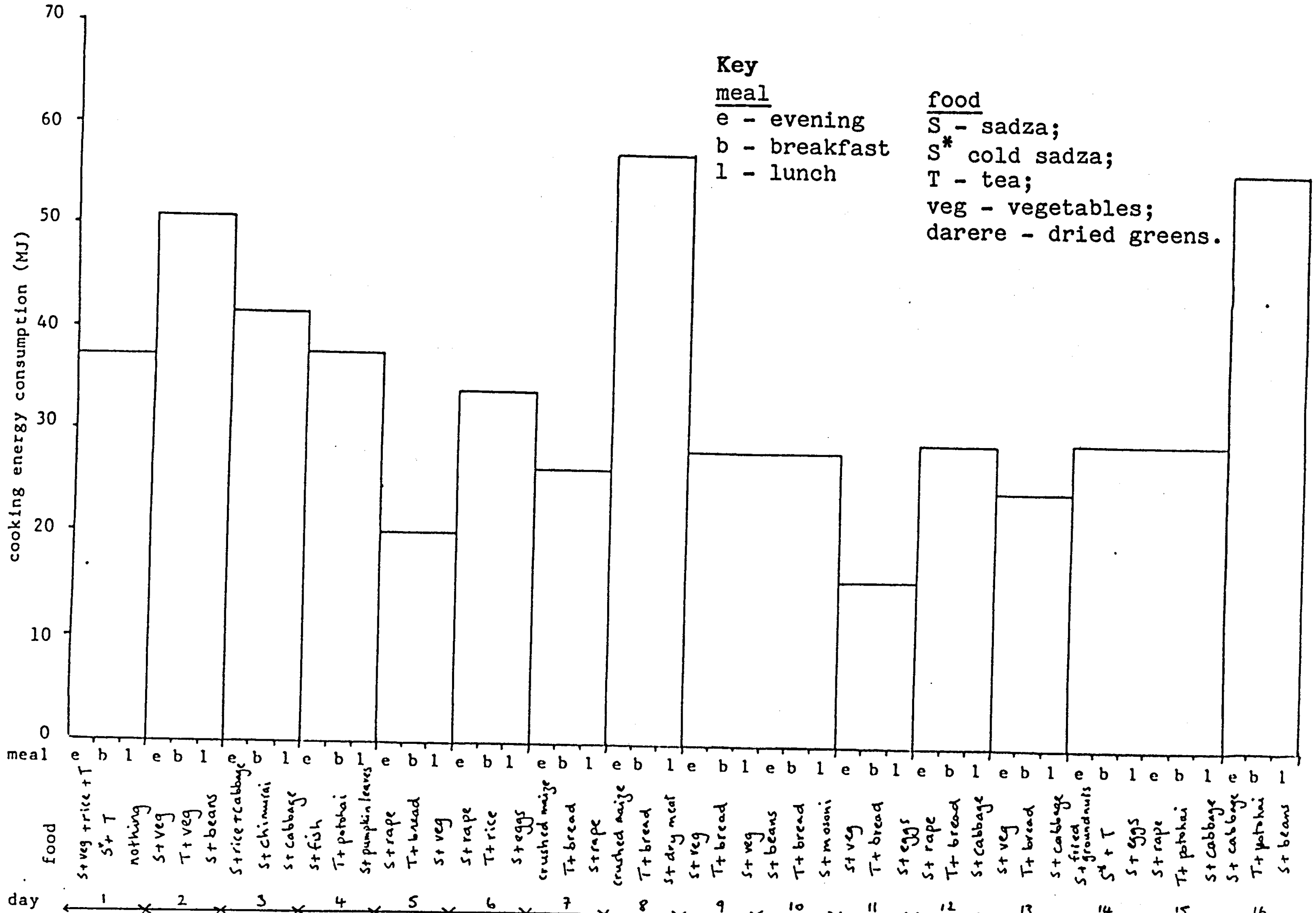


Fig Γ.2 Daily cooking energy consumption (per capita) and food cooked in Mukweva (household B)

Key

meal
e - evening
b - breakfast
l - lunch

food
S - sadza;
S* - cold sadza;
T - tea;
veg - vegetables;
darere - dried greens.

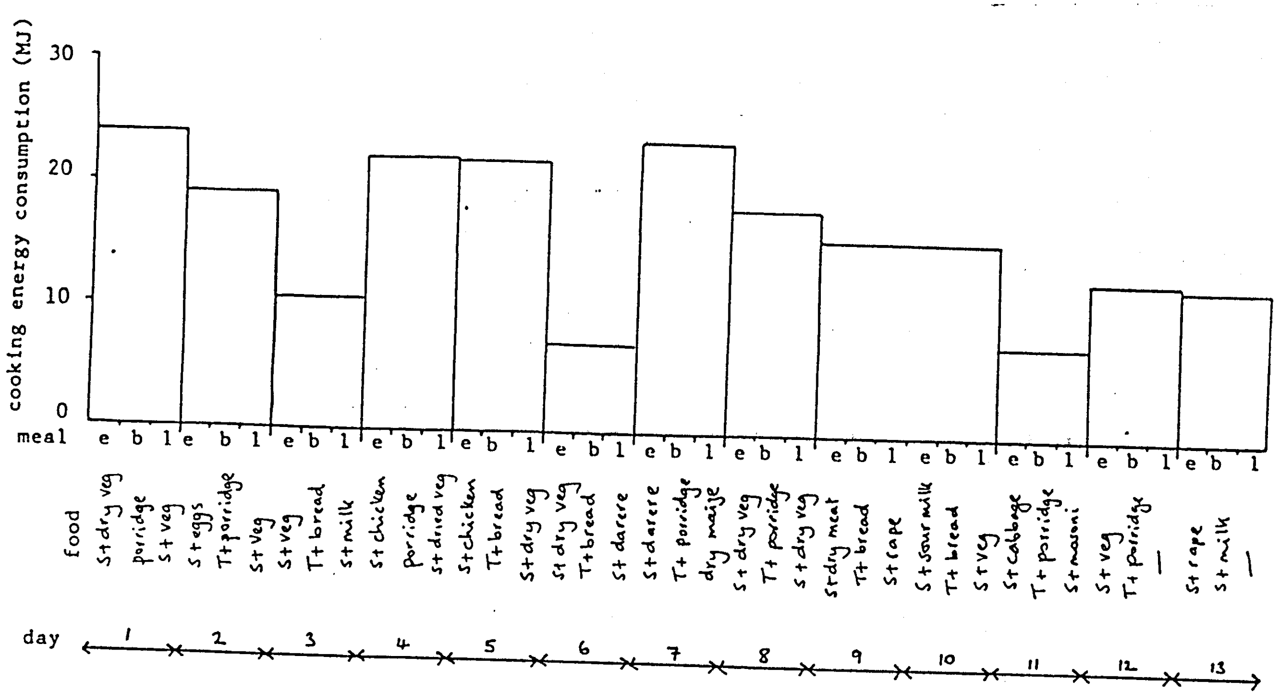


Fig F.3 Daily cooking energy consumption (per capita) and food cooked in Mukweva (household C)

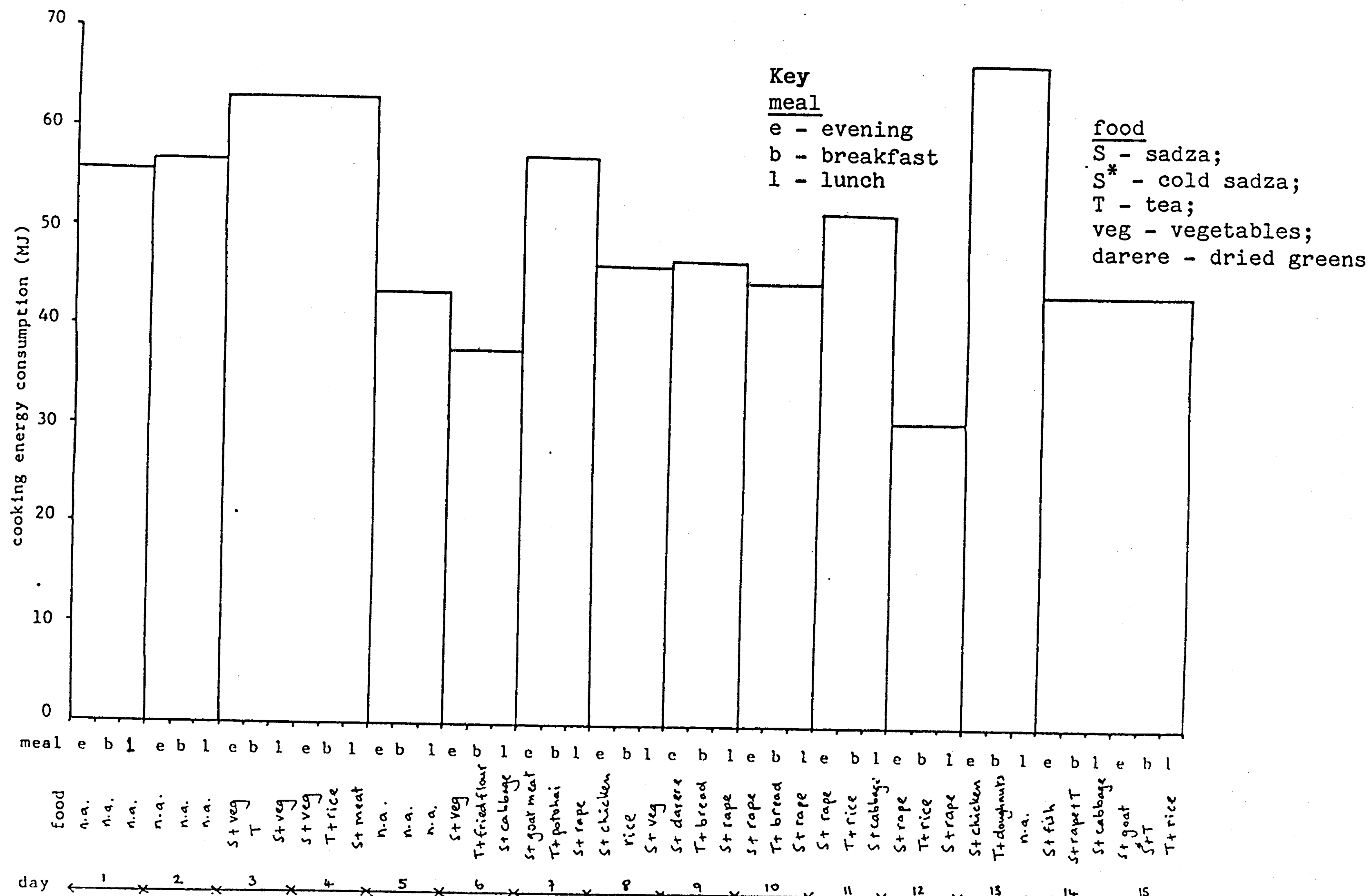


Fig F.4 Daily cooking energy consumption (per capita) and food cooked in Mukweva (household D)

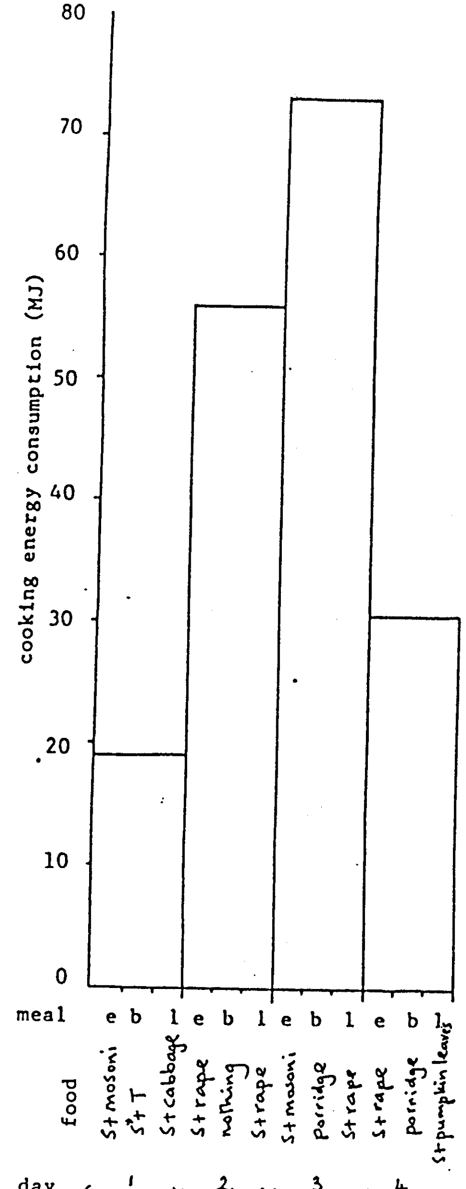


Fig F.5 Daily cooking energy consumption (per capita) and food cooked in Ellenvale (household A)

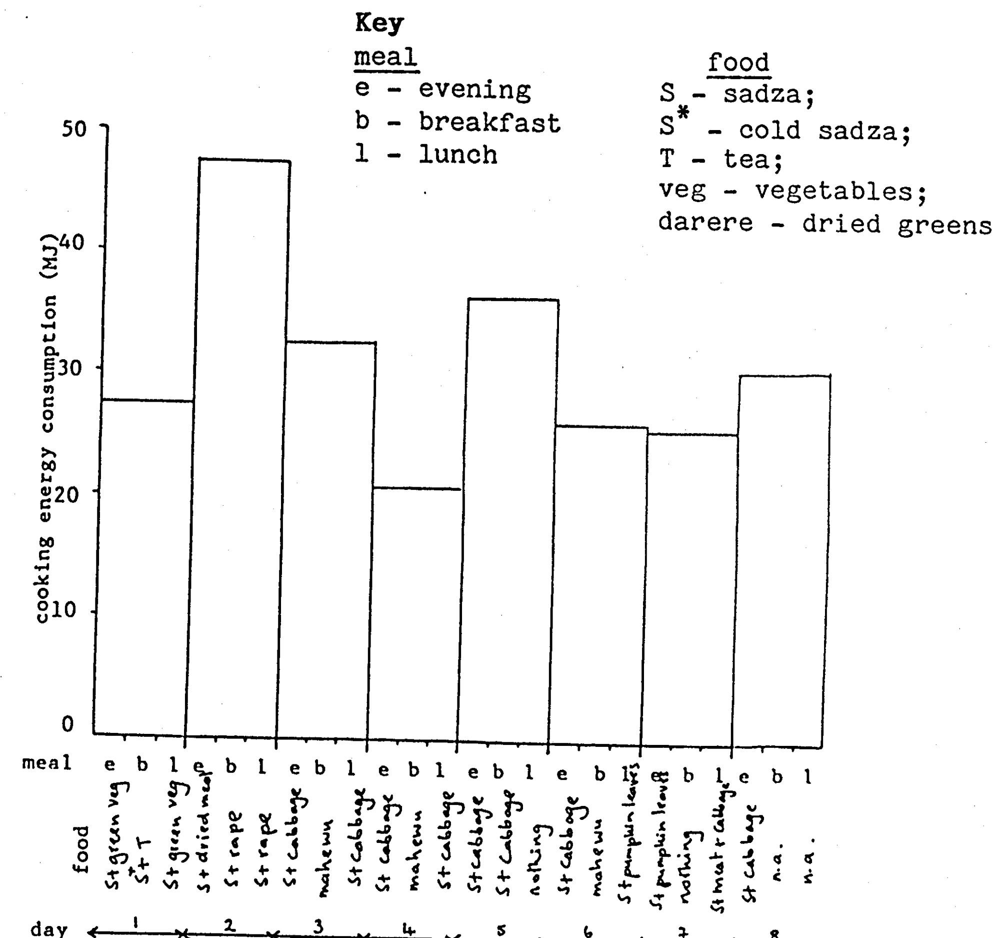


Fig F.6 Daily cooking energy consumption (per capita) and food cooked in Ellenvale (household B)

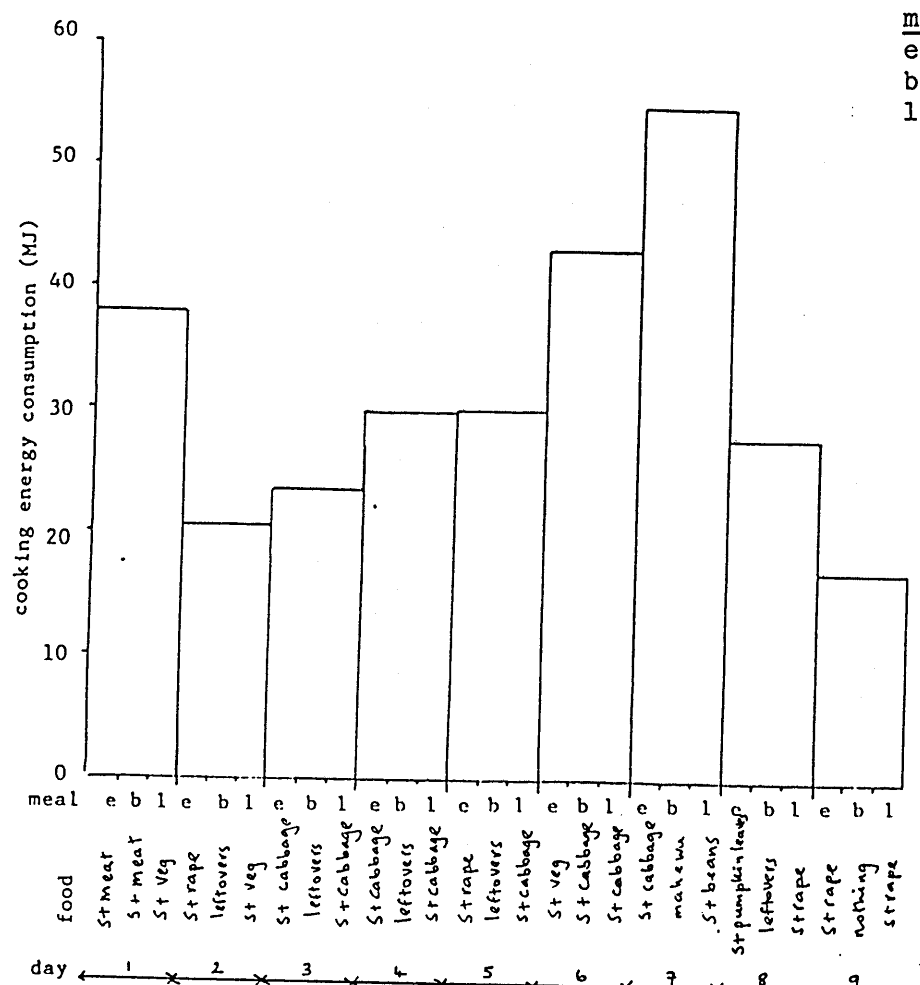


Fig F.7 Daily cooking energy consumption (per capita) and food cooked in Ellenvale (household C)

Key

<u>meal</u>
e - evening
b - breakfast
l - lunch

<u>food</u>
S - sadza;
S* - cold sadza;
T - tea;
veg - vegetables;
darere - dried greens.

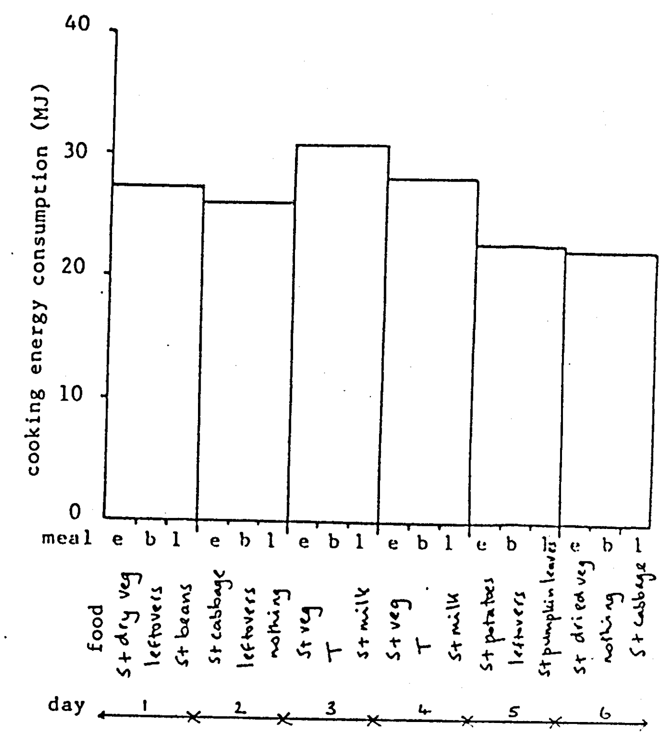
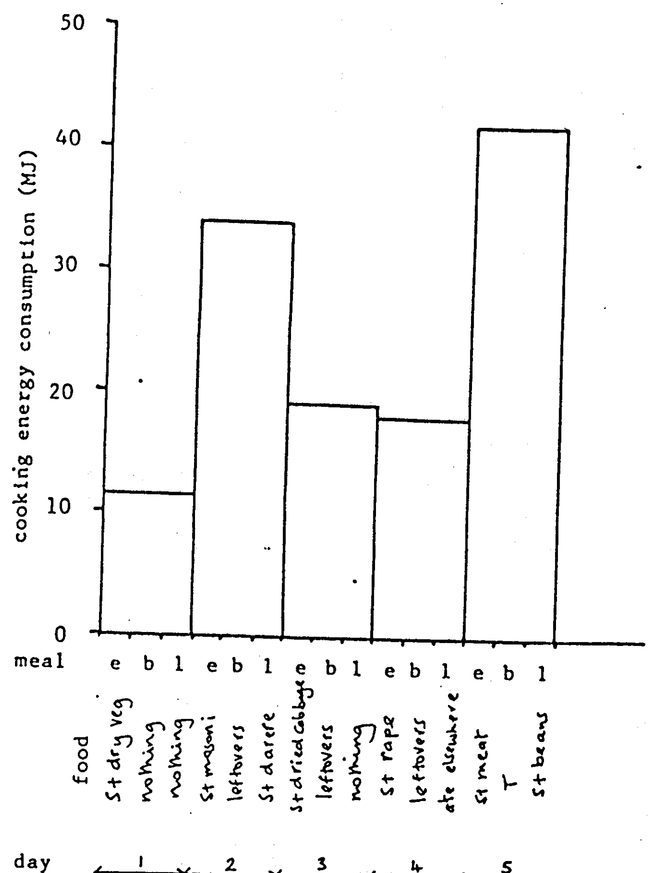


Fig F.8 Daily cooking energy consumption (per capita) and food cooked in Ellenvale (household D)



Key

<u>meal</u>
e - evening
b - breakfast
l - lunch

<u>food</u>
S - sadza;
S* cold sadza;
T - tea;
veg - vegetables;
darere - dried greens.

Fig F.9 Daily cooking energy consumption (per capita) and food cooked in Ellenvale (household E)