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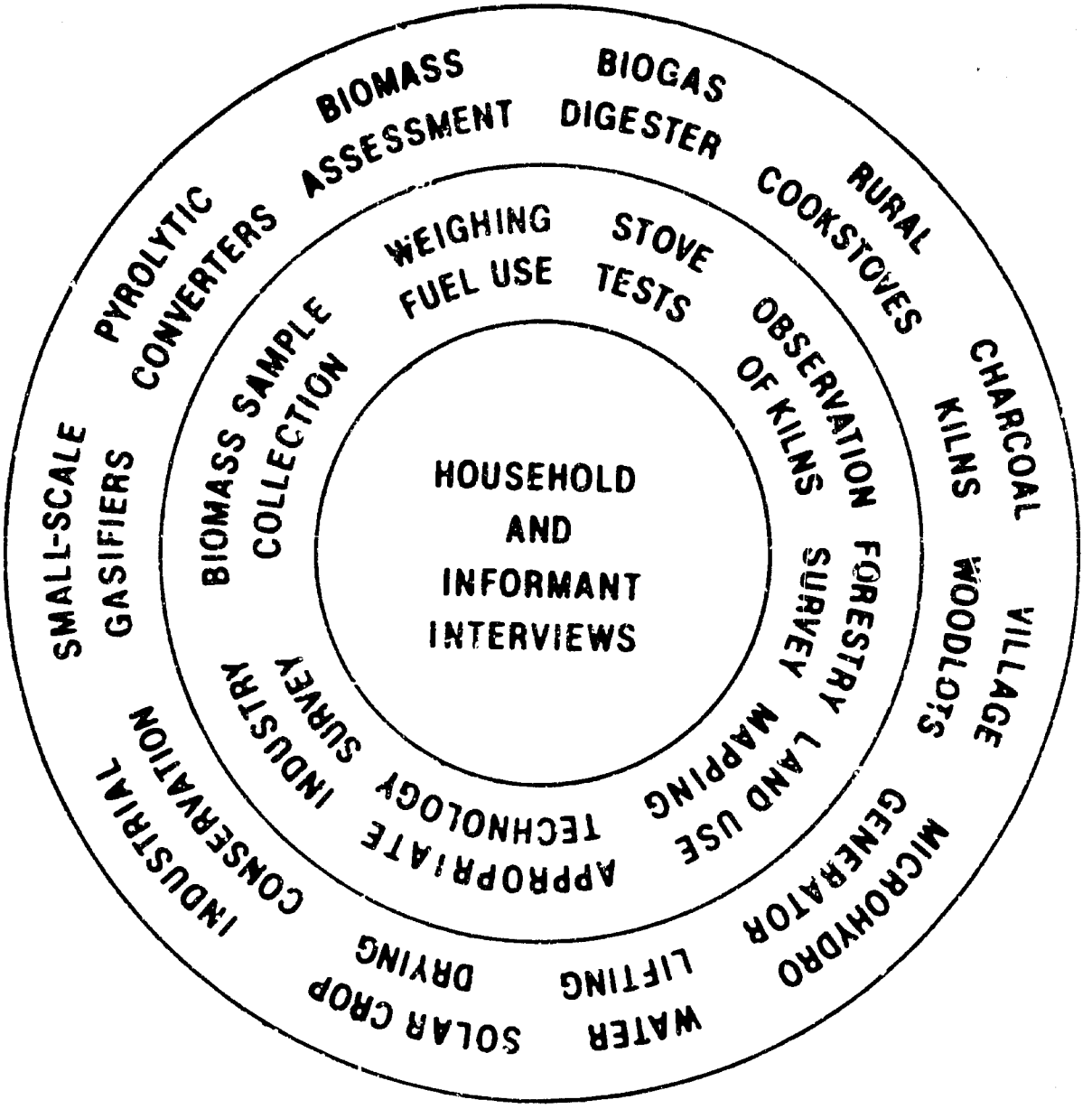

S T O V E S

META SYSTEMS INC THAI GROUP

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STOVES: EXPERIMENTS AND COOKING OBSERVATIONS

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Acknowledgement

This series of reports was produced through the joint efforts of professors and students from four of Thailand's leading universities, Chulalongkorn University Social Research Institute, Chiang Mai University Social Research Institute, Khon Kean University Faculty of Agricultural Economics, and Kessetsart University Faculty of Forestry and research personnel from Meta Systems Inc. Together they were responsible for the design, execution, and analysis of the baseline survey.

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Author's Warning

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Woe to him who wilfully innovates
While ignorant of the constant,
But should one act from knowledge of the constant
One's action will lead to impartiality,
Impartiality to kingliness,
Kingliness to heaven,
Heaven to the way,
The way to perpetuity,
And to the end of one's days one will meet with no danger.

Governing a large state is like boiling a small fish.

Lao Tzu

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Errata Sheet

LIST OF CHANGWAT OF THAILAND

In this report a variety of spellings have been used for the survey Changwat and village. The correct spelling and some of the variants are shown below.

Changwat

Buri Ram: Buriram, Burirum

Chanthaburi: Chantaburi

Chiang Mai: Chiangmai, Chaing Mai, Cheing Mai

Chon Buri: Chonburi

Kamphaeng Phet: Kampangphet, Kampaengpet, Kamphangphet, Kampangphet

Khon Kaen

Lampang

Nakhon Ratchisima: Korat

Nan

Phetchaburi: Petburi, Petchbura, Petchaburi

Roi et: Roi-et, Roi-Et

Si Sa Ket: Srisaket, Sisaket

Udon Thani: Udorn Thani, Udornthani

Villages

Bang Rahong: Bangrahong

Maikan Sangkan: Mailand Sangan

Pa Bhu: Pabhu

Wang Chapou: Wangchapoo

Klong Bon: Klongbon

Nong Wangyao: Nongvangyao

Pa Woe: Paver, Pawer

Pa Han: Pahan

Pa Nai: Panai

Si Chiengmai: Srichiengmai, Srichaiangmai

San Pa Tong: San Pa Toung

Samkhasantisuk: Sam Kha San Tisuk

Mai Ho Phra: Mae Ho Pra

Nong Buaeng: Nongbuadeang

OTHER TERMS

Household - Related individuals living in a house and eating together

House compound - Area around the house which is owned by members of the household and is often demarcated by a fence

Head of household - Male or female leader of the members of the household, usually the owner of the house

Head of village - Phuyaiban

Head of sub-district - Kamnan

Village - Muban

District - Amphoe

Province - Changwat

Errata Sheet (continued)

Phase I - Survey in Petchaburi, Korat, Srisaket, Kampangphet, and Lampang

Phase II - Survey in Songkla, Chantaburi, Roe-et, Udorn Thani, and Chiang Mai

Phase III - Survey in Nan, Burirum, and Chiang Mai

Delivered heat - The amount of energy content in the fuel burned

Captured heat - In cooking the amount of heat which is transferred to the cooking vessel

Moisture content - On a wet basis, weight of water as percentage of total sample weight

Heat or energy content - The high heat content of a substance at 0% moisture as measured in a bomb calorimeter

1 Unit of electricity - 1 kilowatt-hour, a billing unit used by the Provincial Electric Authority

6 1/4 rai = 2 1/2 acres = 1 hectare

jar lamp - small wick lamps

wick lamp - chimney or hurricane lamps

Rice Products - Straw residue in field,
- Stalk residue from threshing,
- Husk shell residue from milling
- Bran edible residue from milling

NEA - National Energy Administration of Thailand

NSO - National Statistics Organizationof Thailand

PEA - Provincial Electricity Authority

1. Introduction

Research into the design of improved cooking stoves should be conducted in three phases. The first phase concerns the way in which stoves are used in the village. The combination of stoves, fuels, food and methods of cooking vary within a village as well as on a regional basis. This combination affects the level of fuel consumption per capita for cooking. The survey data relevant to this first phase of research is contained in this volume, and the "Cooking, Lighting, Heating" Volume. The letter describes the combination of fuel, stove, and food and cooking which was recorded as part of the household questionnaire and the physical measurements of fuel consumption. This volume describes the different effects of operational procedures on stove efficiency.

The second phase in the research on improving stove design involves standardized testing of the different indigenous designs to determine how design affects fuel consumption. This research has been undertaken by Messrs. Sherman and Srison in their study of comparative stove efficiencies for the United Nations High Commission for Refugees in Thailand.* The third phase involves the modification of existing designs and introduction of new designs to perform the tasks identified in the first phase with lower fuel consumption.

1.2 Stove Survey

Various observations on the use and efficiency of household cooking stoves were recorded as part of the baseline survey. These observations were made in support of the project component for improving the design of rural cook stoves. The basic objective was to learn what types of stoves the villagers use and how they operate them. The stove survey involved three activities, a boiling water test, a cooking test and a cooking observation. The first two tests were conducted to measure the fuel consumption of different stove designs and to determine the factors which affect fuel consumption including the stove, the fuel, the type of cooking and the method of operation. The cooking activity was observed in order to identify an appropriate stove testing methodology to be used in the laboratory.

All three activities were under the direction of the household cook with the survey personnel acting as observers. In the first activity the heat captured in boiling water was compared with the amount of energy released from the fuel in order to obtain an absolute measure of efficiency. In the second activity the fuel consumption for cooking food was compared with the quantity of food cooked. In the third activity, the preparation of a typical meal was observed and the sequence of food preparation and cooking recorded.

About 130 boiling water tests, 150 cooking tests and 100 cooking observations were conducted. About half the stoves observed used charcoal and half used wood. Only a few units used other forms of biomass.

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*Their study concentrated on identifying the minimum fuel cost for supplying the refugee camps. The testing was directed towards Khmer cuisine.

Traditional Thai bucket stoves were the most common design although a number of different wood stoves were exmained.

2. Analysis of Data

2.1 Methodology--Testing Procedures

The boiling water test and the cooking test were conducted using the same fuel and cooking utensils. In the first test a measured quantity of water was boiled in a cooking vessel normally used by the household. The operation of the stove and the determination of the appropriate quantitites of fuel and water were left to the household cook. The survey supervisor was responsible for measuring the volume of water and weight of fuel at the start of the test and at the conclusion.

After the fuel was ignited and a sufficient time allowed for the stove to preheat, the cooking vessel was placed on the stove. The survey supervisor recorded the temperature of the water at the start of the experiment and at 10 minutes and 20 minutes after the vessel has been placed on the stove. The water in the vessel was brought to a boil. The time at which the water began to visibly boil was recorded. The water was boiled for approximately 30 minutes,* then the cooking vessel was taken off the stove and the fuel remaining in the stove was removed and smothered in ash. The amount of water left in the cooking vessel was weighed after it had cooled.* The amount of fuel remaining was weighed after allowing a suitable time for the fuel to loose its heat. A sample of the fuel used in the cooking test was collected and brought back to Bangkok where a moisture test was performed. In some instances the sample was also tested for calorific value.

The calculation of the stove conversion efficiency was made by comparing the heat value released from the burning fuel and the heat captured in the water. The calculation did not use the standard formula** which is used when the heated water is measured immediately after being removed from the stove.

If the water is measured immediately after the pot is removed from the stove and the water is at 100°C, the following formula should be used;

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* A period selected a priori to approximate the period of boiling rice; experimental times were within a few minutes of this norm.

*The original instructions were to measure the water immediately after the vessel was removed, but this proved to be difficult and the supervisors usually allowed the water to cool before pouring it into the measuring cup.

**Stove Testing Procedures, S. Joseph, ITDG, 1980.

$$E = \frac{w_i \quad T + 540\ w}{(1-M_c)\ e\ W} = \frac{E_{heat\ all\ water} + E_{vaporize\ water}}{E_{fuel\ burned}} \qquad (1)$$

where $T = 100-T_i$ (C)

$w = w_i - w_f$ (kg)

$W = W_i - W_f$ (kg)

T_i = initial temperature of water

w_i, w_f = initial and final quantity of water (kg)

W_i, W_f = initial and final quantity of fuel (kg)

M_c = moisture content of fuel on a wet basis (decimal)

e = heat value of oven-dried fuel (Kcal/kg)

Where the water is allowed to cool after being removed from the stove, the heat in the water (w_f T) is lost partly through additional evaporation and partly through conduction and convection losses to the surrounding air. Therefore, the total amount of energy captured in the water up to the time the pot was removed from the fire is less than in formula (1) but more than in the following formula (2), which assumes no heat lost into the air.

$$E_1 = \frac{w(\ T + 540)}{(1-M_c)\ e\ W} = \frac{E_{heat\ and\ boil\ water}}{E_{fuel\ burned}} \qquad (2)$$

For the experiments in this survey, formula (2) for E_1 was used as a basis to calculate stove efficiency.

The selection of stoves to be tested was based on two objectives; first to choose stoves commonly used by the villagers and second to choose stoves-fuel combinations which the survey supervisors and enumerators had not seen before. As a result, about half the experiments, 72 out of 132, were performed on charcoal burning stoves, mostly of the bucket design. The bucket design has many variations, some with cylindrical walls, some more conical in shape, some with outer walls of thin sheet metal, some made only of clay, and some with doors which can be used to block off the primary air flow. For all of the stoves that were tested a photograph or drawing was made; however, it was not possible in this analysis to compare the experimental results with differences in structure or features identified from these photographs.

The other group of stoves tested were primarily wood burning units. These stoves included simple three rock stoves; horseshoe shaped units of stone, clay or cement; single or double ported enclosed stoves made of clay, mud or brick; and traditional bucket stoves modified to accept wood fuels. Other designs tested were sawdust and rice husk-burning units made with metal cans and the economical stove made of cement and steel. While most of the experiments were made using either charcoal or wood, some

tests were performed using sawdust, rice husk, coconut palm frond and other forms of biomass.

2.2 Variations in Observed Efficiencies for Basic Models

In this section, the measured efficiencies of the various tests will be discussed. Before presenting the data it is important to consider the range of variation which occurred during the testing. These experiments were not carried out in a laboratory, nor were they carried out in a single location with a single fuel. Instead, the tests were made in individual households in the different villages under the operational direction of the cooks within the household. The survey personnel were assigned the task of observation but did not directly control experimental variables such as quantity of fuel, quantity of water, selection of cooking vessel* or selection of type of fuel. The only controls exerted were the approximate length of time the boiling water experiment would continue once the water had begun to boil and the procedures for dousing the fire at the end of the experiment and measuring the remaining fuel once it had cooled. The variation in types of fuel was analyzed by collecting samples of the fuel and measuring the moisture content and in some cases the heat value of the fuel. As was observed in the "Biomass samples" volume, there is a range of heating content per unit dry weight for charcoal, fuel wood and other forms of biomass. Since not all samples were tested for heat value, standard values had to be used and the effects of this variation could not be analyzed. The standard value were derived in the volume "Biomass Samples" from the average values of the distributions shown in Figure 1 through 3.

The variation in cooking vessels used was in shape not material, since almost all families used aluminum cooking vessels. However, the range in size and shape of the vessels was considerable. There was also considerable variation in the size of the stoves and the relative size of the vessels. Although data was collected on the size of the stove and the cooking vessel, this information was included in the analysis only in a very aggregate form. Another source of variation was the amount of wind passing through the cooking area at the time the experiment was performed. The survey personnel recorded information on the general level of air flow, but in most experiments the stoves were located inside the house so that any breeze would be attenuated.

2.3 Charcoal Stoves--Boiling Waters Tests

The boiling water tests were conducted for 72 charcoal stoves. All the stoves were variations of the basic Thai bucket stove. The ratio of captured heat to released heat was computed according to the formula (2) for stove efficiency E_1. The distribution of the results is shown in

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*No covers were used on the cooking vessels to prevent condensation of the steam to reenter the pot.

FIGURE 1

CUMULATIVE DISTRIBUTION OF OBSERVATIONS OF ENERGY CONTENT OF WOOD

(0 % MOISTURE CONTENT)

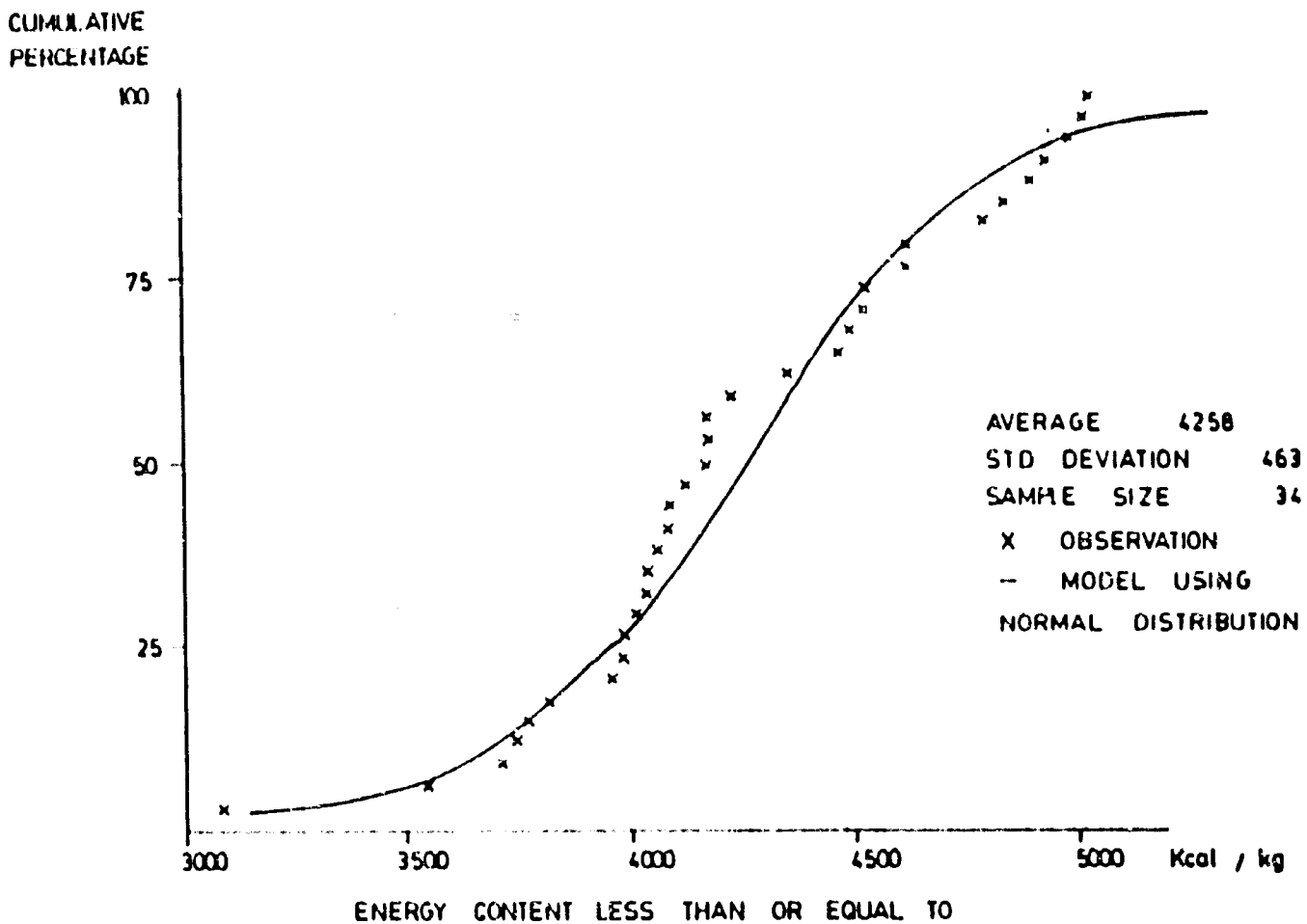

FIGURE 2

CUMULATIVE PERCENTAGE FOR OBSERVATIONS ON THE ENERGY CONTENT OF CHARCOAL

(0% MOISTURE CONTENT)

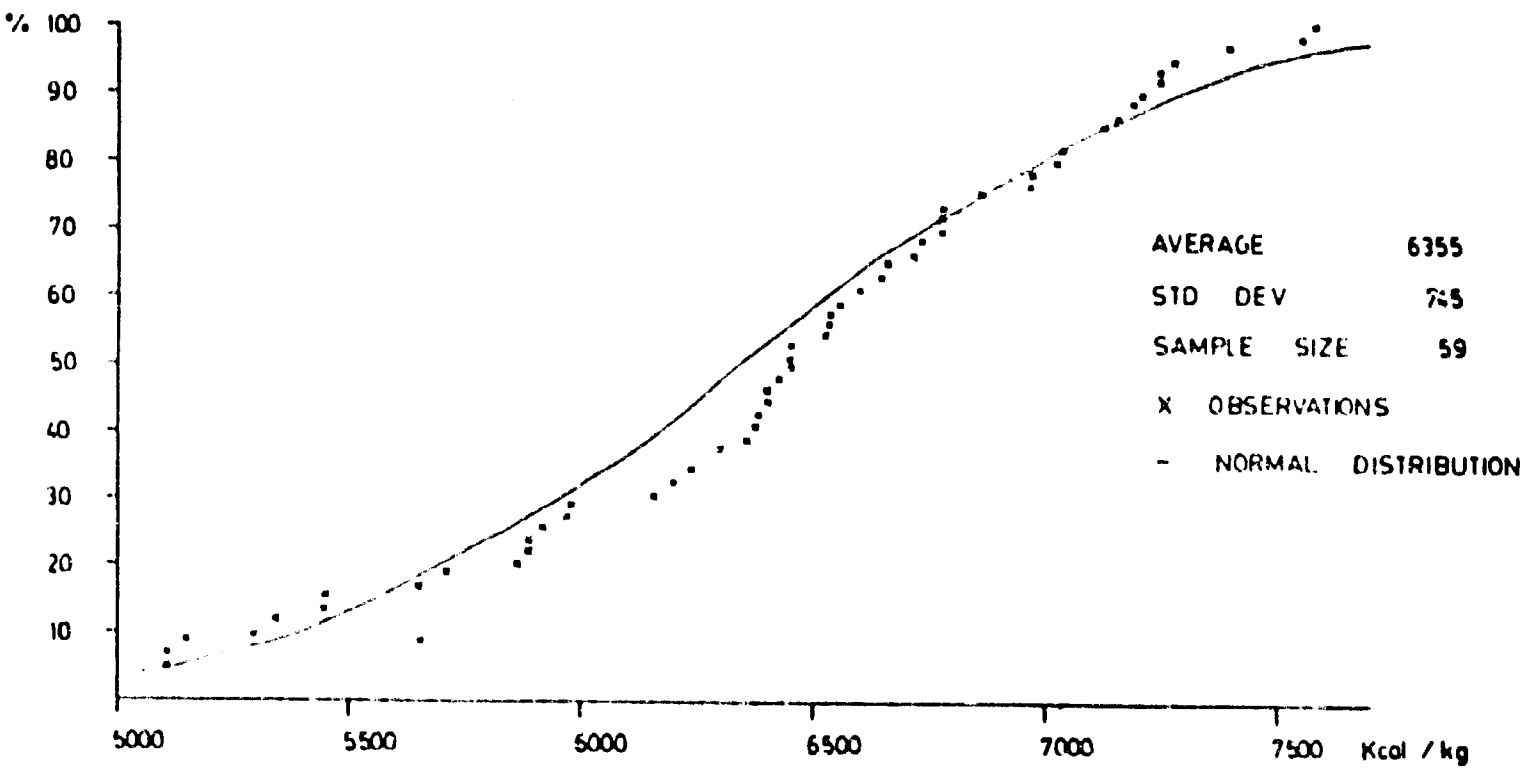

FIGURE 3

BIOMASS ENERGY CONTENT

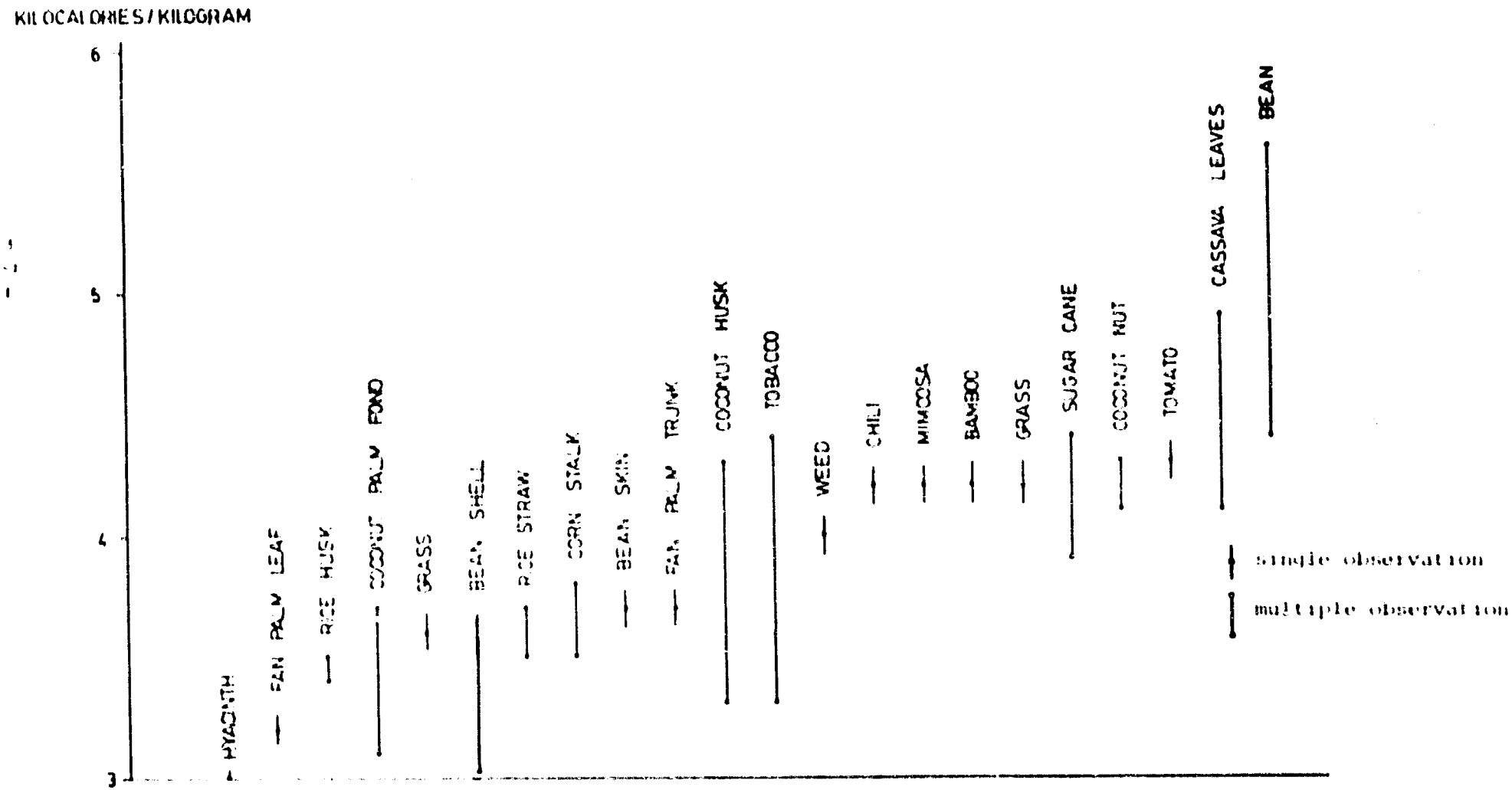

Figure 4. The average efficiency was 24 percent and the standard deviation was 15 percent. If the sample size is edited to remove those results above 35 percent and below 6 percent that are probably due to inaccurate field measurements or unusual operating procedures, then the average and standard deviation are 22 percent and 7 percent, respectively. This edited sample resembles a normal distribution as indicated in Figure A-1. The edited sample, which includes some 52 tests, is used in the subsequent analysis since the purpose is to identify the factors which affect efficiency and unlikely values would detract from this analysis.

A possible source of error in calculating the stove efficiencies was the use of standard values for the moisture content and heat value of the fuels. The effect of this source of error has been examined in Figure 4, where calculations with measured heat value and moisture content are identified separately from those with standard values (6,360 Kcal/kg and 6 percent moisture wet basis) and those with only measured moisture content. The three distributions are sufficiently similar so that the combined sample could be used in the analysis.

The quantities of fuel and water used in the boiling water tests were thought to affect stove efficiency. The graphs in Figures 5 and 6 indicate that individually they had no significant effect. However, the quantity of fuel relative to the quantity of water does have an effect as can be seen in Figure 7. A regression analysis was conducted on the relationship between stove efficiency, E_1, and the ratio of water to fuel. An extended sample including efficiency measurements between 1 and 40 percent was used since the water-to-fuel ratio explains some of the exceptionally low efficiency measurements. The sample was edited to exclude ratios greater than 11 since these values seem unlikely. The resulting correlation coefficient was .80 with the efficiency increasing by 5 percent for an increase of 1 in the water-to-fuel ratio. This relationship is logical. If there is a small quantity of water relative to fuel then the water cannot absorb the heat from the burning fuel at a sufficient rate and considerable heat will be lost to the air. On the other hand, with a large quantity of water relative to fuel, the water will absorb all of the heat conducted through the walls of the cooking vessel.*

An attempt to establish a relationship between charcoal moisture content and stove efficiency proved unsuccessful as can be seen in figure 8. The relatively low moisture content of charcoal should have a negligible effect when compared to other factors and the accuracy of the moisture content measurement was not sufficient to detect any effect on efficiency.

Another factor which was thought to be important for stove efficiency is the rate of combustion of the fuel. Although it was not possible to measure this factor in the field, two indirect measures, the quantity of fuel burned and the time required to boil the water, were recorded. It is assumed that the larger the quantity of fuel burned and/or the shorter the

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* This finding is discussed in greater detail in Appendex A-4.

FIGURE 4

CHARCOAL STOVE EFFICIENCIES

BOILING WATER TESTS

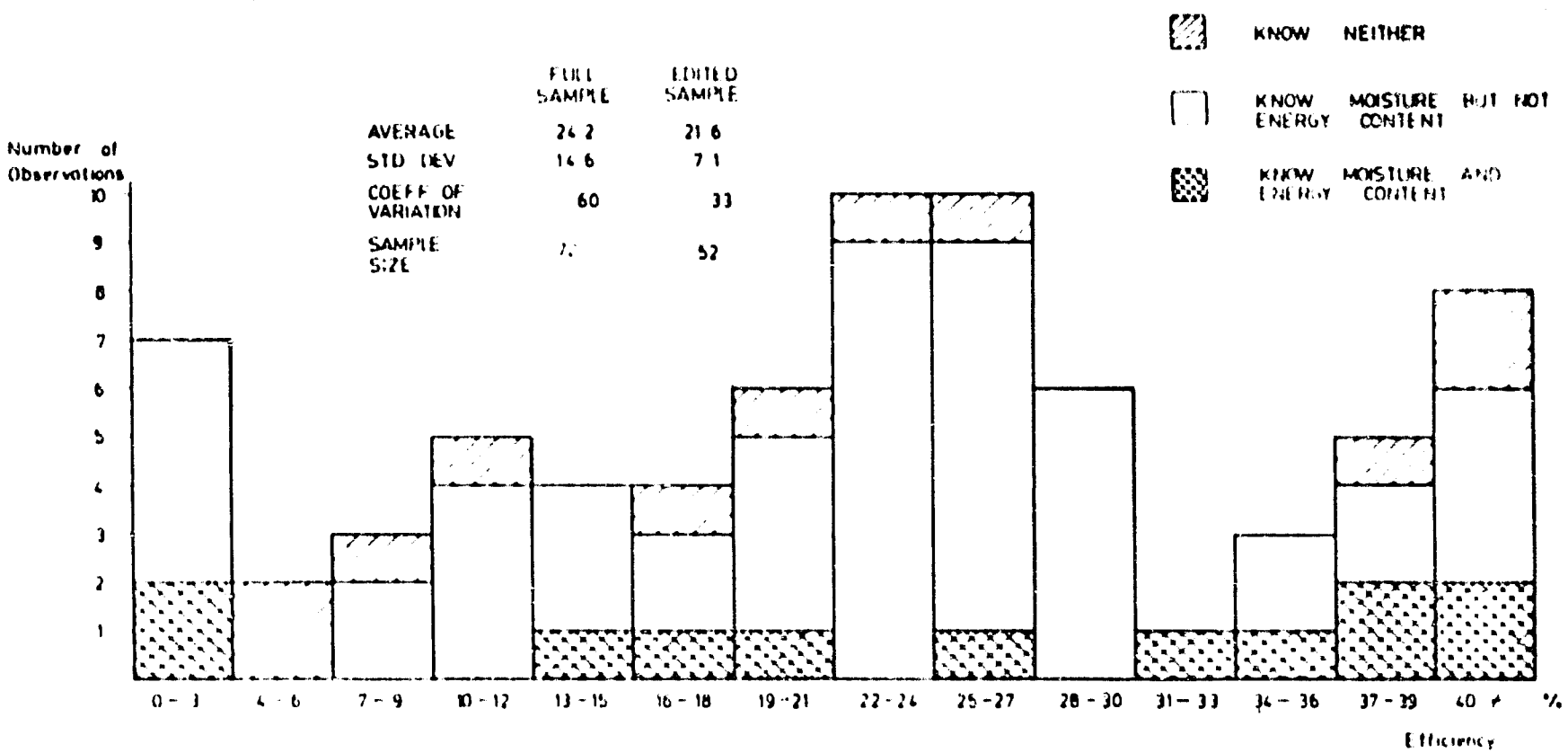


FIGURE 5

EFFECT OF QUANTITY OF FUEL ON EFFICIENCY OF CHARCOAL STOVES

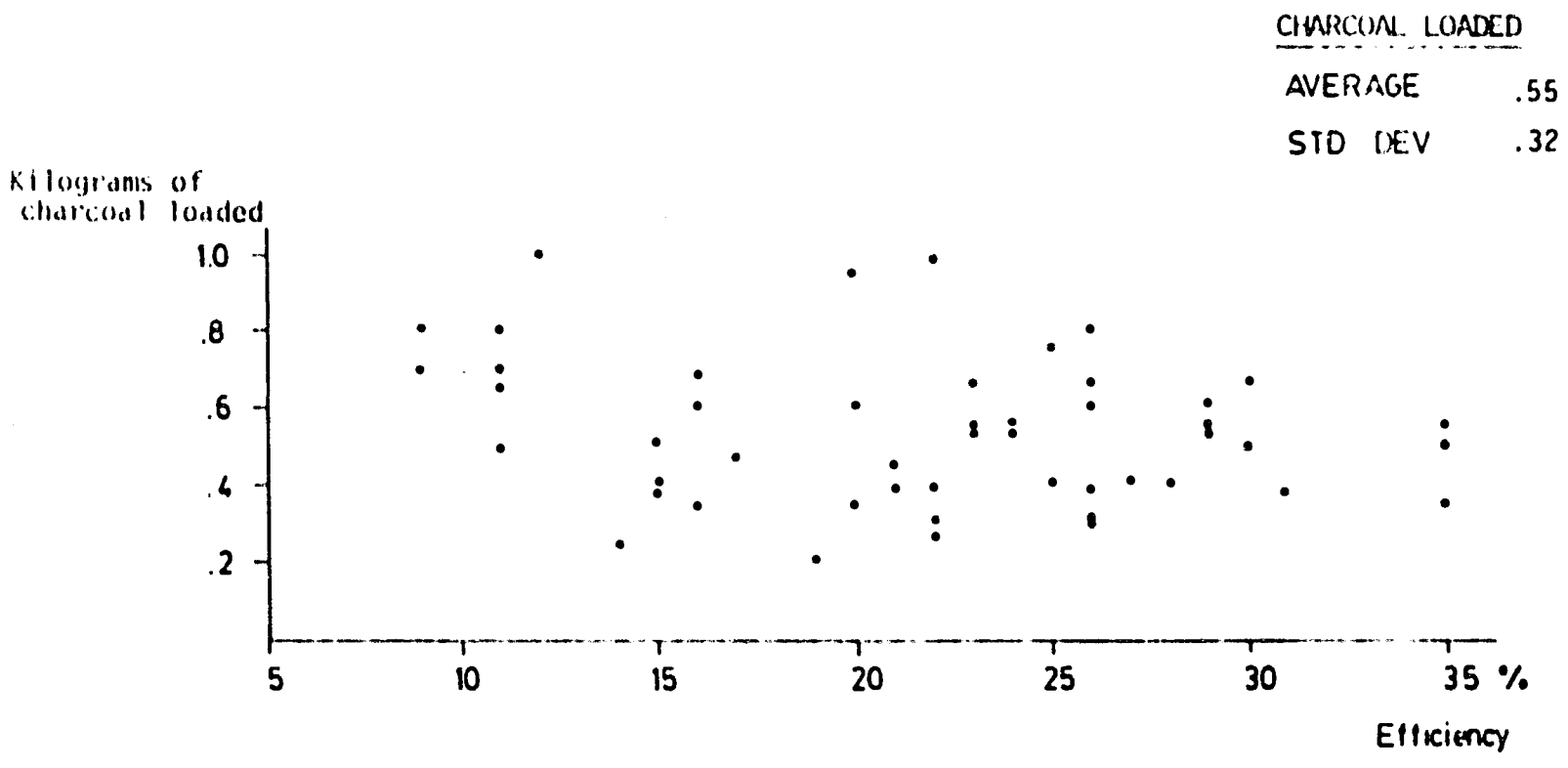


FIGURE 6

EFFECT OF QUANTITY OF WATER ON EFFICIENCY OF CHARCOAL STOVES

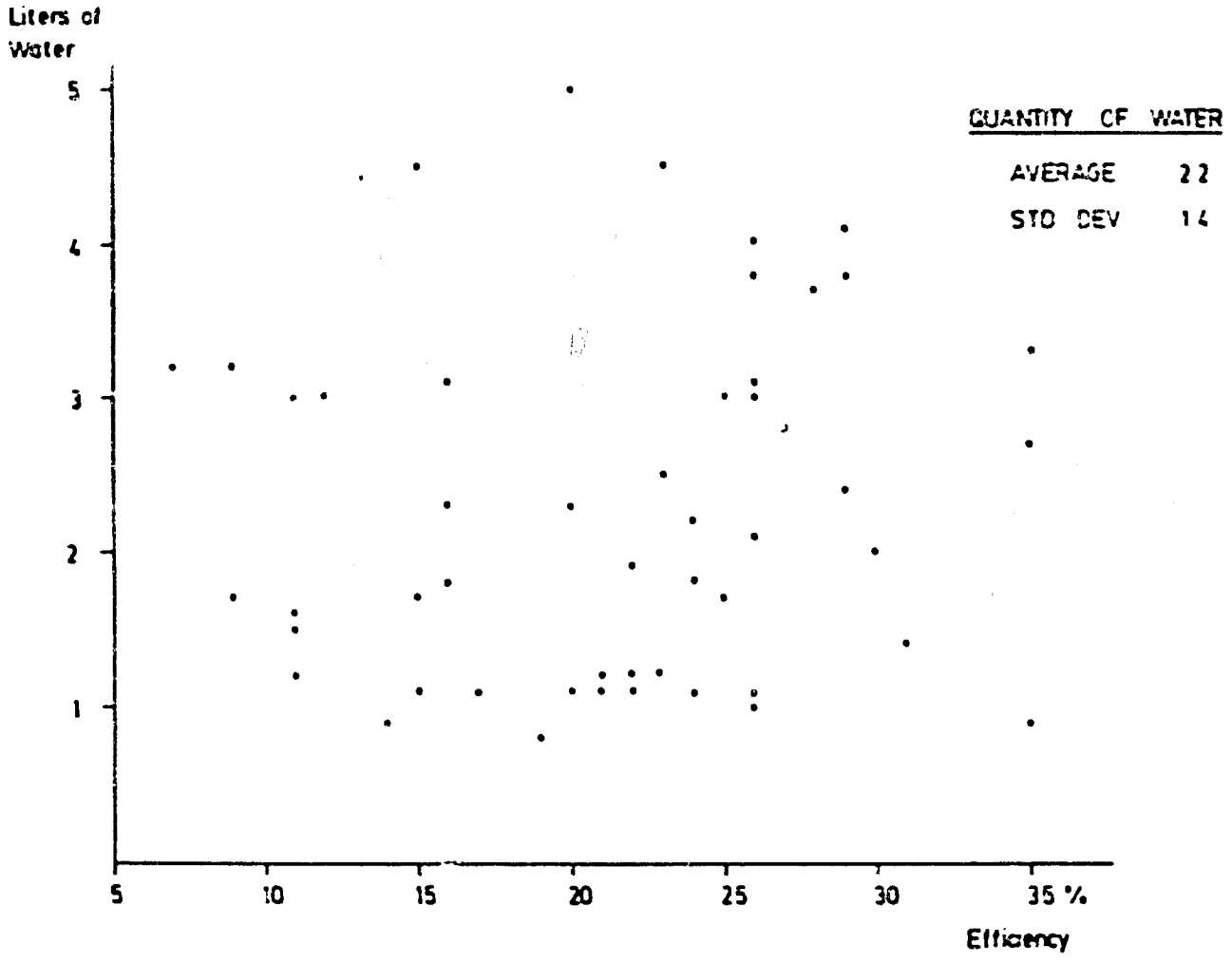


FIGURE 7

EFFECT OF WATER TO FUEL RATIO ON CHARCOAL STOVE EFFICIENCY

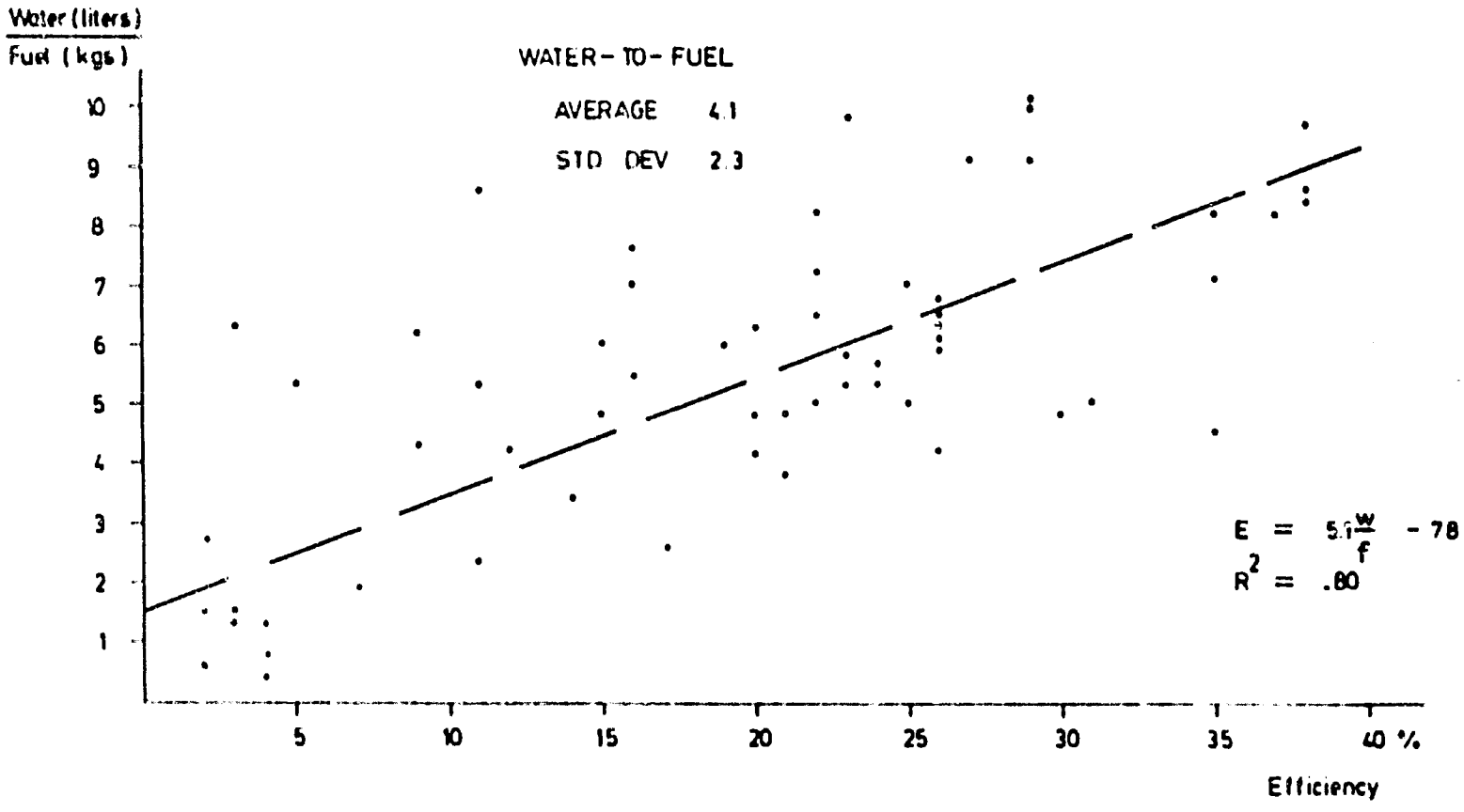
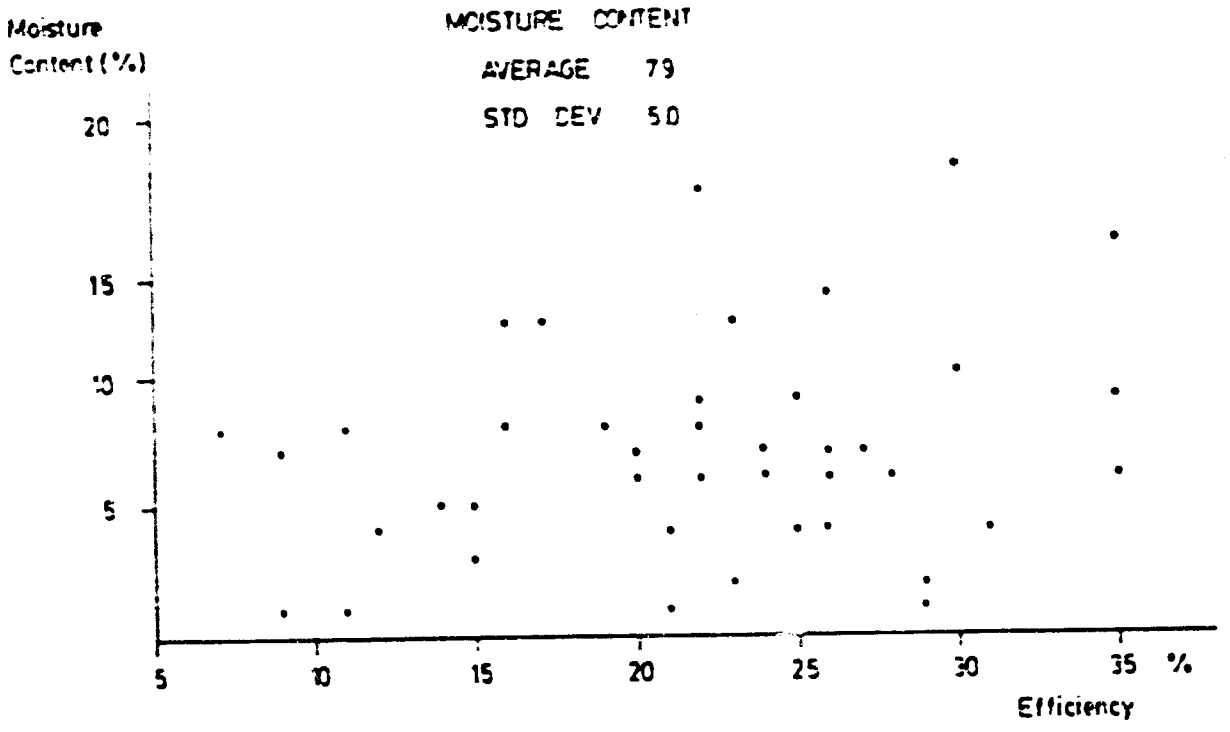


FIGURE 8

EFFECT OF MOISTURE CONTENT OF CHARCOAL ON STOVE EFFICIENCY

(% wet basis)



time to boil, the greater the rate of combustion. No relationship between stove efficiency and time to boil could be established (see figure 9) but the efficiency appears to drop off for quantitites of fuel away from the median value (see figure 10).

The matrix in table 1 combines information on boiling time and fuel loaded. The efficiencies are distributed around higher values for the boiling times of 13-17 minutes and for fuel loads less than or equal to one-half kilogram. The effect is not dominant, but may be significant given the variation in other factors and the difficulty in measuring the time to boil.

The physical factors which might affect the efficiency of the charcoal stoves include the size of the stove and cooking vessel and the presence (or absence) of wind. These factors were examined together with the water-to-fuel ratio in table 2. Clearly the water-to-fuel ratio is the dominant factor. The difference in efficiency between experiments with ratios less than 4 and greater than 4 was at least 12% with a confidence limit of 5%. The other factors appear to have little impact. Larger stoves have a slightly lower average efficiency than small stoves, 22% versus 25% for large water-to-fuel ratios. (The confidence level that the difference is greater than 1% is only .25). Larger pots were more frequently used on both large and small stoves, but the difference in average efficiency with pot size was negligible. The wind was not a significant factor, probably because most tests were conducted indoors in an area protected from drafts.

Two other potential factors, the shape and material of the cooking vessel, turned out not to vary with the experiments. With only one exception the cooking vessels were made of aluminum and all but five were cylindrical rather than curved inward at the top.

The villagers use a variety of starter fuels when cooking on charcoal stoves. These include wood kindling and tree resins. The starter fuel can represent a significant source of energy as shown in the histogram in figure 11. On average the starter fuel contained about 7% of the heat value contained in the charcoal which was combusted, but values as high as 25% were observed. The stove efficiency (E_1) calculations did not include the heat content of the starter fuels since the starter fuel is burned prior to placing the vessel on the stove. A comparison of the relative quantity of energy in the starter fuel and the efficiency, E_1, did not indicate that a larger percentage of starter fuel led to higher values for efficiency (see figure 12). Since the starter fuel accounts for less than 10% of the total combustion heat produced and most of this heat is generated before the pot is placed on the stove, the effect on charcoal stove efficiency was negligible. (This is in contrast to wood stoves where starter fuel energy affected efficiency.)

The average time between the ignition of the starter fuel and placing the pot on the stove was 8 minutes; however, the distribution of times was considerable ranging from 1 to 15 minutes (see the histogram in figure 13). The distribution of time between ignition and boiling was also considerable ranging from 11 to 51 minutes (see figure 14). The average value was 22.5 minutes implying that the average time the pot spends on

FIGURE 9

EFFECT OF TIME TO BOIL ON STOVE EFFICIENCY

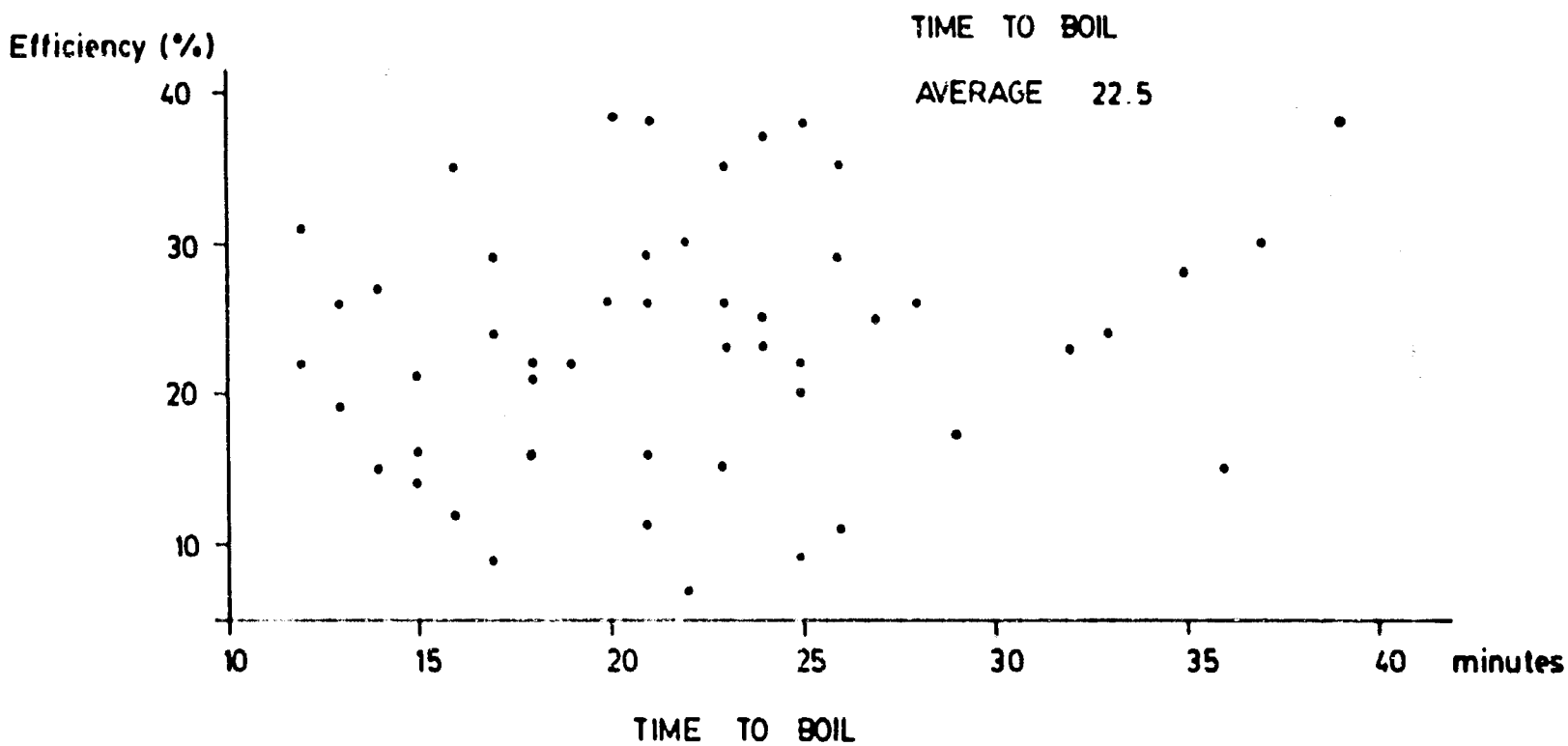


FIGURE 10

EFFECT OF QUANTITY OF FUEL BURNED ON EFFICIENCY OF CHARCOAL STOVES

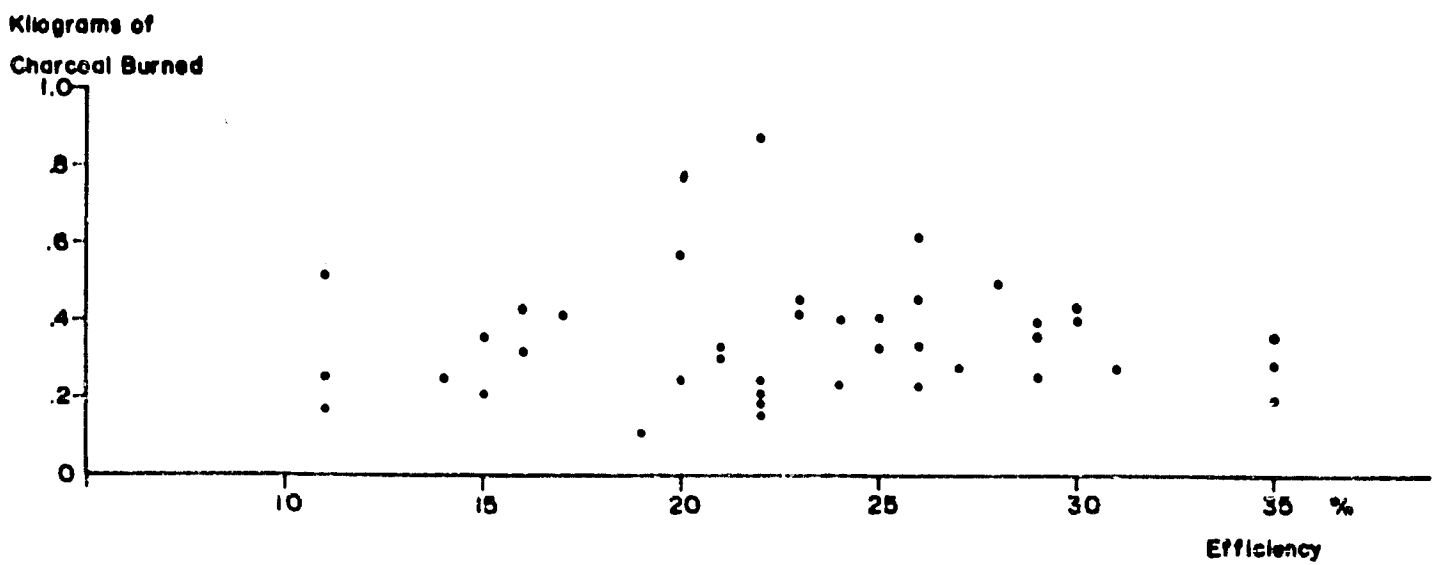


Table 1

Charcoal Stove Efficiency Matrix

- number of experiments

Fuel Loaded (kg)	Boiling Time (min.)	Efficiency (%)			
		5-20	21-26	27-40	All
≤ .5	≤ 12	4	3	2	9
	13-17	1	4	2	7
	≥ 18	1	6	-	7
	all	6	13	4	23
> .5	≤ 12	3	2	-	5
	13-17	3	7	2	12
	≥ 18	4	4	2	10
	all	10	13	4	27
all	≤ 12	7	5	2	14
	13-17	4	11	4	19
	≥ 18	5	10	2	17
	all	16	26	8	50

Table 2

Bucket Charcoal Stove Efficiency Matrix

STOVE SIZE	POT SIZE	WATER : CHARCOAL RATIO			
		≤ 4		> 4	
		WIND		WIND	
		NONE	SOME	NONE	SOME
LARGE	> 22	3 2.2 22	3 4.3 58	9 21.0 35	10 23.1 31
	≤ 22	nx	2 7.0 80	1 35.0 na	1 11 na
SMALL	> 22	nx	nx	8 26.1 25	12 24.9 25
	≤ 22	2 18.0 27	1 17.0 na	1 17.0 na	3 28.0 32

nx - No experiments

na - Not applicable

upper left - Number in sample

lower right - coeff. of variation (x 100)

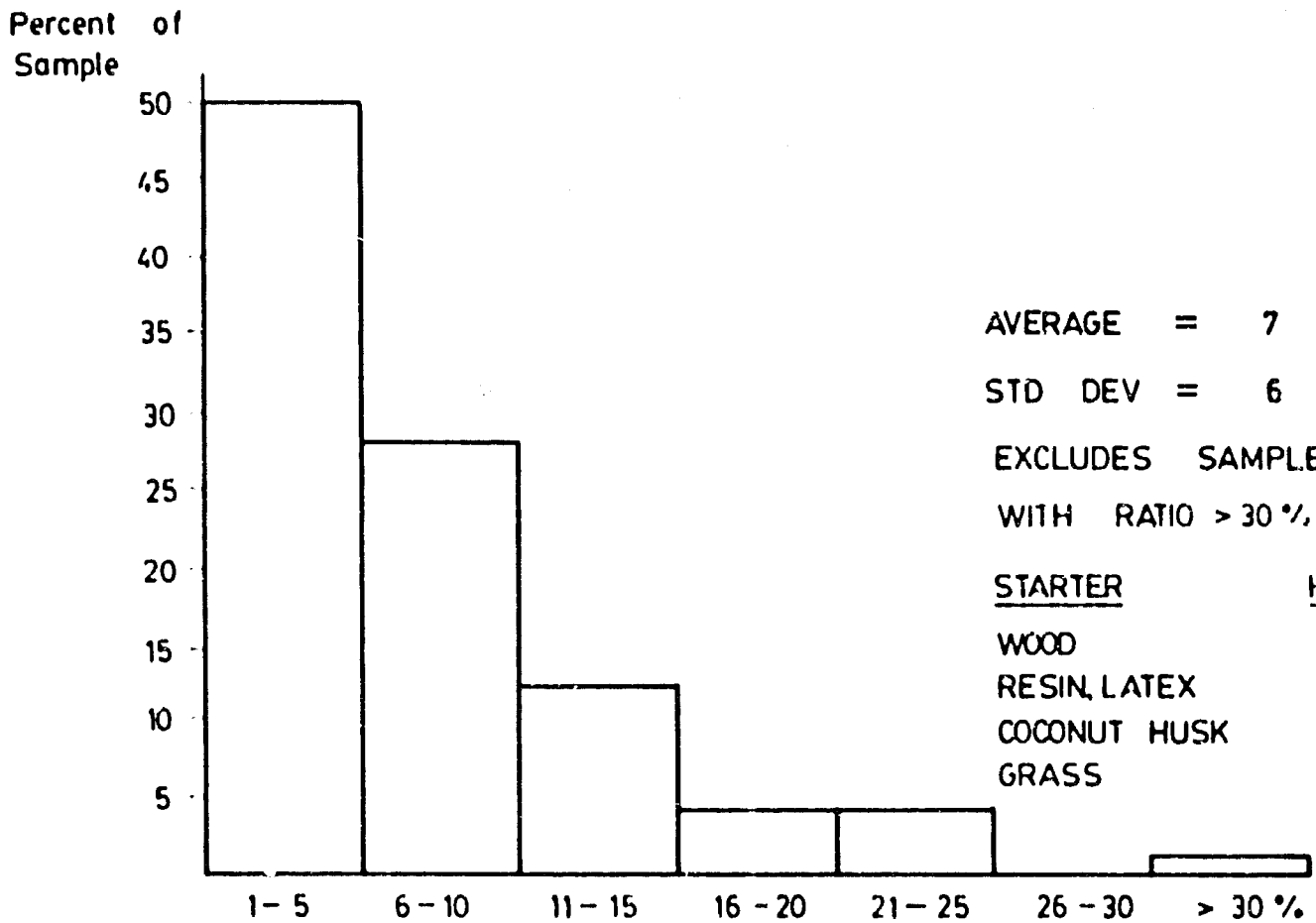
middle - average efficiency (%)

Sample edited to exclude experiments with % greater than 38%.

Pot size refers to the pot rim diameter in centimeters.

FIGURE 11

CHARCOAL STOVES : STARTER FUEL AS PERCENTAGE OF PRIMARY FUEL BURNED



AVERAGE = 7

STD DEV = 6

EXCLUDES SAMPLE WITH RATIO > 30 %

STARTER	HEAT VALUES	MOISTURE
WOOD	4260	14 %
RESIN, LATEX	9700	15 %
COCONUT HUSK	3820	31 %
GRASS	3600	39 %

FIGURE 12

CHARCOAL STOVES : EFFICIENCY VERSUS STARTER FUEL ENERGY

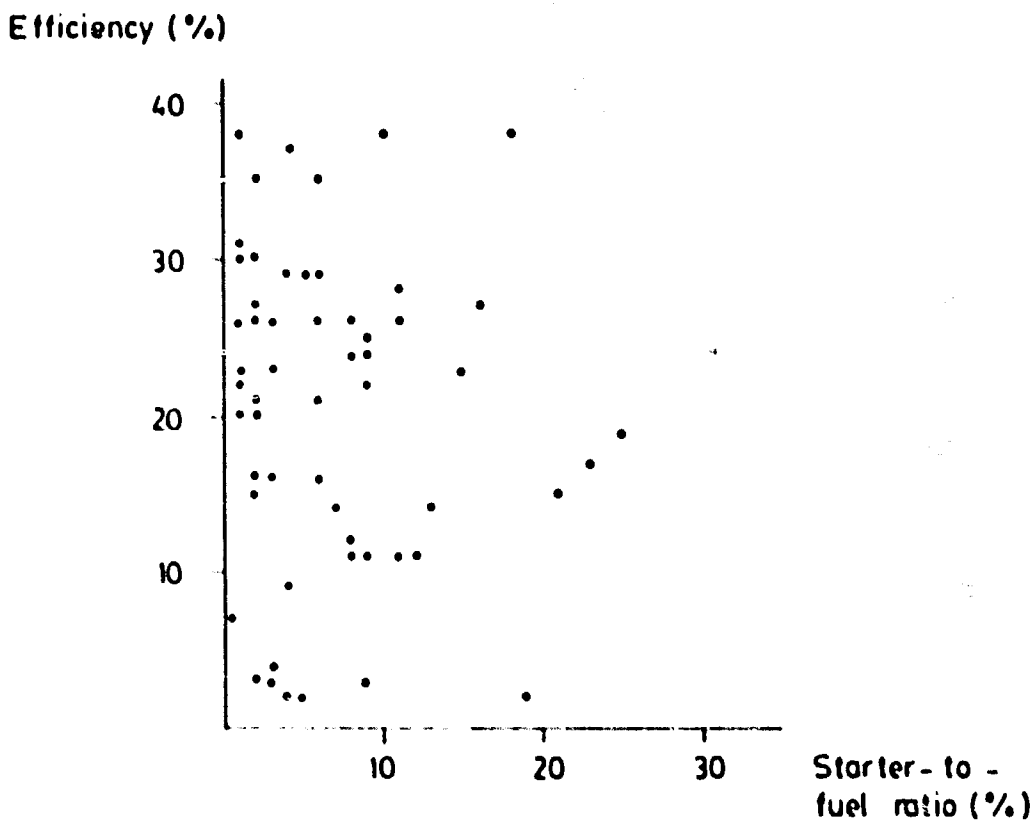


FIGURE 13

PERIOD OF TIME FROM IGNITION TO PLACING POT ON STOVE - CHARCOAL STOVES BOILING TEST

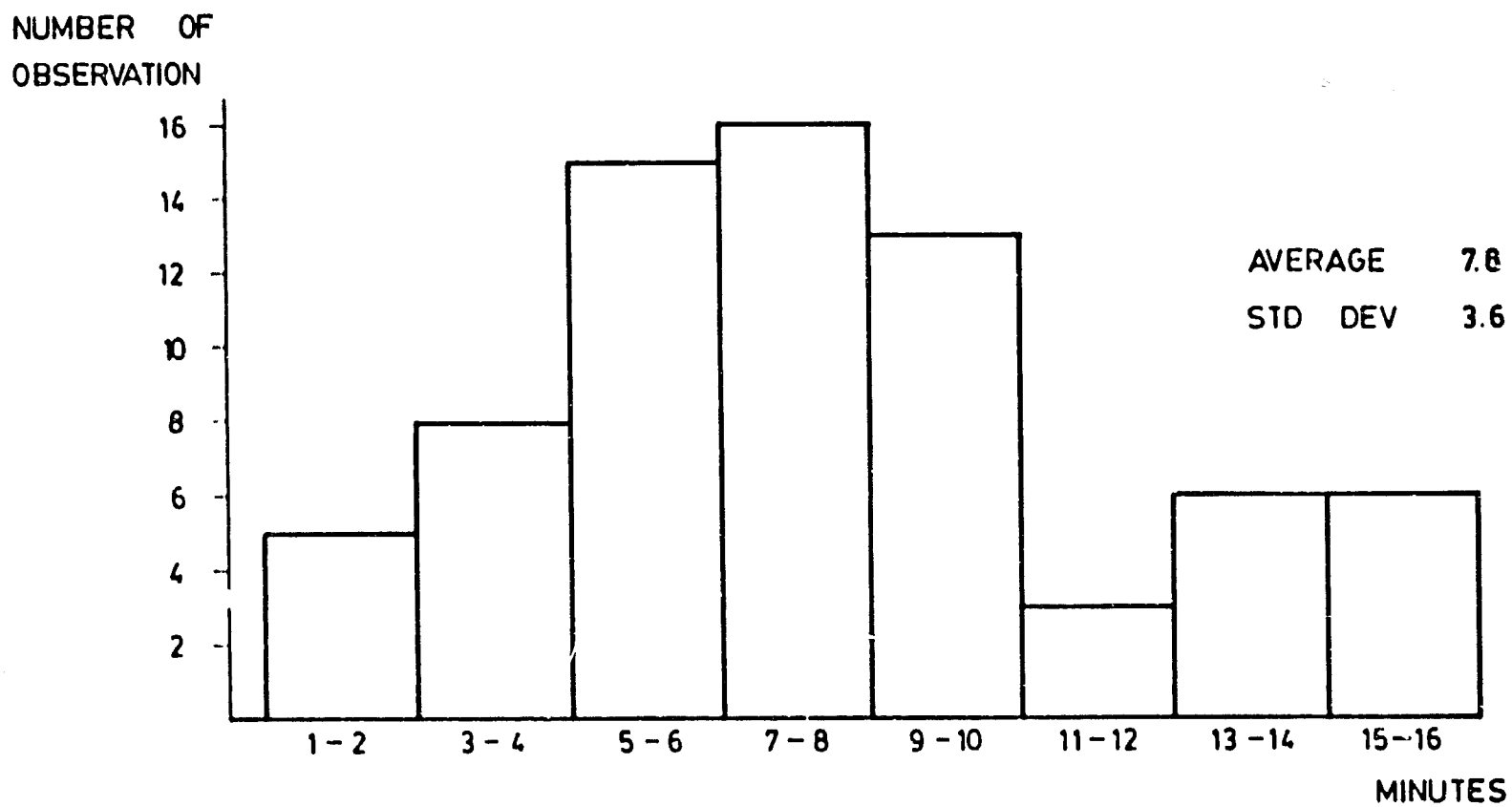
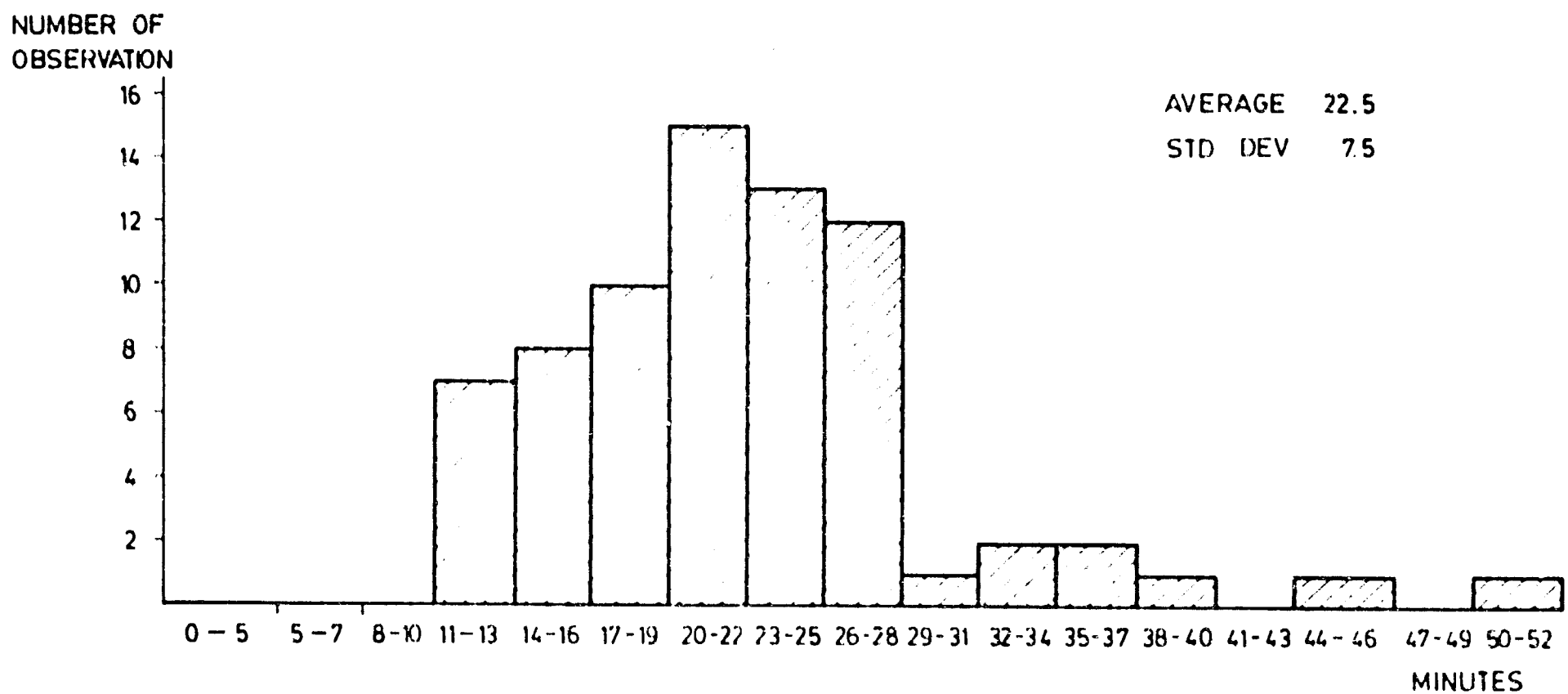


FIGURE 14

PERIOD OF TIME FROM IGNITION TO BOILING WATER - CHARCOAL STOVES



the stove is 14.5 minutes. If a normal probability distribution is assumed for sample value of the three time variables, t_1-ignition to start of heating water, t_2-start heating water to boiling water, and t_3-ignition to boiling, then the three distributions would be as shown in figure 15.

The rate of increase in temperature was recorded at ten minute intervals for all stove experiments. In order to combine the results from different stove tests, the percentage of the time elapsed between placing the pot on the stove and observing boiling water was compared with the percentage of the rise in temperature from ambient to 100°C. From the data in figure 16, it can be seen that the temperature rise began slowly and then increased more rapidly as the temperature rose close to 100°C. The data points finally rise above the line that equates the percentages of temperature increase with the percentage of time elapsed.* The increasing rate of heat generation implies that the measured efficiency will vary depending on the length of time that the experiment is conducted.**

2.4 Wood Stoves--Boiling Water Tests

The boiling water tests were conducted on 59 different wood stoves. These stoves were of several different designs. About 15% of them were traditional bucket stoves modified for use with wood. Another 15% were three rock stoves. Open horseshoe, enclosed horseshoe, and rectangular clay stoves each accounted for about 10% of the stoves tested. Despite this variation in design, the variance in recorded efficiencies was no greater than for the charcoal stoves. The average efficiency was 15% with a standard deviation of 9%. If the questionable efficiency measurement (those less than 5% and greater than 27%) are excluded, then the average and standard deviations are 13.5% and 4.5%, respectively.

The effect of the use of standard values for moisture and heat content (4.26 Kcal/gm and 14% wet basis) on unmeasured samples is examined in figure 17. As with charcoal stoves, no obvious bias was observed, therefore all the results for efficiencies between 5% and 27% were used in subsequent analysis. This sample includes some 53 measurements.

The variation in quantity of fuel loaded was considerably greater for wood stoves than for charcoal stoves, but a comparison between the quantity of fuel and the efficiency revealed no clear relationship (see figure 18). Similarly a comparison between the quantity of water and efficiency revealed no significant relationship. If the two factors are combined in to a water-to-fuel ratio and the stoves are divided into

---

*The data points near the 100% temperature are somewhat misleading since the total time is based on time of visible boiling which in fact occurs after the water reaches 100°C.

**The RFD has conducted additional experiments related to this phenomenon which are discussed at the end of section 2.4.

FIGURE 15

HEATING TIMES FOR CHARCOAL STOVES - PROBABILITY DISTRIBUTION FOR BOILING WATER TESTS

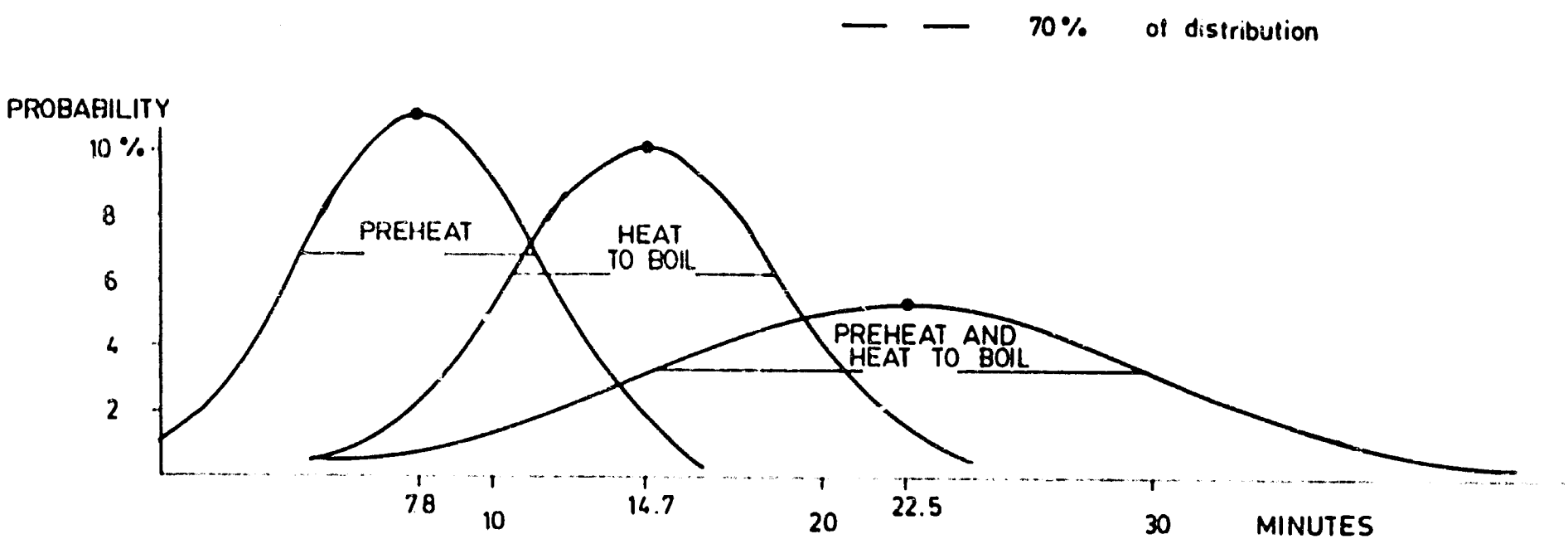


FIGURE 15

RATE OF TEMPERATURE INCREASE – CHARCOAL STOVES

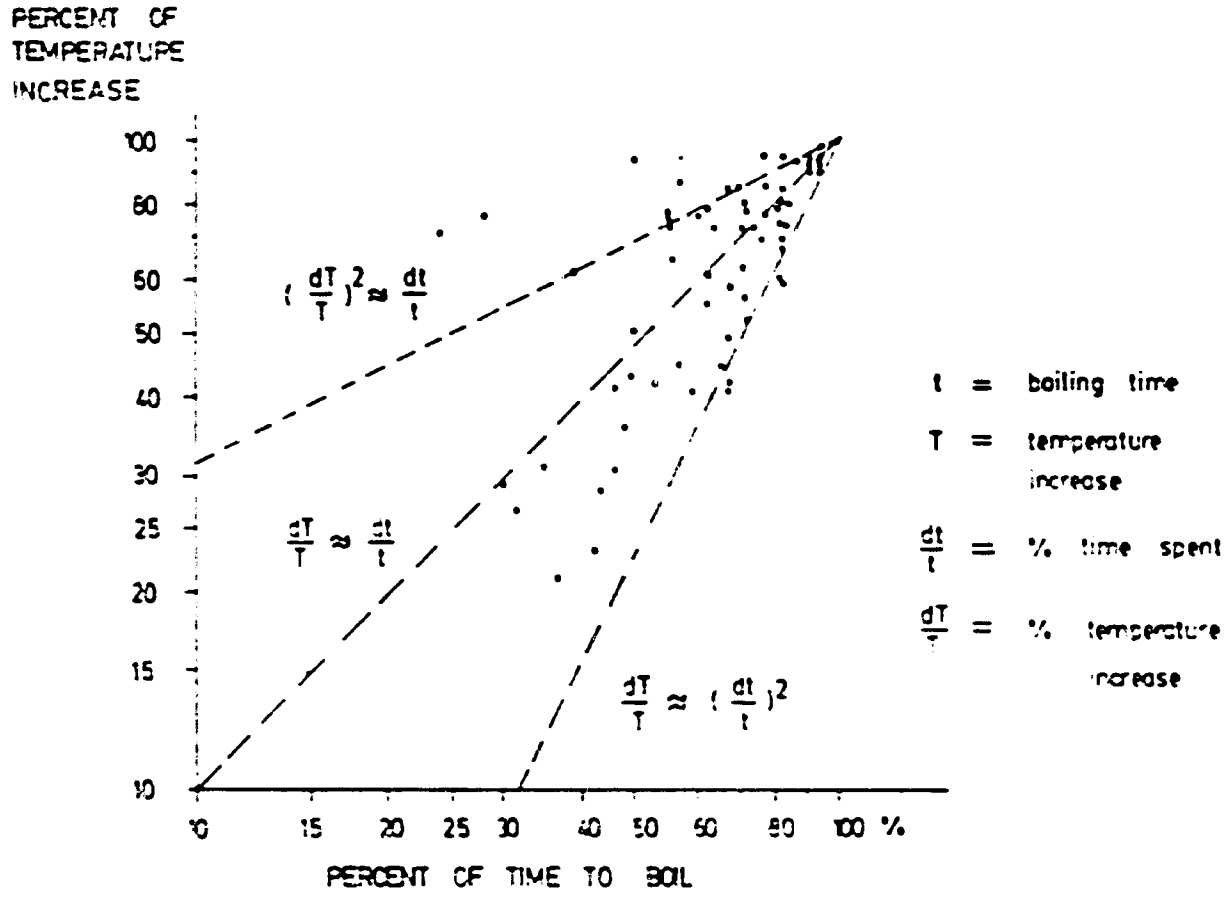
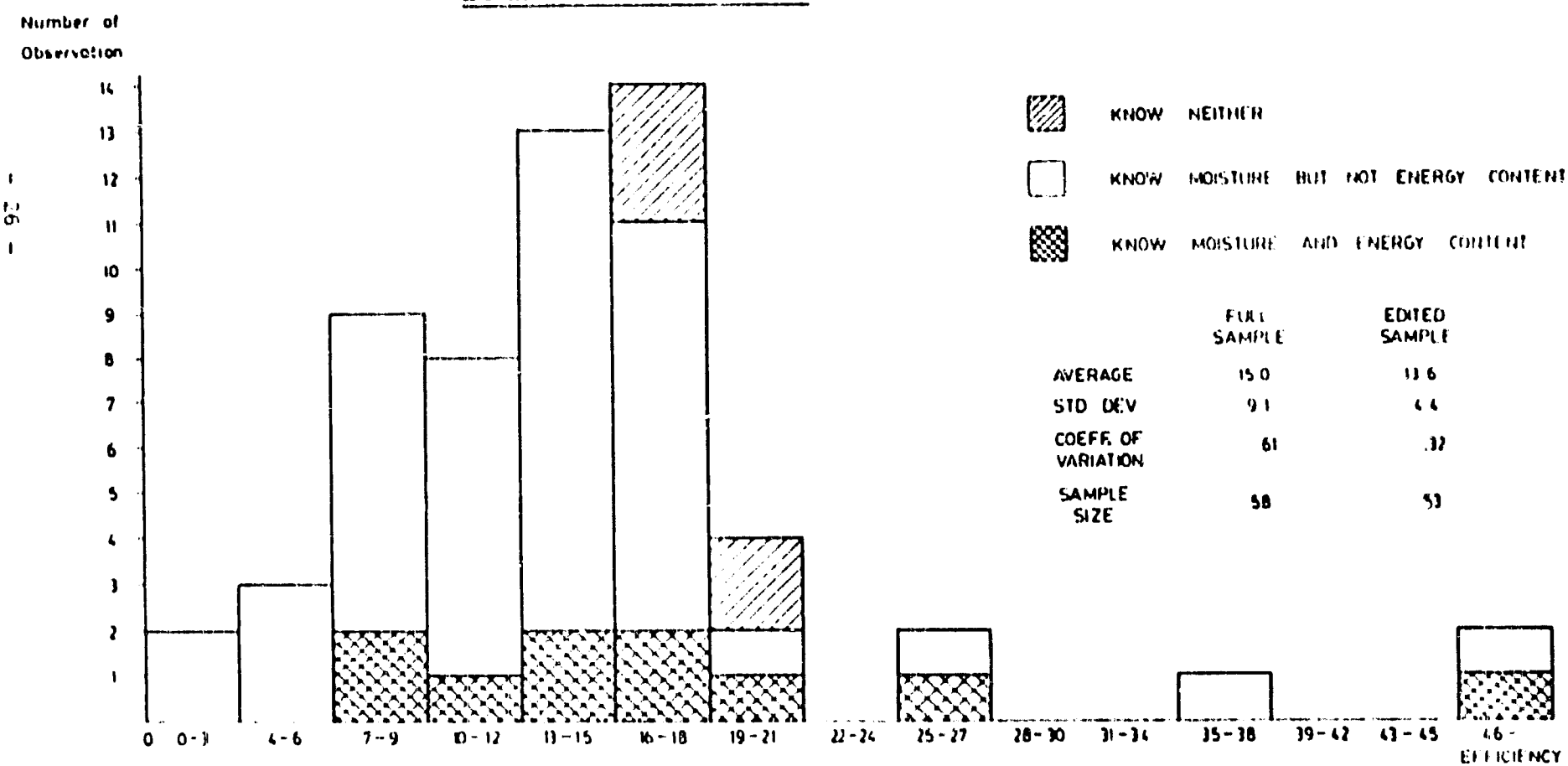


FIGURE 17

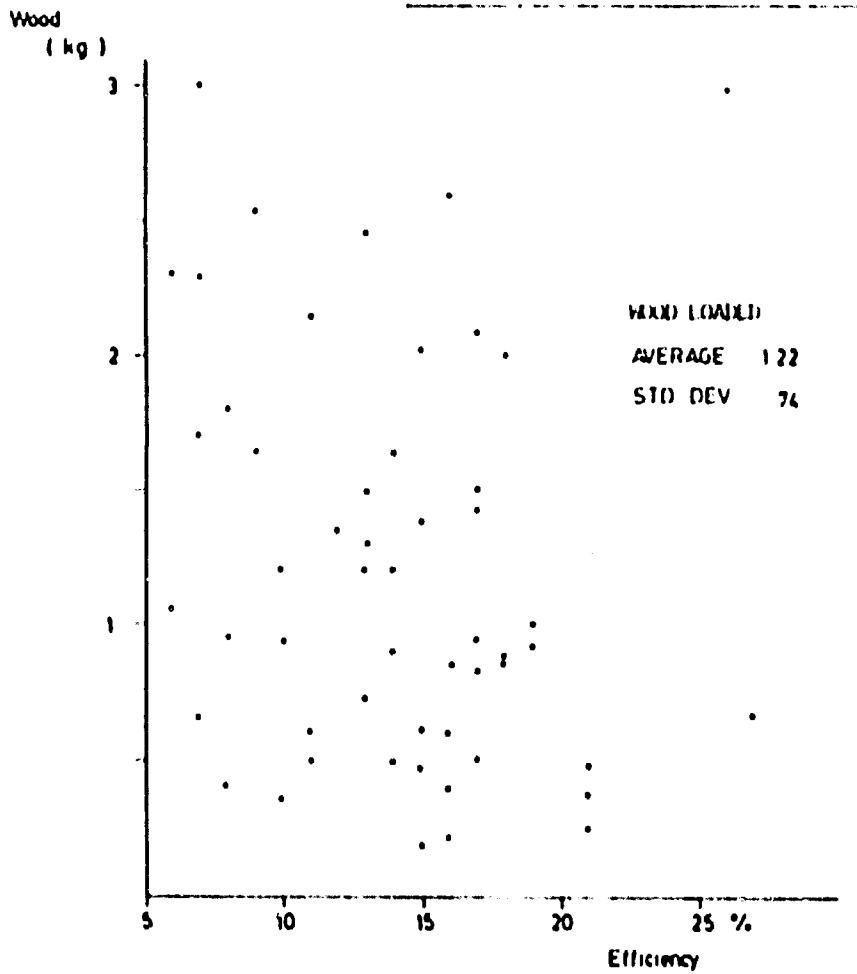
WOOD STOVE EFFICIENCIES - BOILING WATER TEST

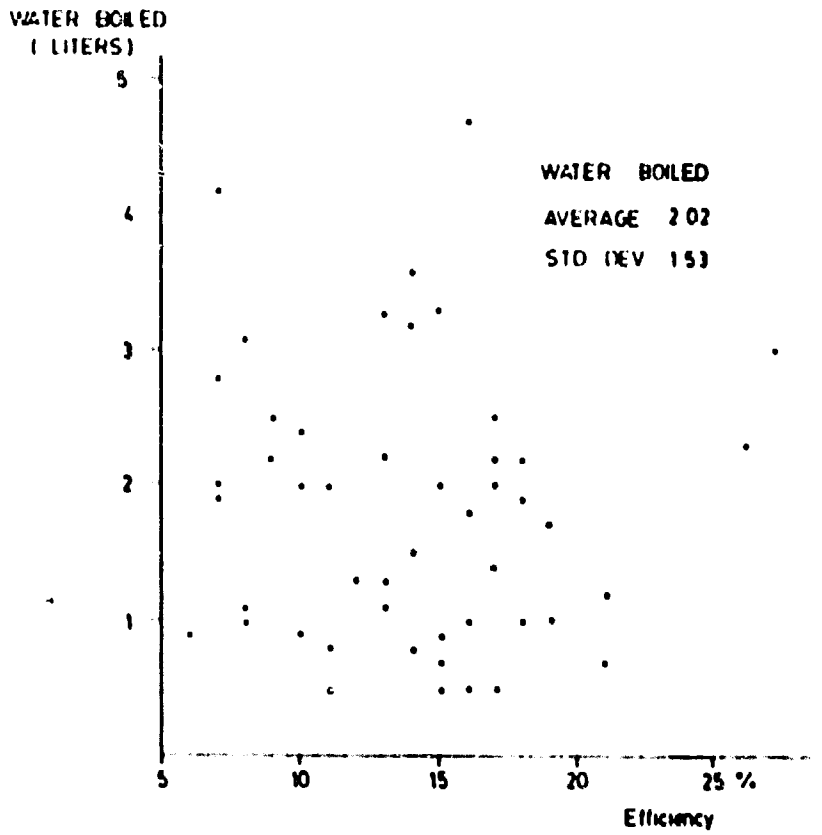


	FULL SAMPLE	EDITED SAMPLE
AVERAGE	15.0	13.6
STD DEV	9.1	4.4
COEFF. OF VARIATION	.61	.32
SAMPLE SIZE	58	53

FIGURE 18

EFFECT OF QUANTITY OF WOOD AND WATER ON WOOD STOVE EFFICIENCY





bucket and nonbucket designs, then the efficiency of the latter increases with an increase in water-to-fuel ratio (see figure 19). No relationship was observed for bucket stoves, except that for water-to-fuel ratios above 5 the efficiency decreases as the ratio increases.

The relationship between the moisture content of the wood fuel and the efficiency of the stove is relatively complex. Theoretically, at low values the wood burns quickly and the rapid generation of heat reduces efficiency. At high values the rate of heat generation would be relatively slow during the early period of combustion when energy is required to remove the moisture. The accuracy of the moisture content measurement was not sufficient and the variation of other factors was too great to establish any clear relationship between moisture content and efficiency as shown in figure 20. At relatively low values of moisture content, the efficiencies were low for non-bucket stoves and high for bucket stoves, whereas for the middle range of moisture content, 8-17%, a wide distribution of efficiencies was observed.

The relationship between stove efficiency and rate of combustion in wood stoves has been established in research by Stephen Joseph of ITDG. The efficiency decreases for low and high rates of combustion. At low values, the heat losses of the stove and cooking vessel are significant relative to the rate of heat generation. At high values, the rate at which the cooking vessel and water can absorb heat limits efficiency. The rate of combustion is in turn determined by a number of factors including the size, shape, moisture content and density of the wood fuel, the quantity being burned, and the spatial characteristics of the combustion chamber. Since the rate of combustion is difficult to determine under field conditions, two surrogate measures for rate of combustion, the quantity of fuel consumed and the time for the water to boil were used. A graph comparing the quantity of the fuel that was consumed and stove efficiency is shown in figure 21.* There is only a slight tendency for efficiency to decrease with large quantities of fuel; this may be due to the fact that the quantity measured was fuel loaded into the stove but not necessarily into the combustion chamber. The graph comparing stove efficiency and boiling time (figure 22) also fails to reveal any significant relationship. For boiling periods between 10 and 17 minutes the efficiencies of the non-bucket stoves appear to peak, while for bucket stoves the variation in efficiencies decreases and the average efficiency is greater.

The matrix in table 3 examines the effect of the quantity of fuel loaded and time to boil. Since these surrogate factors ignore many other factors which affect the rate of combustion, the results are tenuous. The distribution of efficiencies is weighted towards higher values for boiling water tests with fuel loads less than or equal to 1 kilogram. The boiling time does not appear to affect the efficiency for tests with small fuel loads, but it does appear to affect those tests with fuel loads in excess of 1 kilogram. For the latter the efficiencies are distributed around higher values for those experiments with boiling times greater than 13 but less than 19 minutes.

Table 3

Wood Stove Efficiency Matrix

Rate of Combustion

FUEL LOADED (kg)	BOILING TIME * (min)	EFFICIENCY (%)		
		5-12	13-16	17-27
≤ 1	≤ 13	3	7	4
	14-18	3	2	2
	≥ 19	2	-	2
	ALL	8	9	8
> 1	≤ 13	6	1	3
	14-18	-	5	3
	≥ 19	5	3	-
	ALL	11	9	6
ALL	≤ 13	9	8	7
	14-18	3	7	5
	≥ 19	7	3	2
	ALL	19	18	14

* time from placing pot on stove to visible boiling

FIGURE 19

EFFECT OF WATER - TO - FUEL RATIO ON WOOD STOVE EFFICIENCY

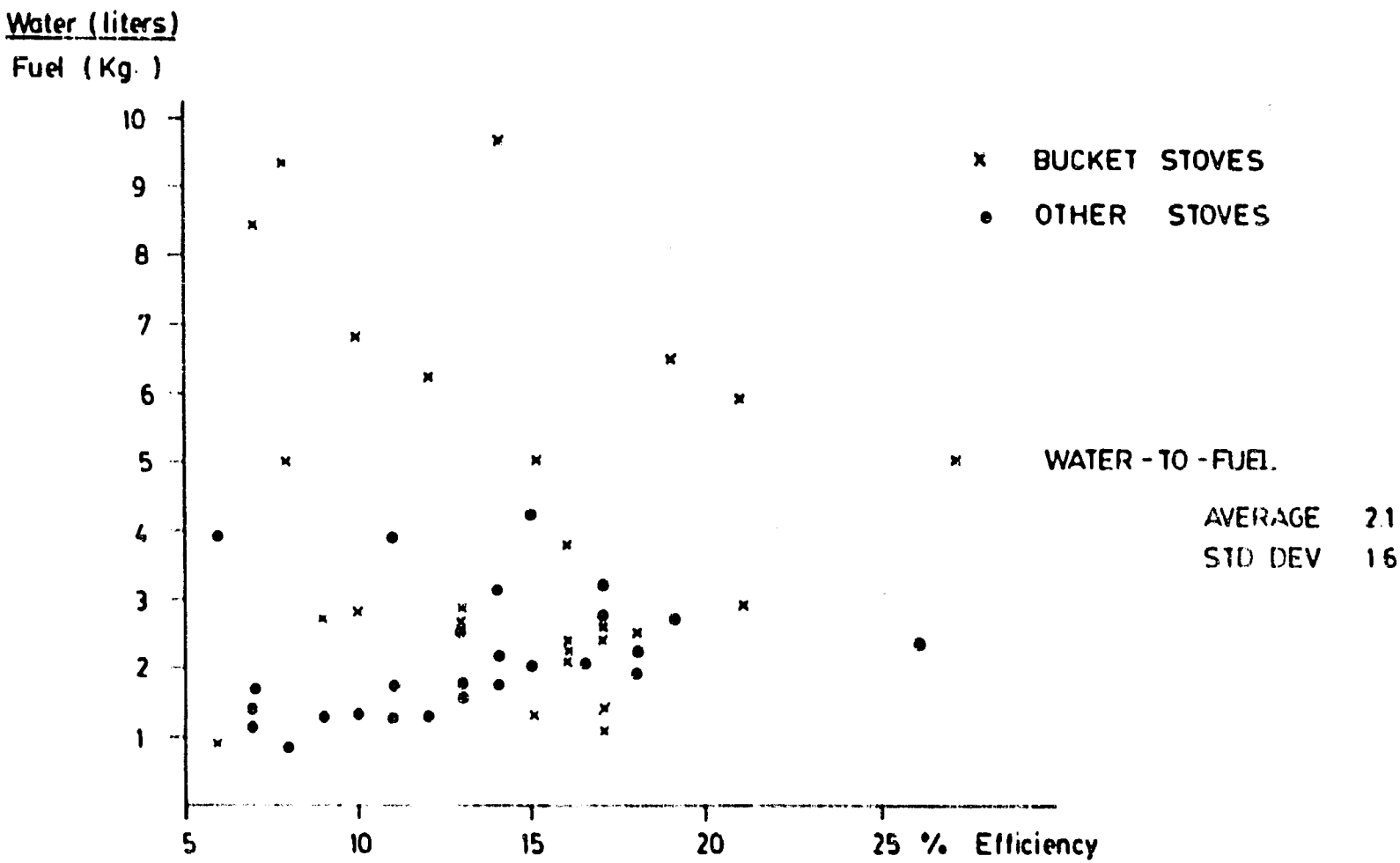


FIGURE 20

EFFECT OF WOOD MOISTURE CONTENT ON STOVE EFFICIENCIES

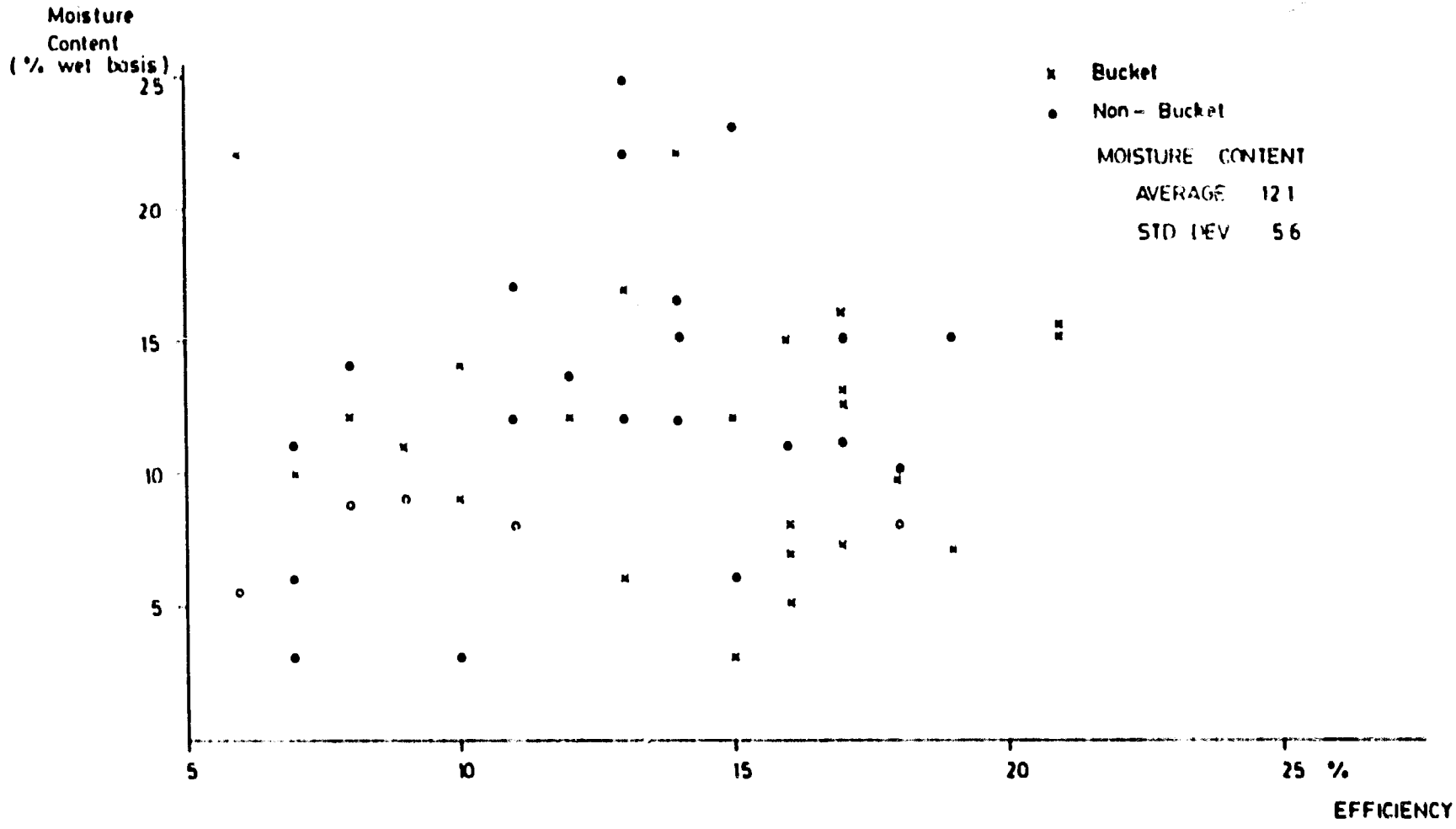


FIGURE 21

EFFECT OF QUANTITY OF FUEL BURNED ON EFFICIENCY OF WOOD STOVE

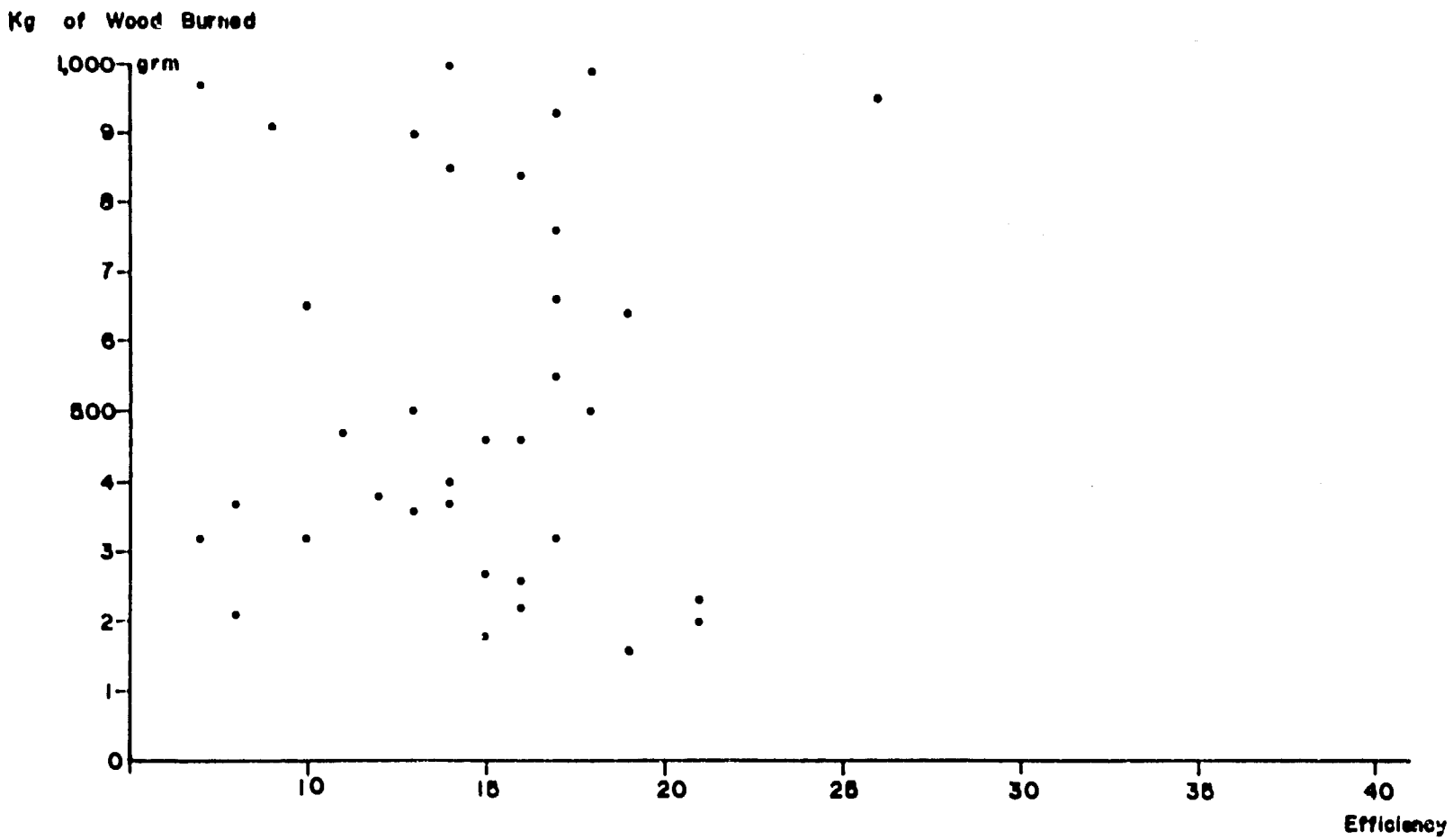
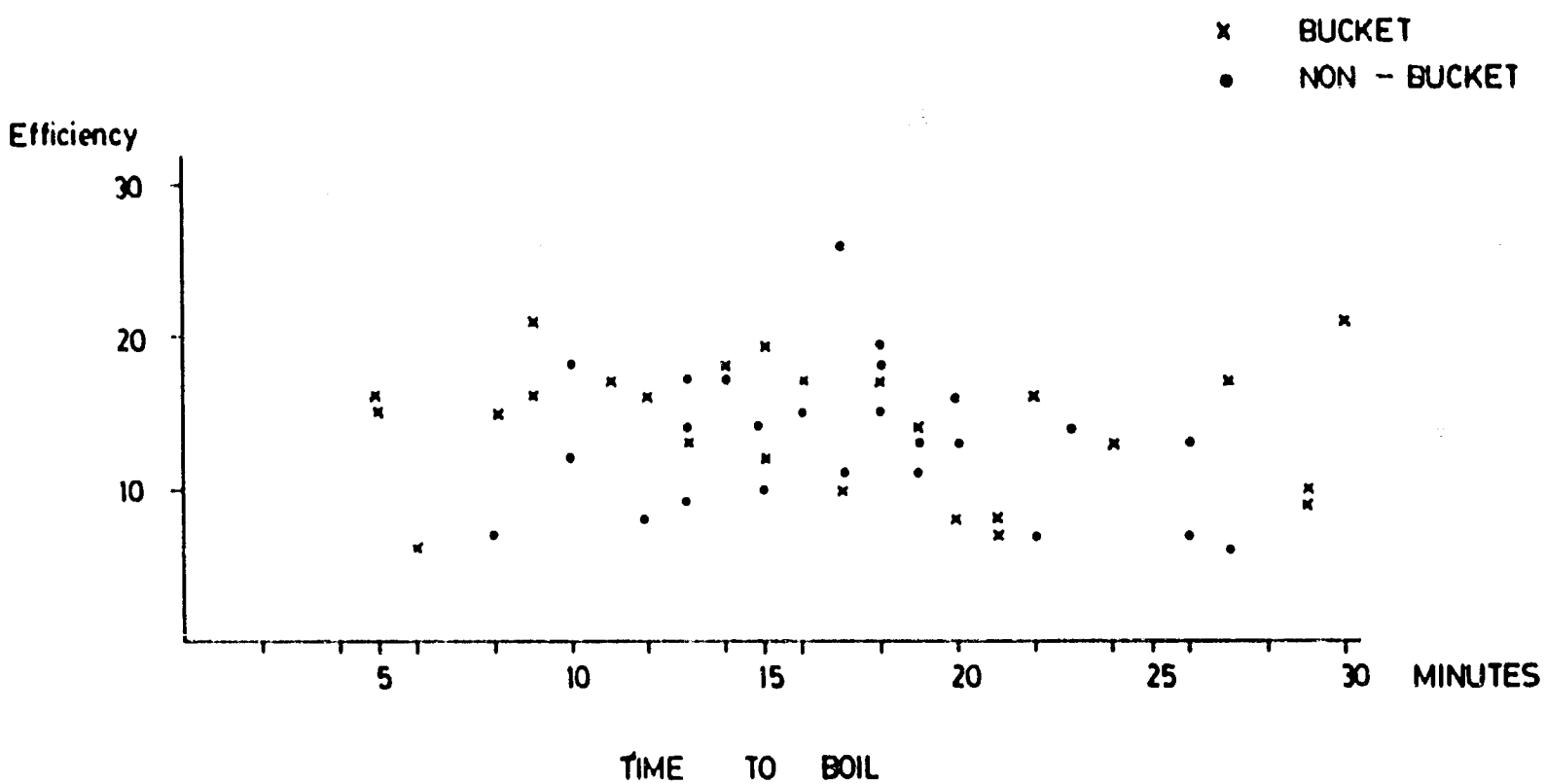


FIGURE 22

EFFECT OF TIME TO BOIL ON EFFICIENCY OF WOOD STOVES



One of the major factors affecting wood stove efficiency is the design of the stove. The highest average efficiency for a particular stove type, 20.5%, was recorded for simple stoves fabricated from kerosene cans; however, only two of these units were tested. The next most efficient units were the enclosed horseshoe and bucket stoves with average efficiencies of 14.6% and 14.2%, respectively. The open horseshoe design had a measured efficiency of 13% while the basic three rock unit had an efficiency of 12.2%. The "Economic" stove had an average efficiency of less than 11%.+ These tests were carried out in the field and to some extent reflect average performance of the different units. However, no firm conclusions can be derived as to the relative efficiencies of different models since the standard deviation for any one unit was generally greater than the range of efficiencies for all units excluding the kerosene can model. The effects of wind were not significant in these experiments as can be seen in the data in table 4.

The quantity of starter fuel had a greater impact on efficiency for wood stoves than for charcoal stoves. On average the heat value of the starter fuel was only 9% of the heat value in the primary fuel burned, but for 25% of the tests the starter fuel had a heat content in excess of 15% of the primary fuel burned as seen in the histogram in figure 23. The measured efficiency for these experiments was affected by the quantity of starter fuel as shown in the graph in figure 24. Two observations should be made with regard to this data. First, it is more difficult to separate starter fuel from primary fuel for wood stoves. The enumerators weighed separately fuels which were visibly different, but no strict definition was given as to what types of fuel were to be considered starter fuels. Second, the starter fuel may continue to produce heat after the pot is placed on the stove and therefore contribute to the measured efficiency, especially, where large quantities of starter fuel are used. Clearly for wood stoves the heat value in the starter fuel should be included in future calculations of the stove efficiency.

The period of time between starting the fire and placing the cooking vessel on the stove averaged about 3 minutes. In only 15% of the observations did this period exceed five minutes (figure 25). The short period of time for preheating supports the idea that the starter fuel is still producing heat when the cooking vessel is placed on the stove. It also indicates that wood ignites more quickly than charcoal and can be expected to reach a steady rate of combustion more rapidly.

The time from starting the fire to visible boiling of the water averaged 17 minutes (see figure 26), 5.5 minutes less than for charcoal stoves. However when the time is measured from placing the pot on the stove until visible boiling, then the average is the same for wood and charcoal stoves. The implication is either that the wood stove is generating heat at the same rate as charcoal but at an earlier time following ignition or that the rate at which heat is generated increases more rapidly for wood than for charcoal during the quarter hour following ignition.

+The "Economic" stove was designed to burn agricultural residues and is not very efficient as a wood stove.

Table 4

Wood Stoves Efficiency Matrix

STOVE TYPE	WIND	
	NO	SOME
THREE ROCK	5 12.2 38	4 12.2 42
OPEN HORSE SHOE	3 11.0 24	2 16.0 18
BUCKET	12 14.2 37	15 14.1 34
CLAY, ENCLOSED	nx	4 11.2 42
ENCLOSED HORSE SHOE	nx	5 14.6 12
KEROSENE CAN	nx	2 20.5 22
ECONOMIC	1 7.[illegible] na	1 14.[illegible] na

nx - No experiments
na - Not applicable
upper left - Number in sample
lower right - coefficient of variance (x 100)
middle - average efficiency %
Sample edited to exclude four experiments with efficiencies less than 4% and more than 31%

FIGURE 23

WOOD STOVES : STARTER FUEL AS A PERCENTAGE OF PRIMARY FUEL BURNED

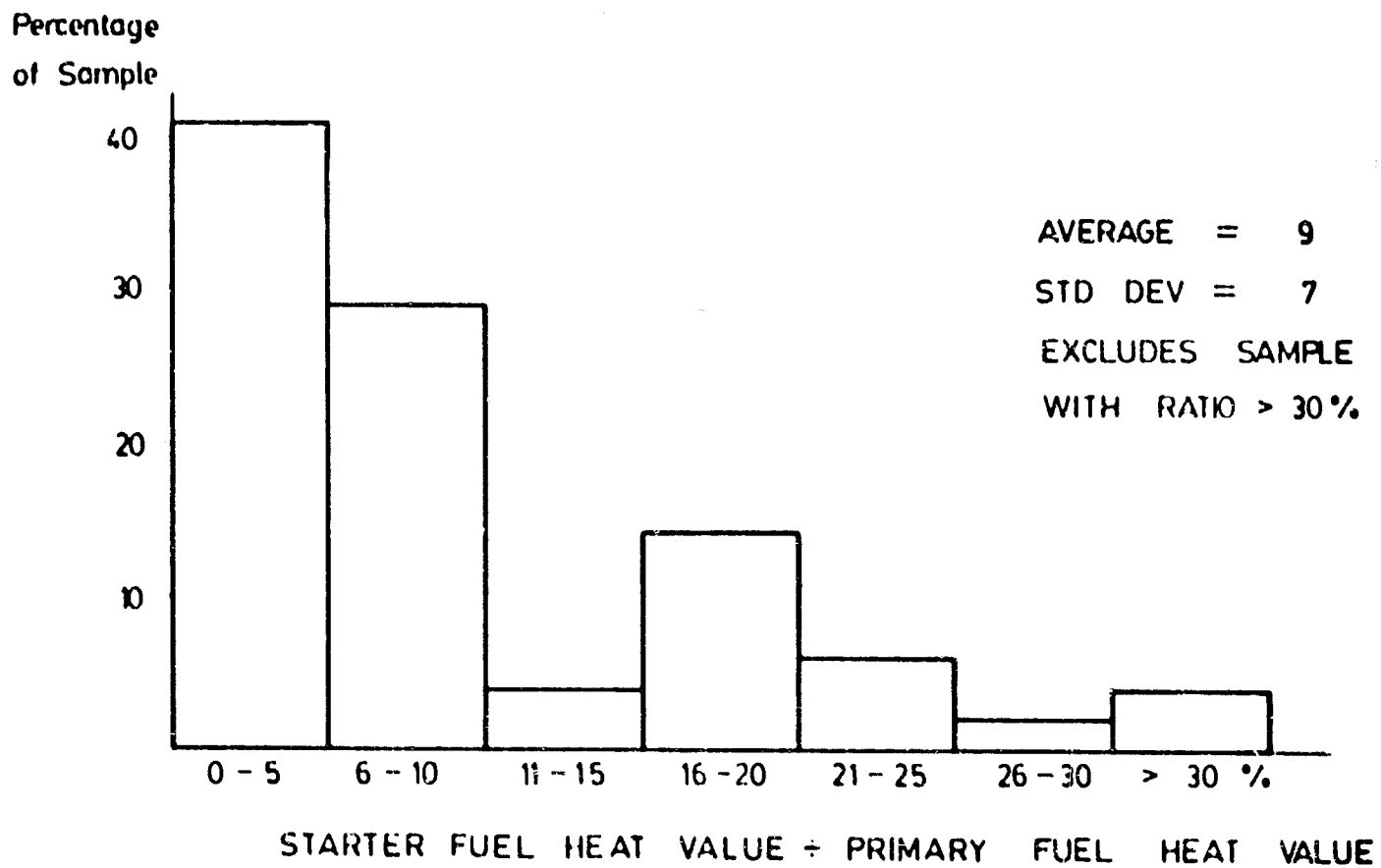
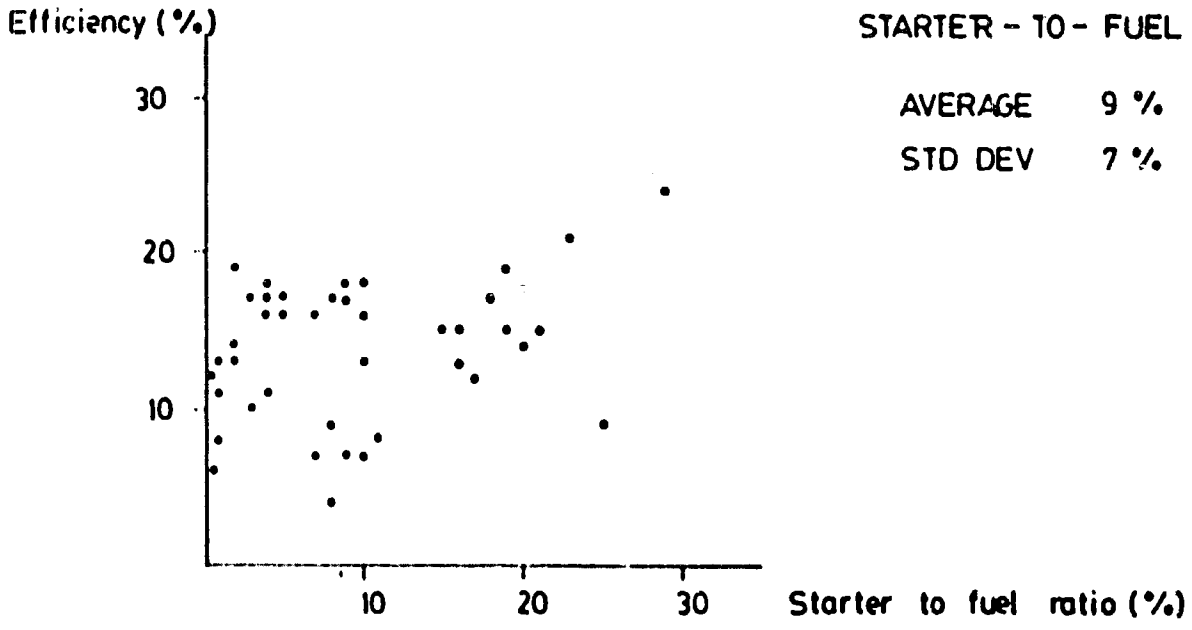


FIGURE 24

WOOD STOVES: EFFICIENCY VERSUS STARTER FUEL ENERGY



STARTER - TO - FUEL

AVERAGE 9 %

STD DEV 7 %

FIGURE 25

PERIOD OF TIME FROM IGNITION TO PLACING POT ON THE STOVE – WOOD STOVE BOILING TEST

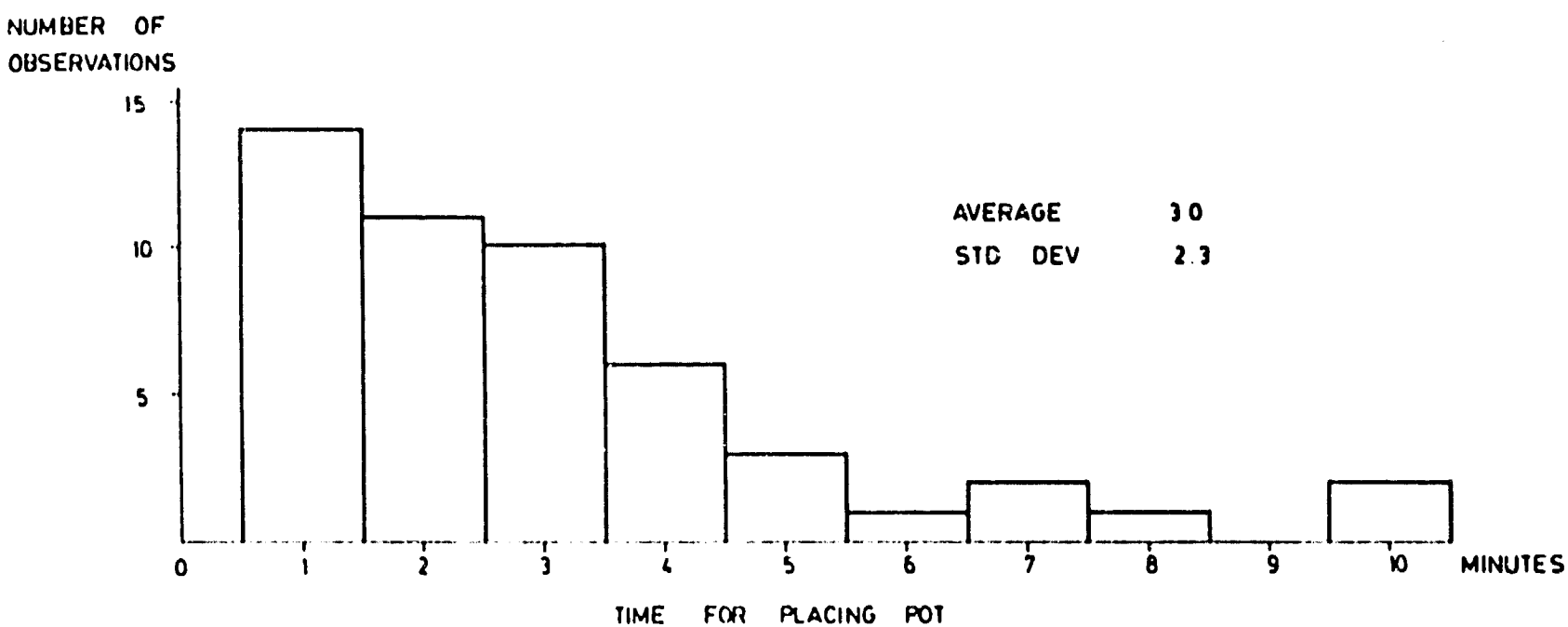
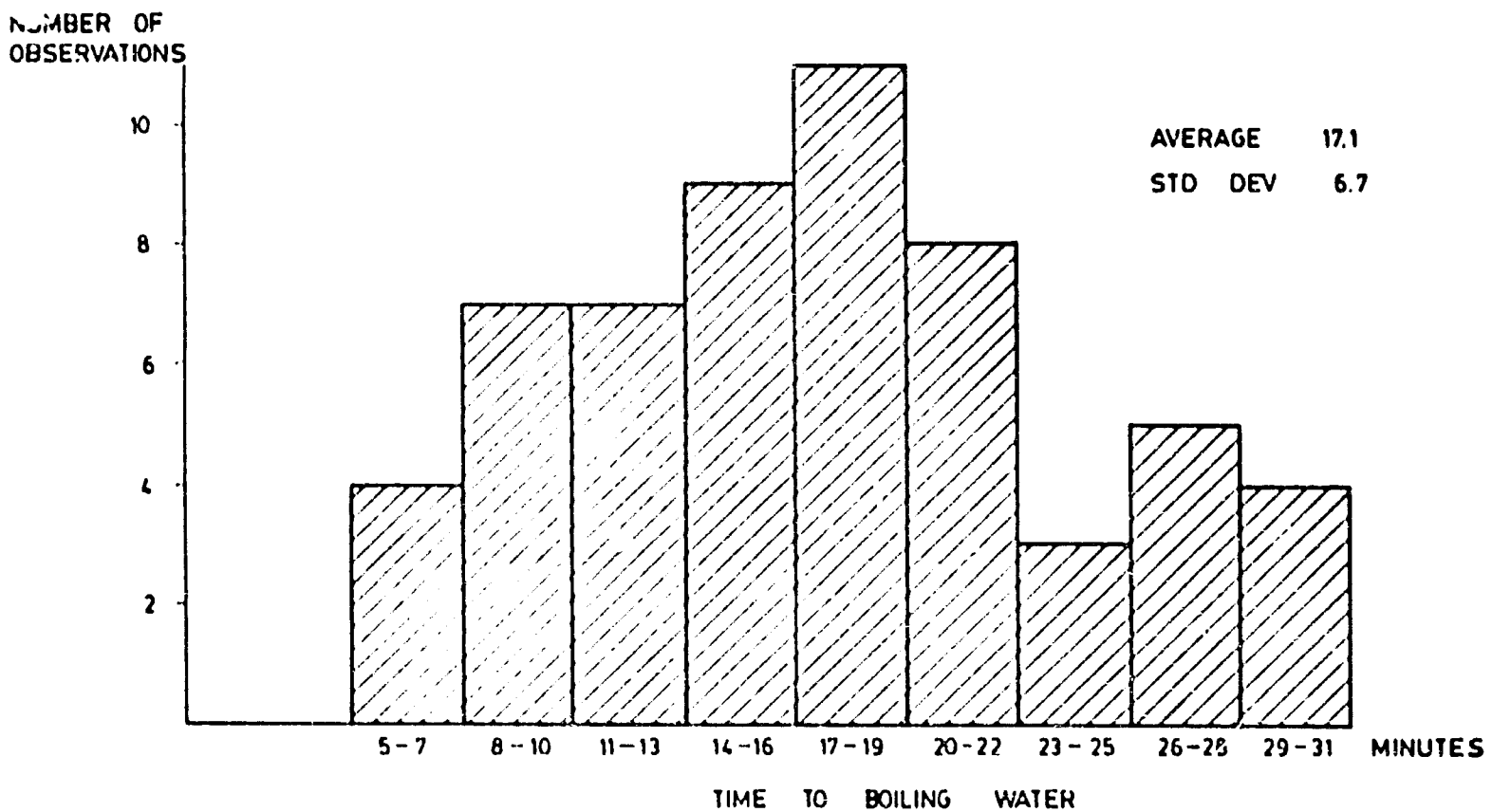


FIGURE 26

PERIOD OF TIME FROM IGNITION TO BOILING WATER - WOOD STOVE



The relationship between temperature and time provides additional information in regard to the matter of heat generation. The increase in temperature appears to be more uniform for wood stoves than charcoal stoves. The percentage increase in temperature versus the percentage of time completed when plotted on a log-log scale is more evenly distributed around the axis of time~temperature for wood stoves than for the charcoal stoves (figure 27). This relationship could be evaluated much more accurately in a laboratory environment.

The Royal Forestry Department* has performed this analysis as part of its experiments on the effects of different fuels and species on stove efficiency. The basis for the analysis was a water heating test in which successive pots of water were heated to 100°C and removed from the stove until the fuel was consumed. The temperature of the water was recorded at intervals throughout the experiment. For the charcoal fuel the temperature in the first pot increased approximately exponentially over time until the rate of heat generation reached a steady state then the rate of temperature increase was relatively constant for the remaining pots. On the final pot, as the last of the fuel was consumed, the rate of temperature increase dropped off at what appeared to be a logarithmic rate. The same test when performed for wood showed a constant rate of temperature increase from the first to the next to last pot. Again there was logarithmic decline in the rate of temperature increase for the final pot. Any build up in the rate of heat generation either took place before the first pot was placed on the stove or during a short interval afterwards, but this build up did not appear in the temperature versus time measurements.

3. Cooking Tests

The stoves which were selected for the boiling water tests were also used to prepare a meal. This cooking test was performed by asking the household member to prepare a food which is cooked daily. In four changwat, Petchaburi, Korat, Songkla, and Chantaburi, the cooking test was performed by boiling rice. The variety of foods prepared is shown in table 5. In the following analysis, the cooking tests are examined as a group and then the rice cooking tests are considered separately. For all tests the quantities of fuel, food, and water used were measured. All the cooking was done with metal cooking vessels. Tops were used where appropriate. The basic method of rice cooking did not vary. Regular rice was placed in a pot and covered with water. The quantity of rice and the ratio of water-to-rice was determined based on household practice. The water and rice were brought to a boil. After a short period of time the excess water was poured off and the rice dried either over the fire or away from the fire. The water that was poured off contained nutrients from the rice and was fed to the dogs. The amount of water boiled had a significant effect on the amount of fuel required.

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*The following paragraph is based on conversations with Dr. Aroon of the RFD who is component leader for the stoves project.

FIGURE 27

RATE OF TEMPERATURE INCREASE - WOOD STOVES

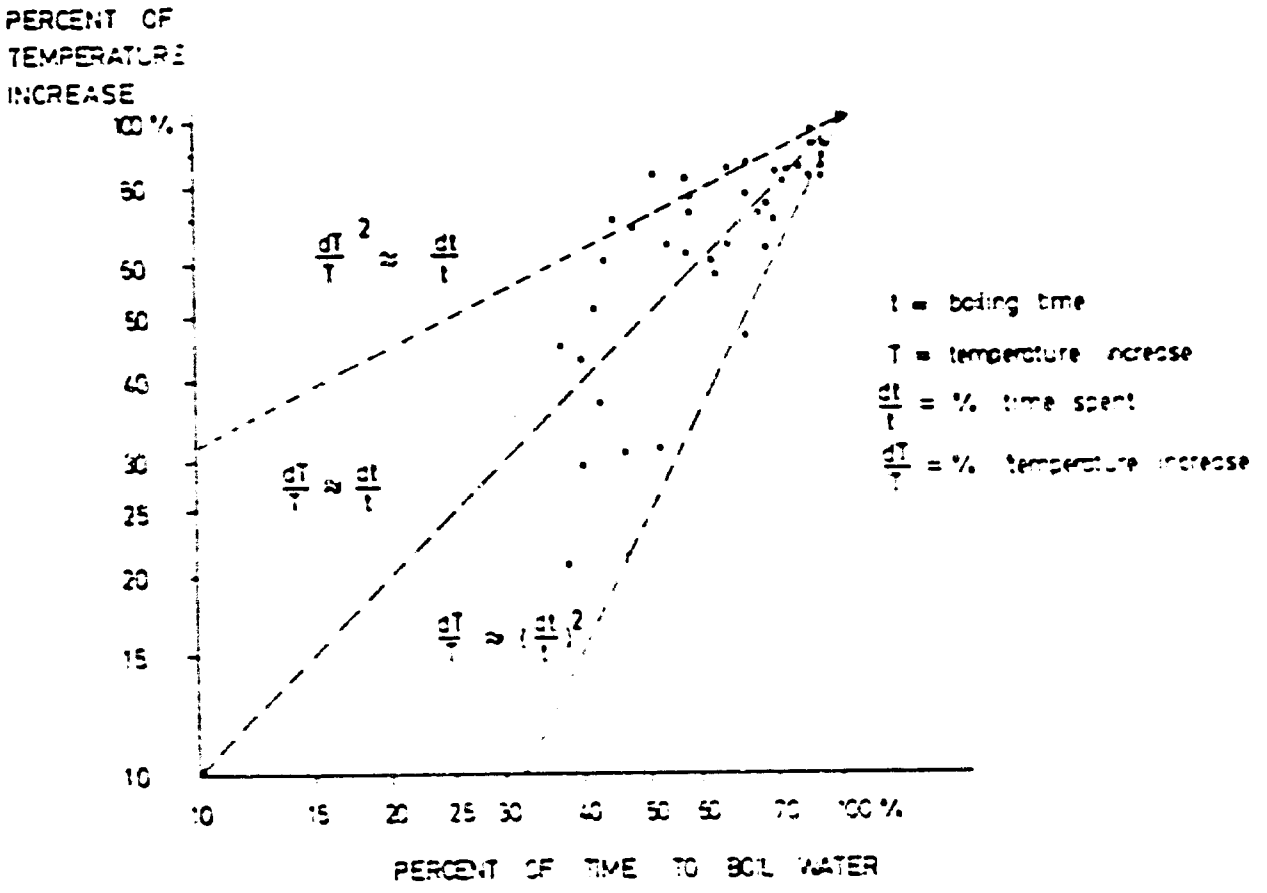

Table 5

Foods Prepared for Cooking Tests

		Number of Experiments	
Food	Type of Cooking*	Charcoal Stoves	Wood Stoves
Rice	Boil	35	19
Fish	Boil	8	1
Fish	Curry	4	3
Pork	Fry	4	-
Vegetable	Fry	5	-
Vegetable	Curry	5	3
Fish	Other	-	4
Pork	Other	3	1
Vegetable	Other	3	3
Canned fish	Various	1	2
Bamboo shoot	Various	2	6
Chicken	Various	2	3
Other	Various	-	13

*Type of cooking: "Various" refers to a mix of fried, boiled, curried, barbecued; "other" refers to a method of cooking other than these.

3.1 Charcoal Stoves Cooking Tests

A total of 72 cooking tests were performed on charcoal stoves. The amount of fuel used for cooking varied with the type of food and method of cooking. A simple comparison between the quantity of fuel (measured in terms of the heat value) combusted and the quantity of food cooked is presented in the first histogram in figure 28. The average released heat from the fuel consumed was 3.2 kilocalories per gram of food cooked,* the coefficient of variation is .69 and the numbers range from .5 to over 9 kilocalories/gram. The quantity of captured heat required to perform the cooking was estimated by factoring in the efficiency of the stoves as measured in the boiling water tests The results are shown in the second histogram in figure 29.† When the two highest values are edited out the average value is 650 calories per gram of food, but the coefficient of variation is still high and the range is from 50 to 1900 calories per gram. In an effort to reduce the variance a comparison was made between the captured heat and the quantity of water used in cooking. However, even with the seven highest value edited out, the coefficient of variation was .86 against an average of 320 calories per gram of water (see figure 29). The high variance was due to the compounding of variances in stove efficiencies and water-to-food ratios as well as differences in heat requirements to cook different foods.

The rice cooking tests produced more useable statistics. The method of cooking was analyzed by comparing the quantites of fuel, food and water used. The statisics on the ratio of water heated to charcoal burned is shown in the histogram in figure 30. The average value was 7.8 grams of water to 1 gram of charcoal but the standard deviation was 5.7. About 14% of the sample has ratios of less than 1 to 1 and 25% ratios greater than 11 to 1. The ratio of water to rice also had a wide distribution as shown in figure 31. The average was 2.7 liters of water per kilogram of rice with a standard deviation of 1.9 liters. About one-fourth of the samples had ratios less than .6 liters per kilogram and another fourth of the samples had ratios of more than 4.2 liters per kilogram. The amount of heat captured per liter of water was analyzed for those stoves whose efficiencies as measured in the boiling water test were between 6% and 40%. The results are shown in the histogram in figure 32. On average 155 kilocalories of delivered heat was used per liter of water. Although the coefficient of variation was .62, about one-half of the tests had values between 100 and 200 kilocaloaries. Assuming that a little more than 70 kilocalories are required to bring a kilogram of rice and water to the boiling temperature then an average of 85 kilocalories are used in transforming and drying the rice, converting water to steam and heating the atmosphere.

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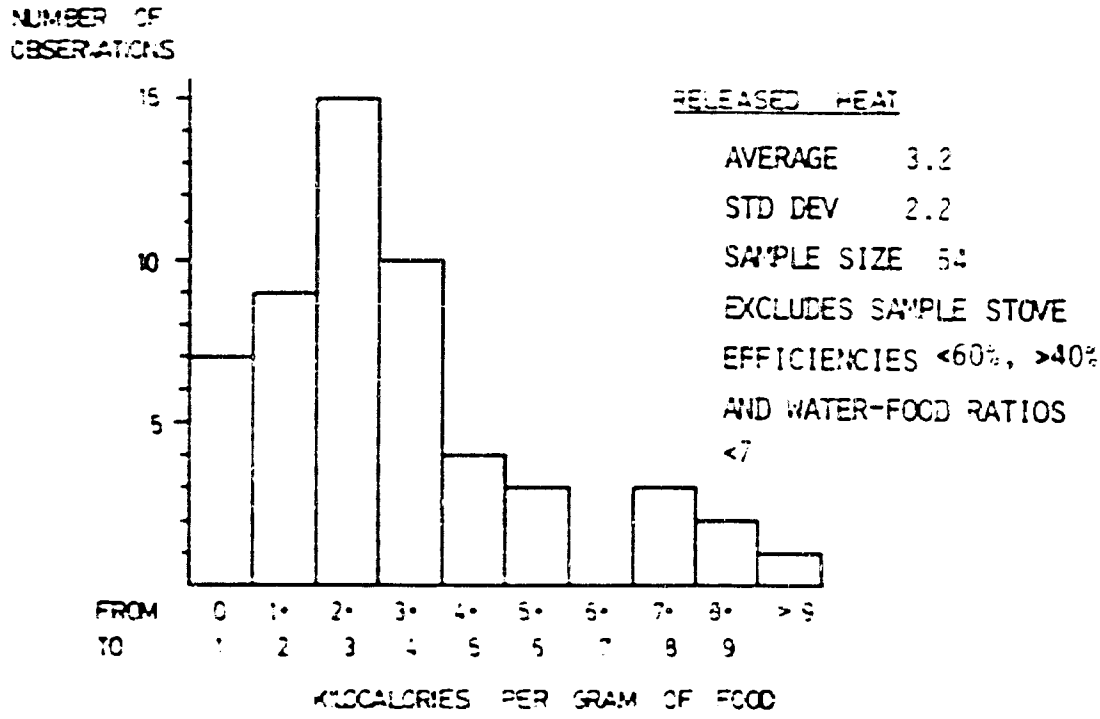
*This is roughly equivalent to .5 kilograms of charcoal per kilogram of food.

†Released or delivered heat from burning fuel is equal to the heat content of the fuel multiplied by the quantity of fuel burned, captured heat is the released heat multiplied by stove efficiency to determine the quantity of heat entering the pot.

FIGURE 28

CHARCOAL STOVE COOKING TESTS
DELIVERED AND CAPTURED HEAT



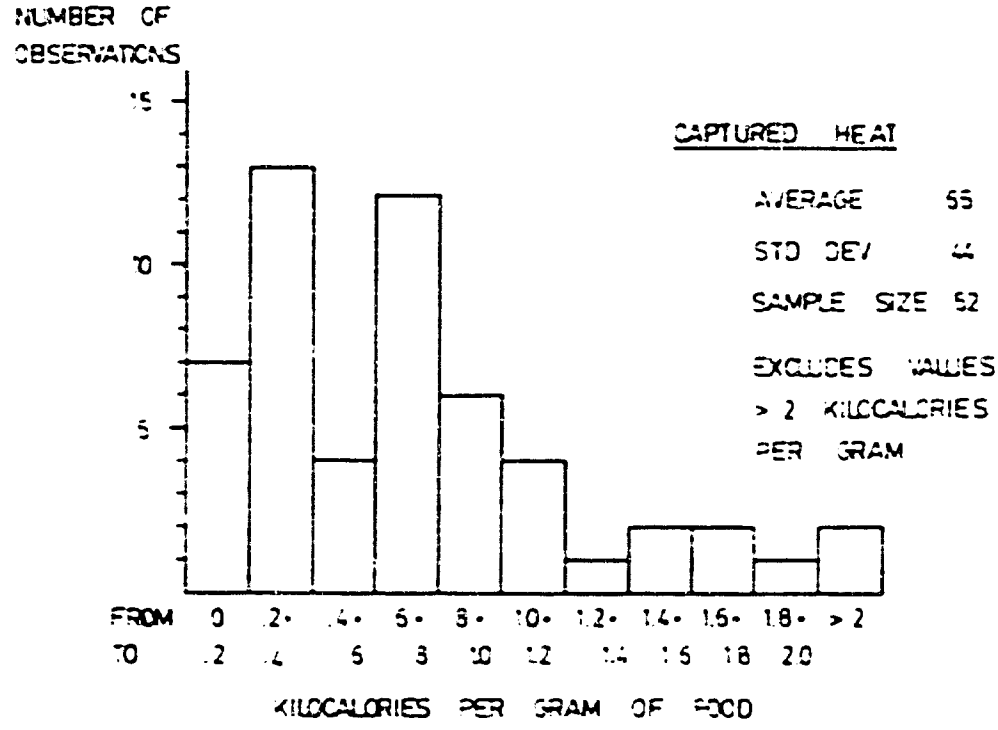


FIGURE 29

CHARCOAL STOVES COOKING TESTS: CAPTURED HEAT PER KILOGRAM OF WATER

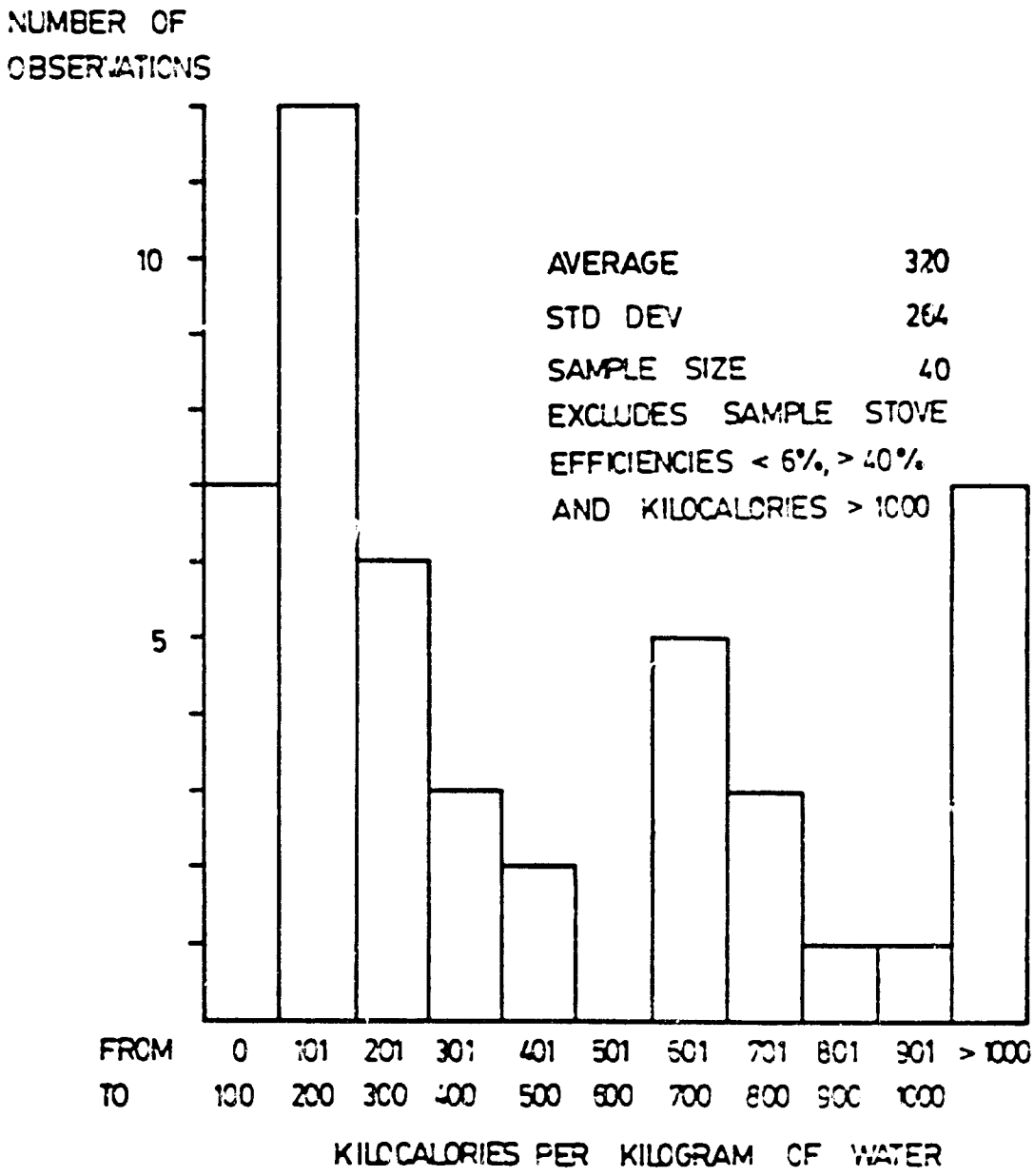


FIGURE 30

RATIO OF WATER TO FUEL FOR CHARCOAL STOVE RICE COOKING TESTS

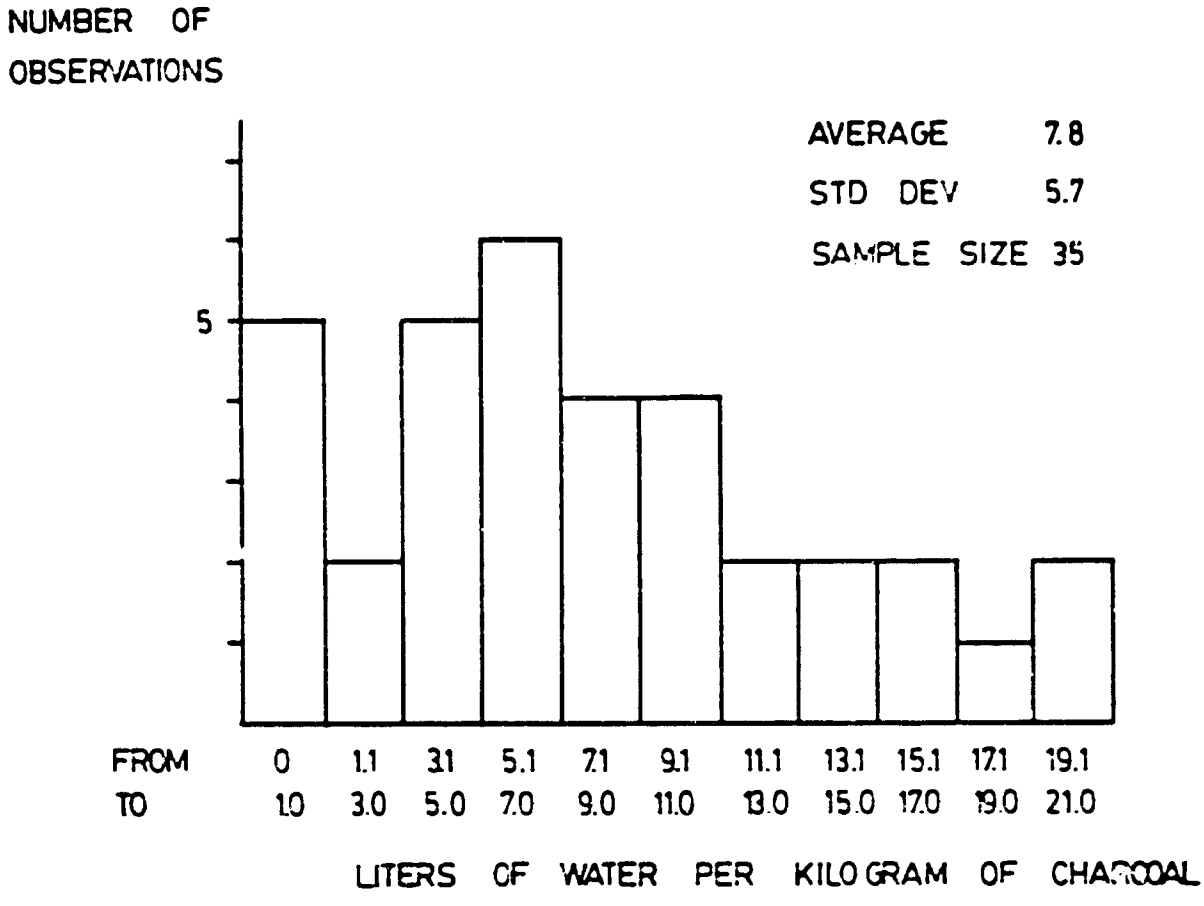


FIGURE 31

RATIO OF WATER TO RICE FOR CHARCOAL STOVE COOKING TESTS

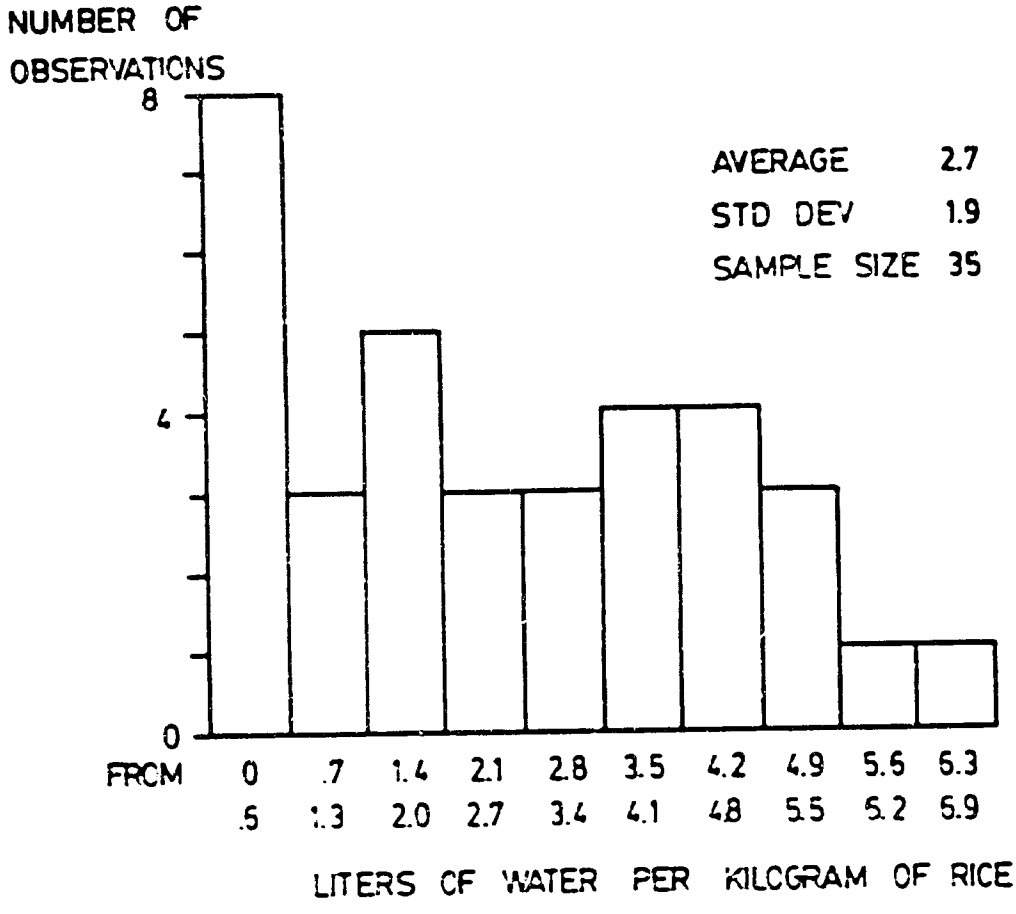
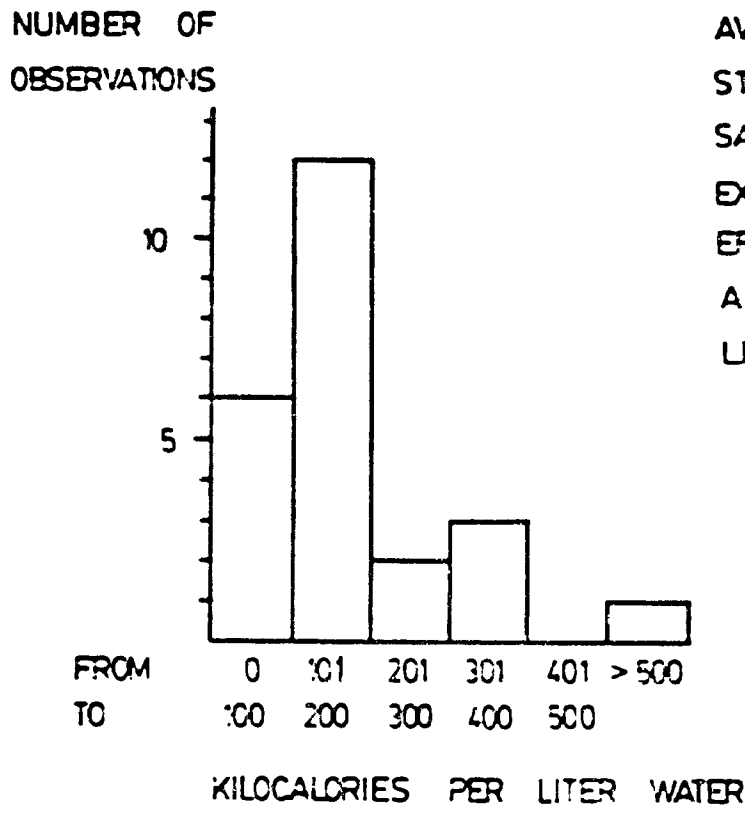


FIGURE 32

CHARCOAL STOVE RICE COOKING TESTS: CAPTURED HEAT PER LITER OF WATER



AVERAGE 155
STD DEV 96
SAMPLE SIZE 23
EXCLUDES SAMPLE STOVE EFFICIENCIES < 6%, > 40% AND KILOCALORIES PER LITER > 1000

3.2 Wood Stoves--Cooking Tests

A total of 58 cooking tests were performed on wood-fueled stoves. Of this sample seven were not analyzed because the boiling water tests had produced unrealistic efficiencies.* The fuel consumption was compared with the quantity of food cooked as shown in the histogram in figure 33. When this sample was edited to exclude tests in which the heat value of the fuel burned was in excess of 13 kilocalories per gram of food (3 tests), then the average released heat was 4.3 kilocalories per gram of food* with a standard deviation of 3.1 kilocalories per gram. If the measured efficiencies of stoves are used to calculate captured heat per gram of food, then the results are as shown in the second histogram in figure 33. When the sample was edited to exclude excessively small or large stove efficiencies and results greater than 2.2 kilocalories per gram (2 tests), then the average captured heat was 640 calories per gram of food, but the coefficient of variations was .77. About half the edited sample had captured heat values between 200 and 500 calories per gram. When the captured heat was compared with the amount of water used in the cooking tests, the distribution was as shown in the histrogram in figure 34. The average heat captured was about 290 calories per gram of water, slightly less than one-half that for food. The averages and standard deviations for the captured heat calculations are remarkably similar for the wood and charcoal fueled stoves, see table 6. This fact increases the acceptability of these results despite the large coefficients of variations.

Rice was prepared in about one-fourth of the wood stove cooking tests. The ratio of water to rice varied considerably around a mean of 2.6, see figure 35. When the test results were edited to include only stoves whose boiling water test had efficiencies from 5% to 30% and these efficiencies were multiplied by the released heat of the fuel combusted, then the distribution of results is as shown in figure 36. The average estimated captured heat was 195 kilocalories per liter of water with a standard deviation of 130. These results were about 20% higher than those for the rice cooking tests on charcoal stoves. This difference is difficult to explain other than by the small sample size for wood stove rice cooking tests, but the proximity of the results for charcoal and wood stoves lends credence to the numbers.

4. Cooking Observations

The regional variation in cooking practices can be defined by two general parameters. The first is the method of preparing rice, either steaming glutinous rice or boiling regular rice. The second is the type of food which is prepared with the rice, e.g., curries, soups, fried food, etc. The survey personnel were requested to observe the cooking of a

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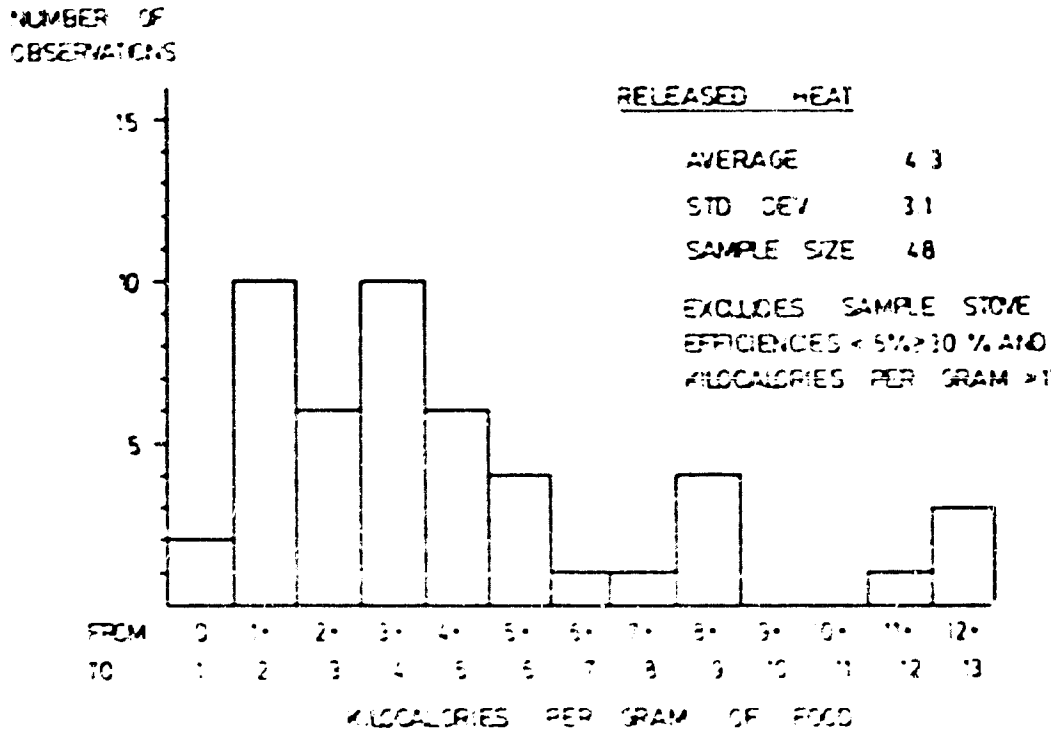
*Sample results were edited to exclude observations which were clearly separated from the distribution of the other observations.

*This is roughly equivalent to 1.2 kilograms of wood per kilogram of food cooked.

FIGURE 33

WOOD STOVE COOKING TESTS

RELEASED AND CAPTURED HEAT



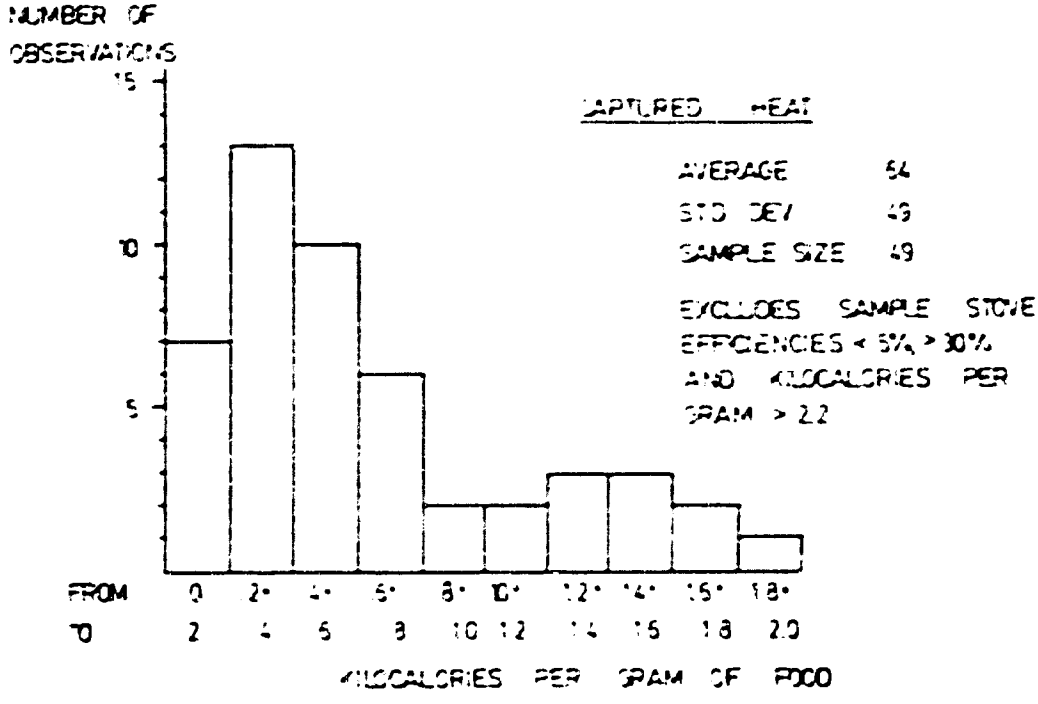


FIGURE 34

WOOD STOVE COOKING TESTS: CAPTURED HEAT PER LITER OF WATER

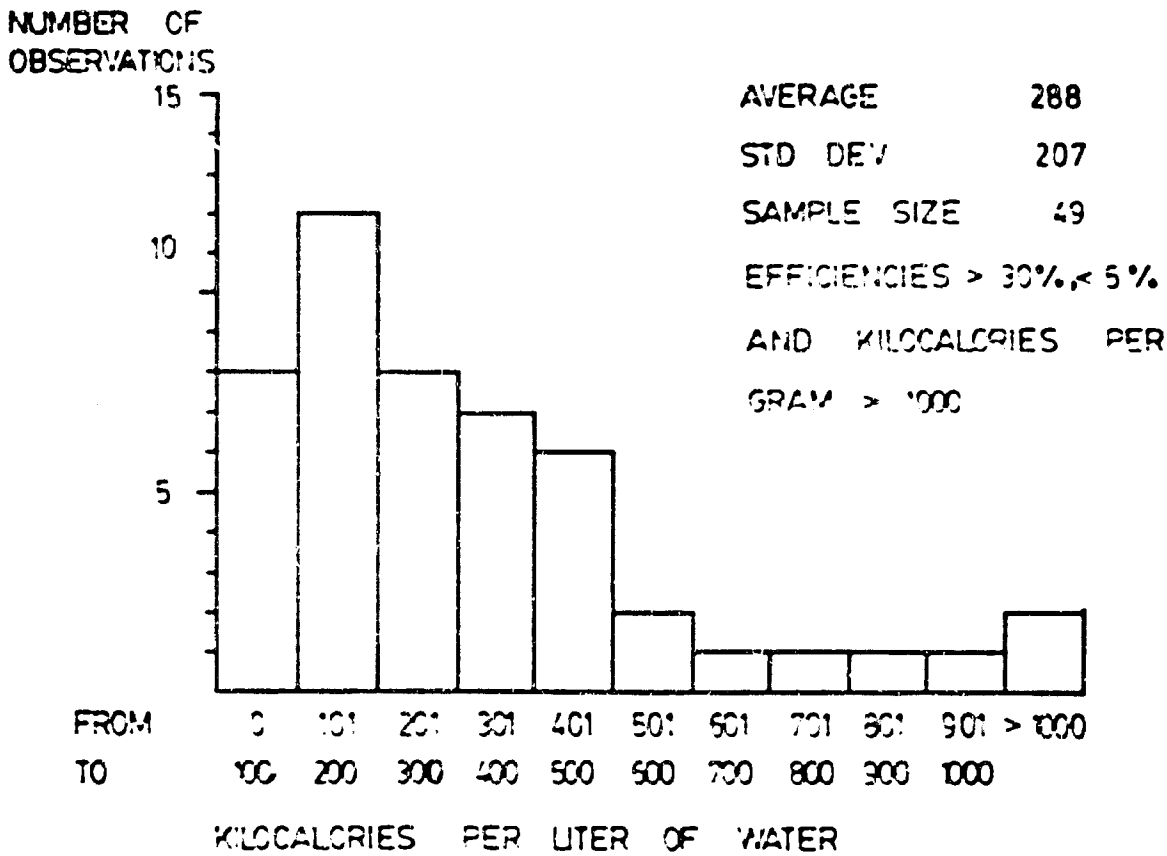


FIGURE 35

RATIO OF WATER TO RICE FOR WOOD STOVE RICE COOKING TESTS

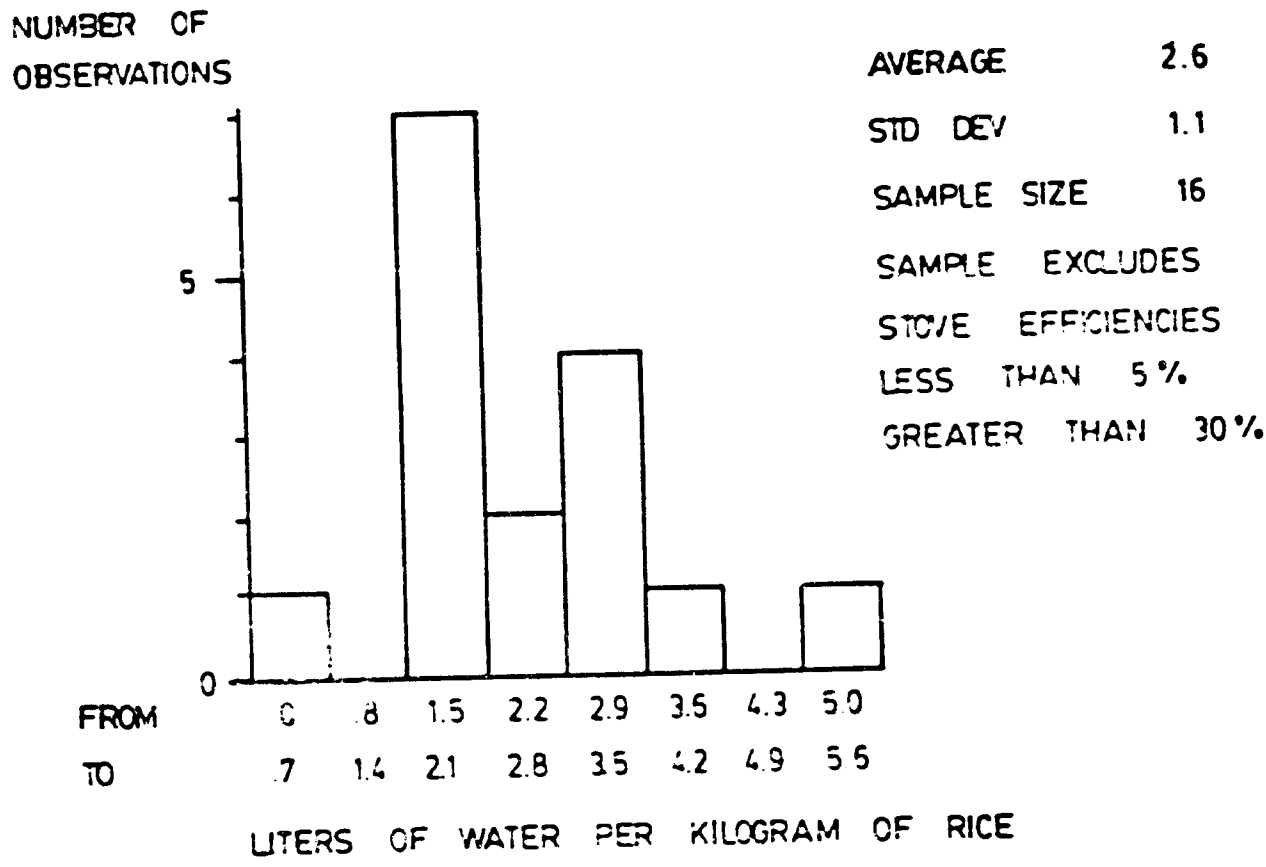


FIGURE 36

WOOD STOVE RICE COOKING TESTS: CAPTURED HEAT PER KILOGRAM OF WATER

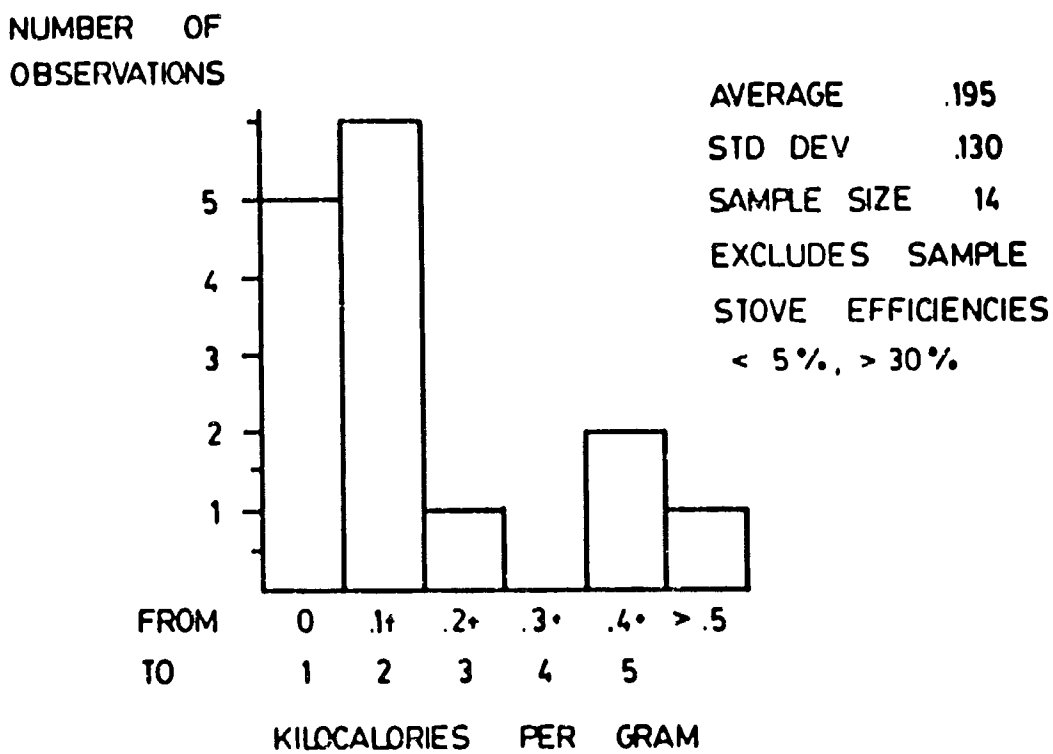


Table 6

Comparison of Captured Heat Estimates for Charcoal and Wood Stoves

	Captured Heat (Kilocalories)		
	Charcoal Stove	Wood Stove	Difference
All food			
per liter of water heated			
average	320	288	10%
std dev	264	207	22%
per kilogram of food cooked			
average	650	640	10%
std dev	440	490	10%
Rice			
per liter of water boiled			
average	155	195	20%
std deviation	96	130	26%

typical meal in their village and to record the procedure. A summary of these observations has been made by identifying a typical meal for each changwat. These typical meals are described in the flow charts in figure A.1 to A.10. The menus include bullfrog, pickled salt fish, buffalo, eggs, chicken, snail, horseshoe crab, vegetables, green gram noodles, and bamboo shoots.

For those meals in which regular rice was prepared the cooking was done in four stages. First the rice was rinsed and water was added for cooking; second, the water was brought to a boil; third, the rice was boiled for several minutes and the excess water was poured off; fourth the rice was dried over the stove. For meals in which glutinous rice was prepared, either the rice was cooked in a steamer and stored in a bamboo container, or rice from a previous meal was warmed over the stove.

For each of the typical meals the food was cooked sequentially over a single port stove. The rice was cooked first and then the other food. The non-rice foods were generally prepared while the rice was being cooked or a pot was being heated. For some meals all the food was prepared in the same pot by first cooking the rice and then cleaning the pot and adding the second course. For other meals the rice was cooked in a pot but the other foods were either fried or boiled in a wok.

Where the cooking was done with wood, fuel was added during the cooking but with charcoal, a single load of fuel was burned. Although the cooking activity included boiling, frying, and warming, the observers did not record any attempts to adjust the heat output of the stove during the cooking. The only heat adjustment for the charcoal stoves was the gradual increase in heat output following ignition during which the rice was being cooked. The cooking fuel was saved after the meal was completed by dousing the fuel in ashes.

The period of cooking lasted from 35 minutes to just over one hour. The rice cooking took from 25 to 40 minutes. No water was boiled for drinking or making tea so only one stove was required to prepare the meal.

The other activities which occurred while the meal was being cooked included preparation of food, cleaning of plates and pots, other domestic chores, and conversing with friends. The level of attention given to the operation of the stove was minimal except during periods when the food was being stir-fried or ingredients were being added to the pot.

These observations have several implications for the design of improved stoves. First, the level of attention which is given to the operation of the stove is minimal. Next, a second cooking port is generally not needed. Third, the rim of the stove should be able to accomodate a variety of shapes and sizes of cooking vessels. Fourth, the stove need not include a mechanism for extinguishing the fuel at the end of the cooking. Fifth, heat control would be desirable only if it could be provided with minimal operational complexity. Sixth, charcoal stoves need not be provided with a means for adding fuel during the cooking activity, but wood stoves should have this capability. Seventh, the fuel chamber in charcoal stoves should be sized to hold enough fuel for one

hour of cooking plus about five minutes of preheating.* Eighth, either the stove should be portable so it can be placed in a position convenient to the area of food preparation or it should include a surface on which the food can be prepared.

4.1 Rice Cooking

The cooking tests and cooking observations which used rice have revealed the wide variation in the amount of water used in rice cooking. This variation has a major effect on the quantity of fuel required per kilogram of rice cooked. The factors which alter the water-to-rice ratio are a result of the highly refined rice cuisine in areas which produce and consume rice as a staple. The two factors already mentioned are the difference between steaming and boiling and the use of excess water to feed animals. Other factors include the moisture content of the rice, (high after harvest, low after storage), the type of rice, whether the rice will be reheated, and the attention which the cook is willing to give to cooking the rice. Although these factors appear to be operational constraints of the Thai cuisine, the popularity of electric rice cookers in electrified villages points to the fact that this habit is not immutable.

Other factors determine the water-to-fuel ratio which also affects fuel consumption. These factors include the time allotted for cooking, the perceived scarcity of fuel, the size of the combustion chamber, and the size of the family.

5. Photographic and Essay Data

The different types of stoves used in the survey villages are shown in the photo sequences in the Appendix. The basic model of wood stoves are shown in photo sequence I. They include various design of the three-rock stove using rocks and bricks; the open horseshoe stove made from mud, rocks, clay, fired clay, brick and cement; the enclosed horseshoe made from mud and clay; the multiple port, retangular stove made of clay; and the traditional bucket stove modified for use with wood. The various designs for charcoal bucket stoves are shown in sequence II. The most interesting unit was a 200 baht cylindrical model with thick metal cladding (same metal as used in making cooking vessels), a tight fitting slide door for the primary air port and a relatively flat rim. The stoves in sequences I and II are the most common. Some of the less frequently used designs are shown in Sequence III. These models include the sawdust bucket stove, the "economical" stove, gas burners for biogas and LPG, bucket stoves modified for gas or electric heat, and stoves made from old car parts.

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*For wood stoves the fuel can be recharged during cooking and not necessarily all of the fuel is placed in the combustion chamber.

Stove operation is described in photo sequence IV. The testing procedures are shown in the first four photos. The next two show vessel arrangements for steaming rice. The following four show the different levels at which the bucket stoves can be placed. Most frequently it is placed on the floor of the kitchen and operated in the squatting position, however, it can be placed on a table or into a permanent cement structure for operation in the standing position. The cooking utensils are generally the same for charcoal and wood stoves, but the effect of the different fuels is shown in the next two photos. For the charcoal stoves the pots are kept cleaned and the bottoms have at most a thin layer of carbon. For the wood stoves the bottoms of the vessels are completely blackened with a thick layer of carbon.

Photo sequence V indicates some of the operational problems which reduce stove efficiency. In this sequence a meal is being prepared for the benefit of a survey coordinator. The stove is a fired clay, enclosed houseshoe with arched loading port as shown in photo sequence I. Normally, the cooking pot would fit closely on the stove rim as shown in the first photo, however, in order to increase the burning rate, the pot has been lifted on small wedges fitted between the rim and the pot. A tree trunk is pushed into the fuel port so it is not possible to control the heat by increasing or decreasing the fuel. In this example, the desire was to produce a quick meal for guests so fuel conservation, a serious concern in Roi-et, was ignored.

The survey enumerators recorded their observations on the use of stoves in their village in essay format. A classification of answers to the essay questions prepared for each village and the results are presented in the "Questionnaire" Volume. The results on a changwat basis are summarized as follows. Bucket stoves are used in all villages. With few exceptions, the fuel is either charcoal or firewood. Simple wood stoves of the three-rock or horseshoe design are observed in Srisaket, Lamgang, Songkla, Roi-et, Udorn Thani, and Chiang Mai. Wood stoves made from metal cans are used in some villages in Songkla, Chantaburi, and Roi-et. In Roi-et the enclosed horseshoe with arched fuel port is used. Enclosed clay stoves are rarely seen in the survey villages.

The bucket stoves and enclosed horseshoe stoves with arched fuel port are purchased in the market but the other stoves are made by the household members. The price of the enclosed horseshoe is between 15 and 17 baht while the cost of the various bucket stoves ranges from 15 to 35 baht. The lower prices for bucket stoves are observed in Srisaket, Songkla, Roi-et, and Urdorm Thani. Although households frequently have more than one stove, especially if they are s[illegible]le port units, they are generally of the same design. The households do not use different designs for different foods.

Among the modern stove designs used in the villages, the most common is the "economical" stove which was observed in one-sixth of the survey villages. Gas and electric stoves were each observed in six of the survey villages. Biogas and rice husk stoves were rarely seen. Some of the modern designs w[illegible] observed in all the changwat except Srisaket. These designs are not widely accepted except for electric rice cookers. The reasons for lack of acceptance are difficult to determine. The enumerators

gave various reasons such as the design was inappropriate, inconvenient, or expensive.

The enumerators in about 60 percent of the villages felt that the villagers would be interested in using improved stove models. This opinion was most widely held in Roi-et, Udorn Thani, and Chiang Mai. The enumerators suggested a number of models or design requirements, especially stoves using alternative fuels or consuming less of existing fuels.

Charcoal is the preferred fuel in all villages except those in Lampang. The convenience and safety of this fuel was cited as its primary attraction. Cooking was done using metal cooking vessels in all villages.

As part of the stove experiments, the survey personnel observed how the household cooks regulate the heat in the cooking stoves. These observations have been summarized by stove type and changwat in the Appendix, Part A-1. The heat output from bucket stoves is increased by adding fuel, smoothing the ashes and fanning the fire. The heat is reduced by removing fuel, which in the case of charcoal, is doused in a container filled with ash. For simple wood stoves, heat is controlled entirely by increasing or decreasing the amount of fuel. For semi-enclosed wood stoves, air is also blown into the fire. The "economic" stove is controlled by adding fuel to increase the heat and by closing off the air channel to decrease the heat.

6. Conclusions

6.1 Measurements

The design of improved cook stoves requires an understanding of the way in which stoves are used in the village prior to laboratory testing and design and acceptance testing in the village. The stove field tests were useful in providing information of how villagers use cooking stoves, but they did not provide controlled efficiency measurements as could be achieved in a laboratory. The major measurement problems had to do with the fuel moisture content (as discussed in the "Biomas Samples" volume), the lack of consistency in the performance of the basic cooking and boiling water experiments on different stoves, and regional differences in fuels, foods, and cooking traditions.

The basis of the field test was to boil water for a specific length of time, however, it was difficult to identify the time at which boiling started. It is possible to measure when the water temerpature reaches 100°C, but there is an indeterminate period after that before the boiling commences. A visual check for rapid formation of bubbles in the water is not very precise. The boiling water test was a controlled time test. This would be suitable for laboratory tests of stove efficiency but the procedures should be modified. A new methodology is discussed in Section 7, based on what was learned from the cooking observations in the survey villages.

The efficiency measurements from the boiling water tests were lower than results from previous tests in Thailand because the water was boiled for a longer period. During the period of boiling there were considerable convective heat losses from the surface of the cooking vessel and the water. Convective losses also occurrred during the period following the cooking test when the water was cooled down prior to measurement. Finally, the efficiency was calculated based on the high heat value for the stove fuel. Since the moisture in the fuel was converted to steam and very little condensed within the stoves or on the surface of the cooking vessels, it would be more appropriate to use the low heat value of the fuel.

6.2 Results

The information obtained from this survey was not the specific relationship between physical factors and resulting stove efficiency. This information must be obtained in laboratory experiments where the necessary controls can be placed on experimental variables so that the influence of a single variable can be determined. Information from the field tests concerns the operational factors which, because of their wide variation in village cooking, exert a dominant effect on cooking fuel consumption. These factors are very important to the design of improved cooking stoves, but it is important to remember that some of the factors which did not appear important in the field tests, may in fact, be important on closer examination.

Approximately 125 stoves were tested in the villages. About half of these used charcoal and the other half wood. The average recorded efficiency for the charcoal stoves with observed efficiencies between 5 and 35 percent was 22 percent with a coefficient of variation of .34. The most important factor affecting stove efficiency, was the weight ratio between the water boiled and the fuel burned. A variable which had less influence on stove efficiency was the quantity of fuel loaded into the stove. Factors which were originally thought to be important but which did not significantly affect the results included the moisture content of the fuel, the time required to boil the water, and the quantity of starter. The charcoal stoves were preheated for an average of eight minutes and boiling required an average of 15 minutes. The rate of rise in water temperature appeared to increase the longer the fuel was burning, an observation which is supported by recent research by the Royal Forestry Department.

The average recorded efficiency for wood fuel stoves with observed efficiencies between 5 and 30 percent was 14 percent . The coefficiency of variation was .33. The major factor affecting the efficiency was the design. Seven major designs were tested. The kerosene can stoves have the highest observed efficiency followed by the bucket stoves and the enclosed horseshoe designs. The open horseshoe, three-rock, and economic stoves were observed to have the lowest observed efficiencies with average values of [illegible], 12.2 and 11 percent, respectively. Other factors which affect the efficiency of wood-fueled stoves were the quantity of the starter fuel, the water-to-fuel ratio and the period of time required for boiling. The latter was used as a surrogate for rate of heat generation

which is known to be a major factor in determining stove efficiency but which could not be recorded in the field. Factors which were expected to affect efficiency, but did not, include the quantity of fuel loaded and the moisture content.

The average time for preheating the stove was three minutes. The time required for the pot to boil once it was placed on the stove, averaged 17-1/2 minutes. The rate of heat generation appeared to be relatively constant during the period the pot was on the stove. This observation agrees with the RFD findings using wood-fueled stoves.

For the cooking tests, separate analyses were carried out for all the tests and for the subset of tests involving the boiling of rice. The heat produced by the burning fuel averaged 3.2 kilocalories per gram of food for charcoal stoves and 4.3 kilocalories per gram of food for wood stoves. When the calculated stove efficiencies from the boiling water tests were included in the calculations to approximate the quantity of heat captured in the cooking vessel, the averages were .65 and .64 kilocalories per gram of food for charcoal and wood stoves, respectively. A similar calculation for captured heat versus the quantity of water, rather than the quantity of food, yielded 320 and 289 kilocalories per liter for charcoal and wood stoves, respectively. For all of these statistics, the coefficient of variation was in excess of .6 because of the variety of foods prepared as well as the variety of stoves, fuel and cooking vessels used. When the cooking tests were limited to those using rice, the coefficients of variation remained close to .6, but the amount of captured heat was lower, 155 and 195 kilocalories per liter of water for charcoal and wood stoves, respectively.

The traditional Thai bucket stoves were the most widely observed. They were used with both wood and charcoal fuels. The other types of stoves used only wood fuels, and were most common outside of the central region.

The observation of cooking activities in each survey village indicated that a single stove is used and that foods are prepared sequentially. The cooking is in two phases; the rice is cooked first and then the other foods. The non-rice foods are generally prepared for cooking while the rice is being cooked. Usually only one cooking vessel is used in the second phase with the foods being added to the pot at various stages in the cooking process. The fuel is always saved after the cooking is completed, unless there is too little to save. Rice is generally boiled with an excess of water. After the water is poured off, the rice is dried. The method of cooking has implications for the future design of stoves as follows. The stove should be a single port requiring a minimum of attention during operation. It should have sufficient fuel capacity for more than one hour of operation and is should be portable. The procedures for controlling the heat, extinguishing the fuel and igniting the fire should be relatively simple.

7. Future Research

The baseline survey has provided most of the field data necessary to begin stove design research. Additional, detailed survey work might be undertaken to determine the basis for different stove operational techniques. Otherwise future field research should concentrate on testing the fuel consumption of new designs. Three testing activities are proposed for future research; a boiling water test and a cooking test to be performed in the laboratory, and a fuel consumption test to be performed in the village.

The survey data has indicated several variables which should be measured in future laboratory tests. Some are difficult to measure and should be collected only occassionally. Others are easy to determine and should be recorded for all tests.

7.1 Physical Variables

1. The fuel/water/food ratio has proved to be very important in determining fuel consumption. This ratio has also proved to be highly variable. Both laboratory and field testing of stove should be done with careful measurement of this ratio.

2. Moisture content is thought to be more important for wood-fueled cooking than for charcoal-fueled cooking. Careful measurement of the moisture content of wood should be made in the laboratory and the field.

3. The quantity of starter used can have a significant effect on the measured efficiency of wood-fueled stoves. Also the period of preheating can be important for both wood and charcoal stove efficiencies. Careful measurements should be made of the weight and heat value of the starter fuel as well as the period of preheating for both the laboratory and the field tests.

4. The shape and size of the pots, will be important since they affect the tightness of fit between the stove lid and the bottom of the pot. Also important is the amount of carbon on the pot bottom and the resulting color. The effect is different for the charcoal and wood stoves. For the former, the pot bottom's reflectivity is important, for the latter, the pot bottom's insulation is important.

5. The three periods of time; preheating, time to boil, and total testing time, should be carefully measured as these affect not only fuel consumption but also acceptability to user.

6. The rate of heat generation can only be measured in the laboratory. The easiest method is to place the stove on a scale and observe the rate of weight loss per unit time. This variable is the basic parameter describing the effect of different fuels on stove efficiency.

7. Low heat values should be used in calculating stove efficiency when the fuels have moisture contents above 10 percent. For wood and charcoal with moisture contents on a wet basis of 15 and 20 percent,

respectively, the low heat value of the fuel will be approximately 1-1/2 and 3-1/2 percent less than the high heat value.

8. The maximum rate of heat absorption of the cooking vessel and water should be measured or extrapolated for different pots, volumes of water and temperature gradients.

7.2 Operational Variables

These variables must be considered when performing research on stove design however, they are not under the control of the designers but are determined by traditional food preparation, cooking and stove use practices.

1. Ignition: The charcoal is ignited using a variety of fuels. The stove can be designed to facilitate rapid starting of the fire, but the period of ignition will depend on the type and quantity of starter used relative to the type and quantity of fuel.

2. Water-fuel ratio: Traditional cooking practices determine the ratio of water-to-fuel. Small ratios produce more rapid cooking but higher fuel consumption. The quantity of fuel in the initial charge can be limited by the size of the combustion chamber, but there is no control over the quantity of the water other than the limited influence of the size of the stove rim.

3. Rate of Combustion: The rate of fuel combustion and heat generation will affect stove efficiency dramatically; however, this value is only partially determined by stove design. More important is the type of fuel and the preparation of the fuel as reflected in the moisture content and surface-to-volume ratio.

4. Use of cooking vessels: The rate of heat absorption of the cooking vessels will be limited by the carbon insulation on the bottom, the reflectivity of the surface, and the surface to volume ratio. Only the latter variable is controllable through design. The use of lids on cooking vessels is widespread in Thailand so this factor need not be stressed.

5. Location of the stove: Stove effficiency can be improved by placing the stove in a sheltered area. In most village households the stove is located inside the kitchen which has walls that restrict but do not eliminate airflow because of the desire to remove smoke and cooking fumes. Villagers in the North and Northeast will sometimes cook outside with wood in the dry season because of easier fuel storage and handling and less smoke.

6. Ash removal: The design of stoves must take into account the size of fuel used and the removal of burned fuel and ash. In the bucket stoves the primary air hole is sized to permit ash removal rather than efficient combustion. In wood stoves the primary air port, fuel loading port and ash removal port are the same and the size is determined by the maximum requirement.

7. Portability: The portability of a stove is not so important once the stove is located in the kitchen since it is usually not moved. However, the bucket stoves are purchased in the market and it is necessary that they be carried easily from the market to the home.

8. Stove height: Stove heights vary. With portable stoves it is possible to place them either on the floor, on a stand, or on a table. Personal preference is the dominant issue. Where conversation and food preparation take place between people seated on the floor, it is appropriate to have the stove on the floor. In other households all kitchen activities take place while standing and a stove height at hip level is desirable.

7.3 Design Variables for Bucket Stoves

The following design variables relate to traditional bucket stoves and should be examined as part of the stove design project. The selection of these variables is based on field observations, conversations with Stephen Joseph and his colleagues at the ITDG stove testing facility and one of the authors' own research.

1. Primary air port: This port is currently used for ash removal and is too large. The flow of air is in excess of that required for combustion thus increasing convective losses. Separation of the ash removal and primary air ports with the former being sealed during stove operation should be considered.

2. Size and position of grate: For bucket stoves, the major heat transfer mechanism is radiation. The position of the grate will determine the solid angle subtended by the cooking vessel with respect to the source of radiation. The size of the grate will determine the quantity of fuel which can be burned and the distribution of the heat source.

3. Angle of the walls: Much of the radiant heat in the bucket stoves and other single port stoves is reflected off the stove walls. The angles of the walls will determine the pattern of reflection as well as the proportional relationship between the grate and the cooking vessel surface exposed to the radiant heat.

4. Angle and thickness of the walls: From a structural viewpoint vertical walls would last longer than angled walls since the total load is taken up in compression. However, angled walls may minimize the quantity of clay required and also improve the reflection pattern mentioned in #3. The thickness of the walls will affect both the cost of construction and the rate of heat loss. Since the stoves are used for quick cooking, the heat storage capacity of the walls is not of interest; however, the rate of loss of heat through the walls of the stove is of concern.

5. Materials: The cost of local stove designs depends on both labor and material costs. Bucket stove designs make use of burnt biomass for insulation and thin metal sheeting for structural strength. Changes in materials can affect not only the efficiency of a stove but the cost of

construction and the durability. The cost of construction can vary with the procurement price of the materials and the labor costs for the technical skills required to work with these materials.

7. Stove rim: The shape of the stove rim determines the gap between the cooking vessel and the stove. In single port stoves this gap must be sufficient to permit the hot gases to exit from the stove. However, if the gap is too large, then any wind will increase the air flow through the stove and increase convective losses.

8. Air flow control: Air flow control can be used to restrict the flow of primary air into the stove and to channel the flow of hot gases through the stove in such a way as to maximize the residence time of the gas or the turbulence of the flow.

7.4 Laboratory Test

The basic laboratory test is a boiling water test in which the heat captured in water is compared with the heat released by the burning fuel. This test should be standarized so as to permit comparison between different units and to record the effect of changes in design parameters.

The observed efficiencies for different stove-fuel combinations are affected by the design of this test. Although the ordinal scale of efficiencies for different units may remain the same over a variety of tests, the cardinal scale for the conversion efficiency will differ considerably. Where there are major differences in stove testing procedures the ordinal scale may also be altered. The major factors to be considered in designing a test are:

1. Is the fuel to be burned completely or is the test to be halted according to other criteria?

2. Is the water to be raised to 100°C, brought to a boil or boiled for a specific length of time?

3. Is only one cooking vessel with water to be used or are several to be used sequentially as required?

4. Is the test to be run for a fixed time or until a specific activity is accomplished?

5. Is the quantity of water remaining at the end of the test to be measured after the water has cooled or while it is still at boiling temperature?

6. What size, shape, and material of pot is to be used?

7. How much fuel is to be used in the initial load? In subsequent additions?

8. How much water is to be placed in the cooking vessel?

9. How much starter fuel should be used?

10. How long should the stove be preheated following ignition before the cooking vessel is placed on the stove?

11. How should the cooking vessel be cleaned?

The measured conversion efficiency for a given test will decrease with longer boiling periods, lower water-to-fuel ratios, uncleaned cooking vessels, cooled water measurements at the completion of the test, complete burning of the fuel, the presence of wind, the higher fuel moisture contents.

The recommended test procedures are described in Table 7. The water should be raised to the boiling point, 100°C, and then kept of the stove for 10 minutes more. The pot should then be removed from the stove, and weighed and the fuel should be placed in an ash pit for cooling.

7.5. Cooking Tests

The cooking test is less precise than the boiling water test because the characteristics of the food and the decision on when the cooking activity is completed are difficult to control. The recommended cooking tests are shown in flow chart form in Figure 37. Two foods are cooked in each test. In the first test, sticky rice is steamed and then a vegetable is boiled. In the second test, regular rice is boiled followed by stir frying some vegetable. Because of the cost of the food and time for preparation, the cooking tests would be performed less frequently than the boiling water tests. Also a shorter version of the cooking test involving only the rice could be used for screening. The quantities of food would be determined from the results of "Cooking, Lighting and Heating" volume regarding the amount of food normally cooked. The amount of fuel loaded should be determined relative to the amount of food. The amount of starter should be similar to that used in the boiling water tests. (See Table 8)

7.6 Field Tests

New stove designs should be tested in village homes. The villagers would be given the new stoves and asked to use them for a period of one week. The fuel to be used during this period would be identified, measured, and placed in a separate location. The villagers would record the foods prepared and the number of people eating at each meal. The fuel remaining at the end of the period would be measured and the villager would be asked about the advantages and disadvantages of the prototype stove over the normal designs. The number of tests conducted in the village, the regional coverage of the testing activity and the logistics and procedures would be decided based upon the availability of project prsonnel and the willingness of the villagers to participate.

Table 7

Proposed Laboratory Test

Stove Size	Small		Large	
Cooking Vessel	22 cm. Pot		26 cm. Pot	
Fuel	Charcoal	Wood	Charcoal	Wood
Preheat Time	8 min.	3 min	8 min	3 min.
Starter Fuel	resin	kindling	resin	kindling
Quantity of Water	1.5 liters	1.5 liters	2.5 liters	2.5 liters
- of Fuel	.4 kg	.7kg	.55 kg	1 kg
- of Starter	25 gm	30 gm	30 gm	40 gm
Moisture Content	3-6%	12-18%	3-6%	12-18%

Method of Starting: light starter with match, fan the burning fuel.

Method of Measuring: weigh pot and water together immediately before placing pot on stove and after removing the pot from the stove;

Timing of Experiment: record the water temperature, stop test 10 minutes after water reaches 100°C.

Table 8

Proposed Cooking Test

	Test 1	Test 2
First Food		
Type	Rice	Rice
Quantity-Food	2.75 kg (1)	2.75 kg (1)
Water	(2)	8 liters
Cooking	Steaming	boiling
Second Food		
Type	vegetable	vegetable
Quantity-Food	(1)	(1)
Water	(2)	none
Method of Preparation	dice	dice
Cooking	boiled	fried

	Wood	Charcoal	Wood	Charcoal
Fuel Quantity	(3)	(4)	(3)	(4)
Starter Quantity	30 gm		30 gm	
Preheat	3 min	8 min	3 min	8 min

(1) assume typical family size of 5 with equivalent rice for 4 adults
(2) to be determined
(3) ¼ quantity of water (subject to review)
(4) 1/8 quantity of water (subject to review)

Figure 37

Proposed Cooking Test Flow Chart

	Test 1		Test 2
T	ignite fire		ignite fire
	place pot with water on stove	T	pour rice into pot
			rinse rice
35-45 min	place glutinous rice in bamboo strainer		add water
	place steamer on top of pot and seal	25-35 min	bring water to boil
			simmer rice
	steam rice		pour off water
↓	remove steamer	↓	dry rice over fire
	put coconut milk in second pot		put wok on stove
	place pot on stove	10-15 min	heat oil
20-30 min	boil milk		add vegetable and stir fry
	add spices		remove wok
	slice vegetables and place in pot	⊥	extinguish fire
	boil vegetables		
	remove pot		
	extinguish fire		

Figure A.1

PETCHABURI

- [illegible]
- [illegible]
- [illegible]
- [illegible]

menu
- rice
- bullfrog hot soup
- boil eggs
- boil water

ignite the fire
(fire the coconut husk and add the charcoal)

10 mins — pour the rice into the pot and clean it

place the (rice) pot on the stove
(aluminium pot)

crush and mix the spices

bring the water to a boil

16 mins — prepare coconut milk

simmer the rice

chop bullfrog into small pieces

pour the water into bowl (jar)

11 mins

dry rice over the fire (2 mins)

mix spice and coconut milk in pot and bring to boil

put the bullfrog into pot and boil soup

remove the pot

boil eggs in the kettle
(open the top)

10 mins — wash the plates

remove the kettle and place eggs in dish

wash the kettle and boil the water

extinguish the fire

Note : usually the villagers will extinguish the fire by wetting the burnt fuel and drying it; there is a little they will let burn.

Figure A.2

KORAT

- ทุ่งข้าว - ปลาร้า - ต้มผักเพื่อกินกับปลาร้า		menu - rice - preserved fish - blanch vegetables
	↑	ignite the fire (fire pieces of wood and add the charcoal)
		clean the rice one time and pour the water into the pot
10 mins		
	↑	place the pot on the stove (aluminium pot)
		bring the water to boil
		simmer the rice
		pour the water out (for animal)
40 mins		
		dry rice over fire
		warm the pickled salt fish with clay pot (3 mins)
		place the pot on the stove blanch the vegetables for a few minutes
	↓	extinguish the fire (put the burn fuel into jar and close the top)

Figure A.3

SRISAKET

- ข้าวสาร
- ต้มยำปลา
- ไข่ดาว
- ทอดปลา

menu

- rice
- fish curry
- fry eggs
- fry fish

ignite the fire

(fire starter made of resin and oil and add the charcoal)

7 mins

pour the water into the pot (aluminium) and place on the stove

pour the rice into the pot after water boiling

cut fish into small pieces

boil the rice

30 mins

pour the water out

dry rice over fire

remove the pot

add the charcoal

pour water into the other aluminium pot and place on stove

put the fish into pot after water boiling

20 mins

prepare the spice

mix the spice in pot and cook with the fish

remove the pot

place wok on stove

fry eggs and place in dish

fry fish and place in dish (the same wok)

extinguish the fire

put the burnt charcoal into unused pot and close the top.

Figure A.4

KAMPANGPHET

- ข้าว
- แกงปลาใส่ไก่

menu

- rice
- fish curry with chicken

ignite the fire
(fire piece of wood and add the charcoal)

5 mins

rinse the rice one time

add water to the rice

place the pot on stove

wash the plates

bring the water to a boil

24 mins

straighten the kitchen

boil the rice

cut chicken into small pieces
cut fish into small pieces
mix the spices

remove the pot

wash wok and pour water in it

pour the water out

place the wok on the stove

bring water to a boil

mix the spice and fish in the wok and boil

12 mins

dry rice over fire

wash the wok and place on stove

heat oil in the wok

stir fry the chicken mixed with the spice

place the chicken in the bowl with the fish

wash the wok

put the burnt charcoal into jar and close the top

Figure A.5

LAMPANG

	Menu
- หุงข้าว	- rice
- แกงผักกาดใส่เนื้อควาย	- green vegetable curry with buffalo meat

prepare the spice

ignite the fire
(fire pieces of wood or cloth and add the firewood)

clean and dice meat

19 mins

mix the spice with chilli and pickled salt fish

place the clay pot on stove and heat the oil

fry meat, spice, chilli and fish in oil

pour water into the pot

clean the vegetables (children work)

boiling the mixture

18 mins

add water to the pot

slice the vegetables

put the vegetables into pot
boil the mixture

remove the pot

extinguish the fire
(by wetting the fuel)

Figure A.6

SONGKLA

- ข้าวสวย
- แกงกะทิหอยขม
- น้ำพริกแมงดา

menu

- rice
- fresh water snail soup with coconut cream
- horseshoe crab sauce

ignite the fire
(fire pieces of paper and wood, add fire wood)

rinse the rice and add water to the pot

place the pot on stove

prepare coconut milk

bring water to a boil

clean fresh water snail

boil the rice until the rice absorbs all all the water

dry rice over fire

5 mins

clean another pot, pour coconut milk into the pot

put pot on stove

crush and mix the spice (9 mins)

add the fuel

place the spice in pot after coconut milk boils

28 mins

place the snail in pot (6 mins)

add the fuel

slice the vegetables and place (3 mins) in pot

straightened the kitchen

remove the pot from the stove

make sauce of horseshoe crab and chili in mortar (11 minutes)

let the fuel burn
(very little left in the stove)

Figure A.7

CHANTABURI

- ทุเรียน
- ตูมกงหน่อไม้
- แกงเลียงหน่อตองกาดพร้อ

menu

- rice
- warm bamboo shoot curry
- Tongaper shoot curry

ignite the fire
(fire the latex starter and add the charcoal)

clean an aluminium pot

19 mins

rinse the rice in the pot

add water to the pot

bring water to a boil — straighten the kitchen

22 mins

boil the rice — crush and mix the spices

pour the water out

slice the vegetables

warm curry from the previous day (1 min)

dry the rice over fire (1 min)
remove pot from stove — cut fish into small pieces

add fuel

place wok on stove
put the spices in wok and add the water

add fish and vegetables to wok and boil

22 mins

add more water and continue boiling

remove the wok from stove

extinguish the fire
(put the fuel into jar and close the top)

Figure A.6

ROI-ET

- [illegible]
- [illegible]
- [illegible]

menu
- warm glutinous rice from the morning
- noodles hot soup with canned fish
- sauce

ignite the fire
(fire pieces of wood and add the firewood)

1 min

place the (water) pot on the stove
(curved pot)

clean the bamboo streamer

place the glutinous rice from the morning in steamer

4 mins — feed the hens

place the steamer over the pot and seal the top

24 mins — crush and mix the spices
prepare noodles (made of green gram)

remove the glutinous rice from stove

place the glutinous rice in bamboo vessels

pour the water into the aluminium pot and place on stove

after boiling water, add the spices, noodles and canned fish

12 mins

boil the soup

remove the pot from stove — make sauce for vegetables in mortar

let fire burn out

Figure A.9

UDORNTHANI

- [illegible]
- [illegible]
- [illegible]

menu
- warm glutinous rice
- fry eggs
- bamboo shoot curry with coconut milk

↑	ignite the fire (fire pieces of wood and add fuel)
40 mins	pour water into a pot
	put the glutinous rice from the morning in bamboo steamer and place over the pot
↓	remove the steamer, allow rice to cool
2 mins	place rice in bamboo vessel
↓	remove the pot
	break and stir eggs
↑	place wok on stove and heat the oil
8 mins	fry eggs in wok
	place the fried eggs in dish
	remove the wok from stove
↑	slice and clean bamboo shoots
25 mins	prepare coconut milk
	put the bamboo shoot and coconut milk in aluminium pot and place on stove
	boil
↓	remove the pot
	extinguish the fire (put the charcoal in clay pot and close the top)
	mix sauce of garlic and chilli (3 mins)

Figure A.10

- แกงผักรวม

CHIANGMAI

menu
- vegetable hot soup

clean and slice the vegetables

19 mins

crush and mix the spices

ignite the fire

heat oil in aluminium pot

19 mins

mix the spices and vegetables
and place in pot

boil

wash dishes and pots

remove the pot

extinguish the fire
(place the burnt fuel on zinc plate
and cover with ash and then water
on the fuel)

Table A.1

Heat Control

CHANG-WAT	VILLAGE	STOVE TYPE	HEAT CONTROL	
			METHOD OF HEAT INCREASE	METHOD OF HEAT DECREASE
6	1	Bucket	increase the charcoal or wood and fan faster	take charcoal and wood out of the bucket.
6	2	Bucket	smooth off the ashes and increase the charcoal, then fan faster	decrease the charcoal and set ashes above the charcoal.
		gas	increase gas	decrease gas.
		three rock	increase wood	take the wood out leaving the charcoal.
		cement semi-enclosed	increase the wood and use hollow bamboo to blow air into this stove	no control.
6	3	Bucket	increase the charcoal	decrease the charcoal.
		three rock	increase the wood	decrease the wood.
		cement semi-enclosed	increase wood in this stove.	take the wood out
6	4	Bucket	increase the charcoal	decrease the charcoal.
		three rock	increase the wood	decrease the wood
		cement semi-enclosed	increase the wood	decrease the wood
		gas	increase gas	decrease gas
		rock semi-enclosed	increase the wood	decrease the wood
6	5	Bucket	increase the charcoal	take the charcoal out of stove.
		Clay semi-enclosed	increase the wood	decrease the wood
7	1	Bucket	increase the charcoal or the wood and fan	decrease the wood or charcoal and keep in the pot.
		gas	increase gas	decrease gas.
7	2	Bucket	increase the wood or charcoal and faster fan	decrease wood or charcoal (by using the ashes)
		gas	increase gas	decrease gas
7	3	Bucket	increase the wood or charcoal and faster fan	decreese the wood or charcoal
7	4	Bucket	increase the charcoal, smooth the ashes, fan faster	decrease the charcoal by using the ashes.
7	5	Bucket	increase the charcoal, smooth the ashes, fan faster	decrease the charcoal.
		gas	increase gas	decrease gas
8	1	Bucket	increase the wood or charcoal	decrease wood or charcoal

CHANG-WAT	VILL-AGE	STOVE TYPE	HEAT CONTROL	
			METHOD OF HEAT INCREASE	METHOD OF HEAT DECREASE
		three rock	increase the wood or char-coal	decrease wood or charcoal
		zinc enclosed	increase the wood or char-coal	decrease wood or charcoal
		Clay enclosed	increase the wood or char-coal	decrease wood or charcoal
8	[illegible]	three rock	increase the wood and use the zinc at the top	decrease wood or charcoal
		Bucket	increase the wood (char-coal)	using the ashes
		semi-enclosed	increase the wood and shelter from the wind	not done
8	3	Bucket	increase wood	take charcoal out
		semi-enclosed	increase wood	decrease wood
		three rock	increase wood	decrease wood
8	4	three rock	increase wood	decrease wood
		Clay-enclosed	increase dry wood	decrease wood
		semi-enclosed	increase wood	decrease wood
		Bucket	increase the small charcoal	decrease the charcoal
		zinc enclosed	increase wood	decrease wood
8	5	Bucket	increase charcoal	decrease charcoal
		three rock	increase wood	take wood out
		Clay enclosed	increase wood	take wood out
		semi-enclosed	increase wood	take wood out
9	1	Bucket	increase charcoal	take charcoal out by the ashes
		three rock	increase wood	decrease wood
9	2	three rock	increase wood	decrease wood
		Bucket	increase wood or charcoal	decrease charcoal
		gas	increase gas	decrease gas
9	3	three rock	increase wood	decrease wood
		Bucket	increase charcoal	decrease charcoal by the ashes
9	4	Bucket	increase charcoal	decrease charcoal by the ashes

CHANG- HAT	VILLA- AGE	STOVE TYPE	HEAT CONTROL	
			METHOD OF HEAT INCREASE	METHOD OF HEAT DECREASE
		three rock	increase wood	decrease wood
9	5	Bucket	increase wood and charcoal	take away charcoal and wood
		three rock	increase wood and take ashes out	take wood out
10	1	Bucket	increase wood	decrease wood
10	2	Bucket	increase wood	decrease wood
10	3	Bucket	increase wood	decrease wood
10	4	Bucket	increase wood and charcoal	decrease wood and charcoal
10	5	Bucket	increase wood and close the stove at the front, fact the fire take out	decrease wood
		economic stove	increase fuel to fire	close the channel

STOVE PHOTOGRAPHS
PHOTO SEQUENCE 1
WOOD STOVES

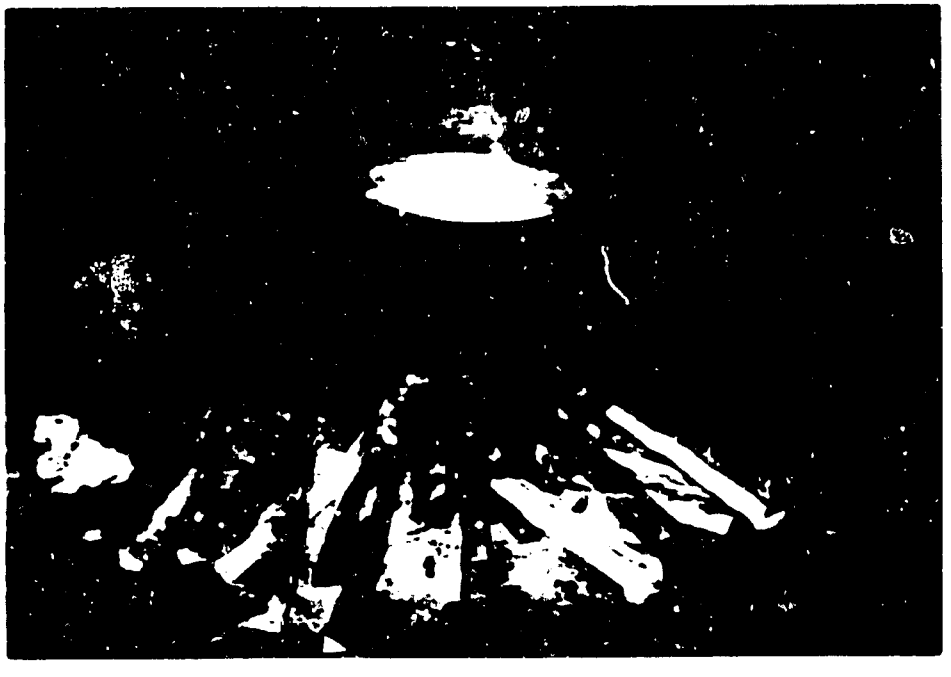
Three rock - Srisaket

Three rock - Ayutthaya

Horseshoe stove - Songkla

Horseshoe, loose brick - Lampang

Horseshoe, brick and grouting - Songkla



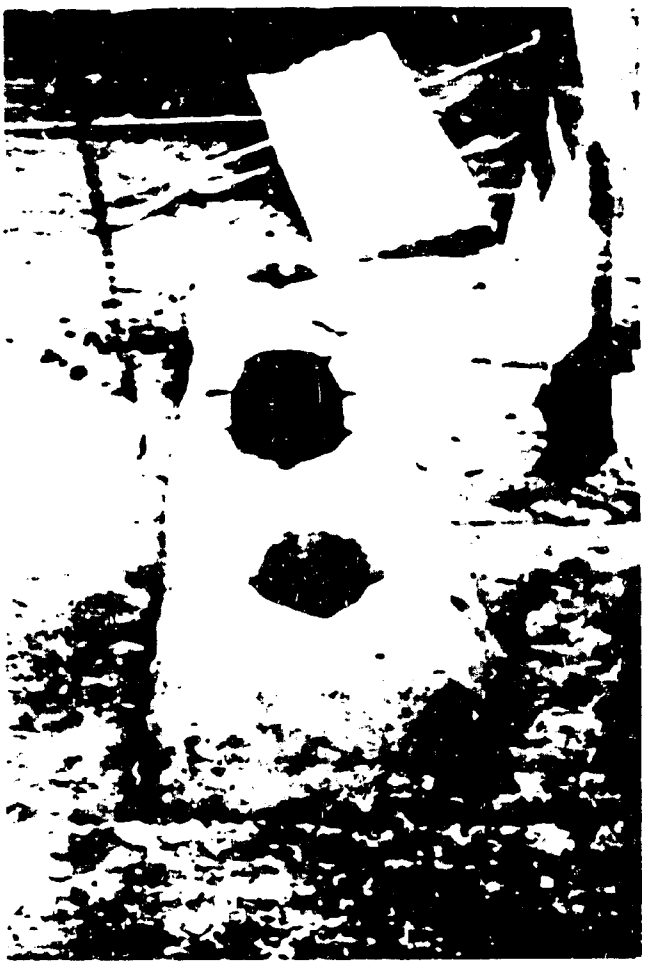
Horseshoe, cement - Songkla

Enclosed, clay - Roi-et

Enclosed, clay - Roi-et

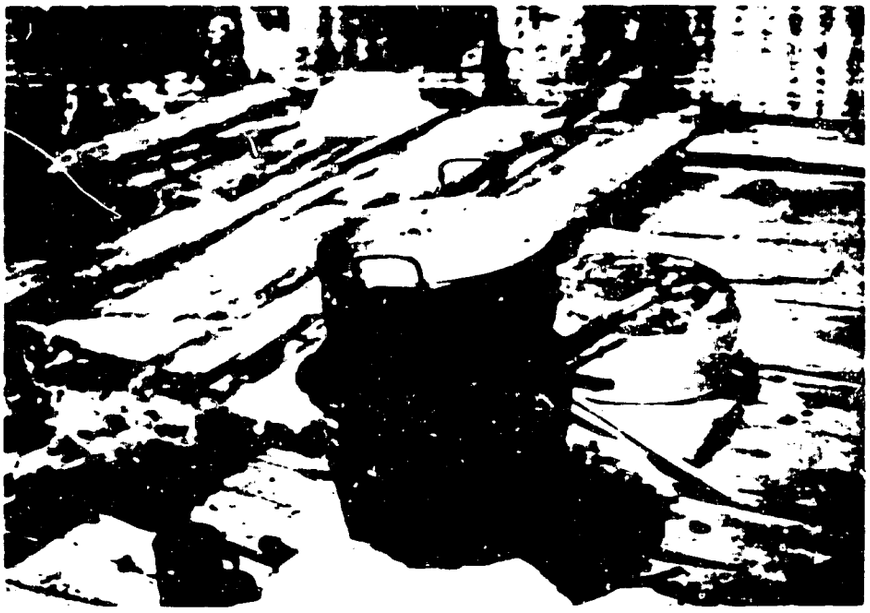
Enclosed horseshoe fired clay - Roi-et

Enclosed horseshoe fired clay - Roi-et

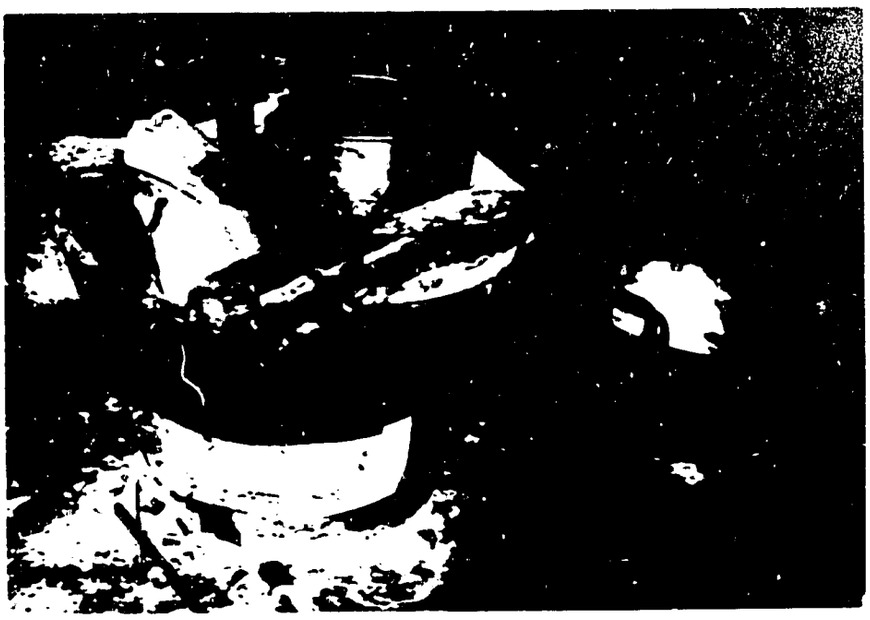


Enclosed multiple port,
mud - Roi-et

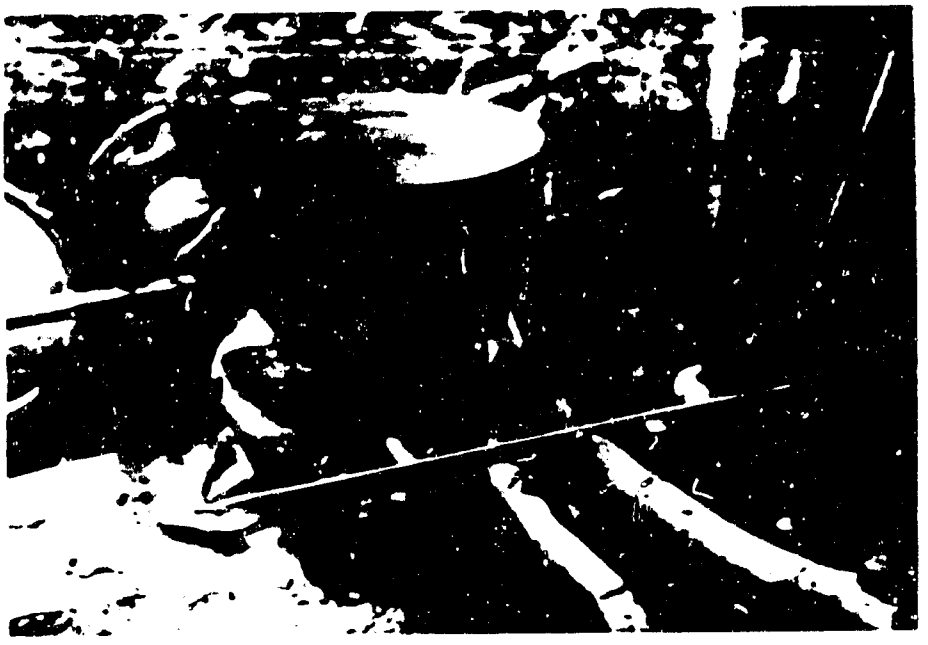
Enclosed sugarmaking,
mud - Udorn Thani



Bucket - Korat

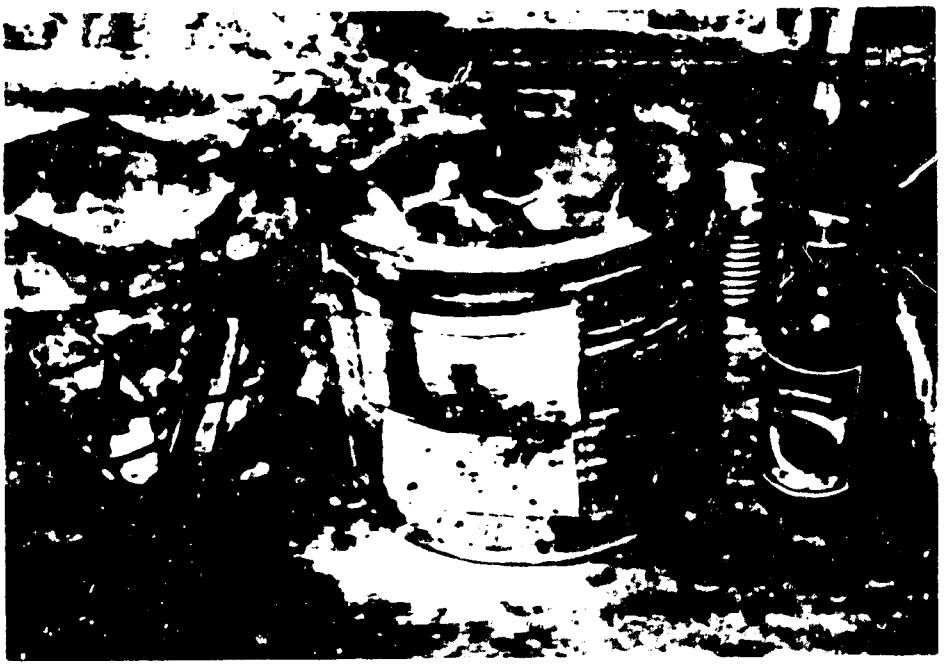


Bucket - Chaing Mai

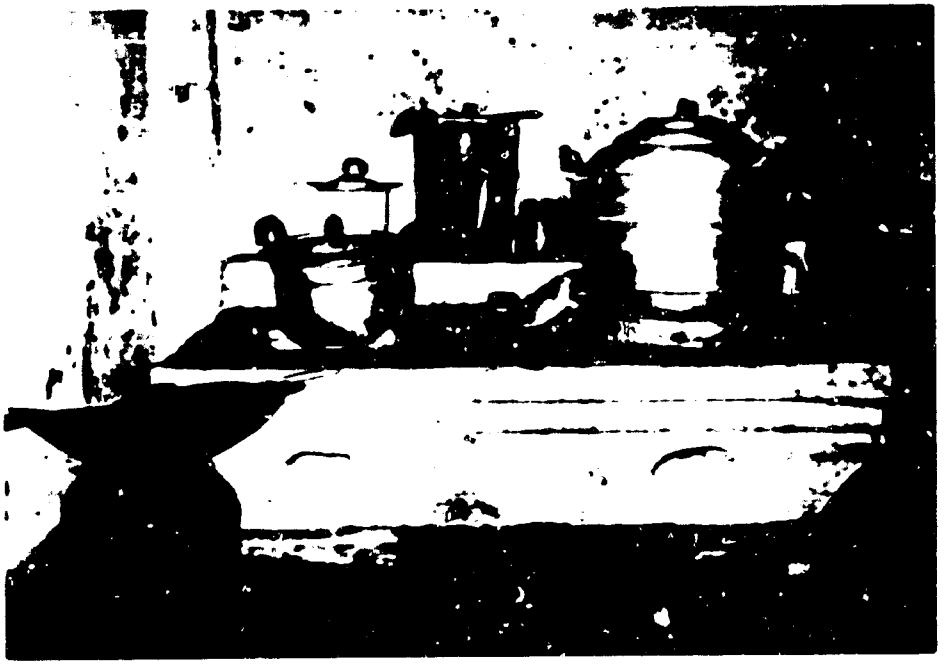


Bucket - Lampang

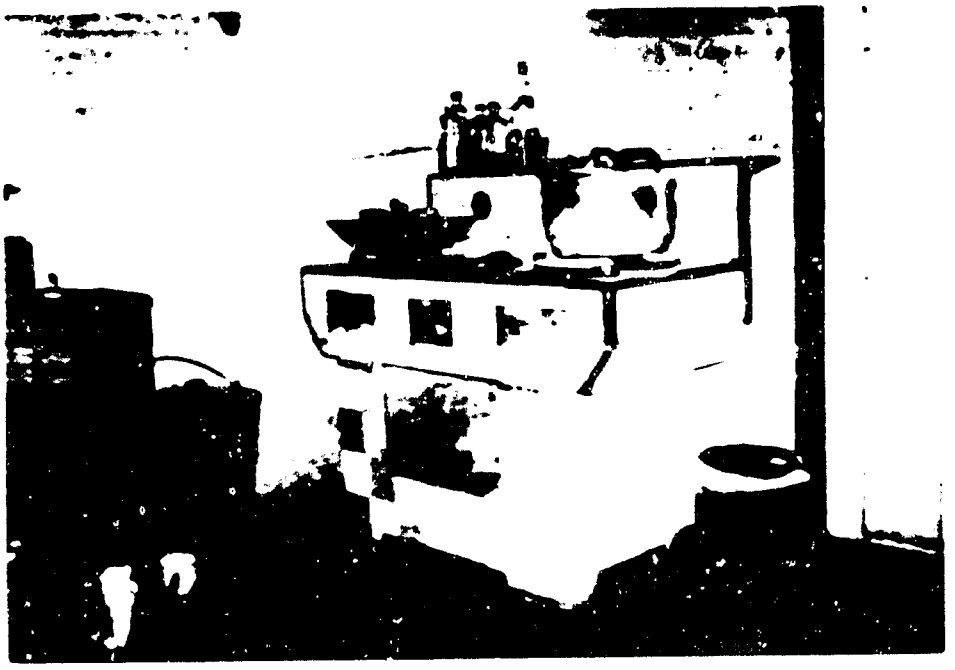
PHOTO SEQUENCE II
CHARCOAL STOVES



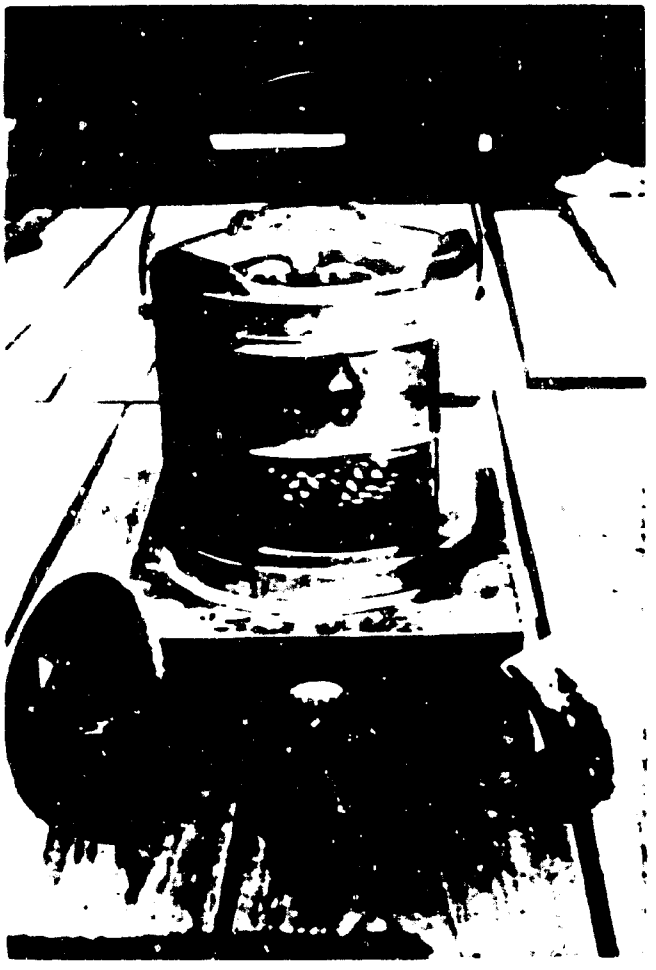
Bucket - Korat



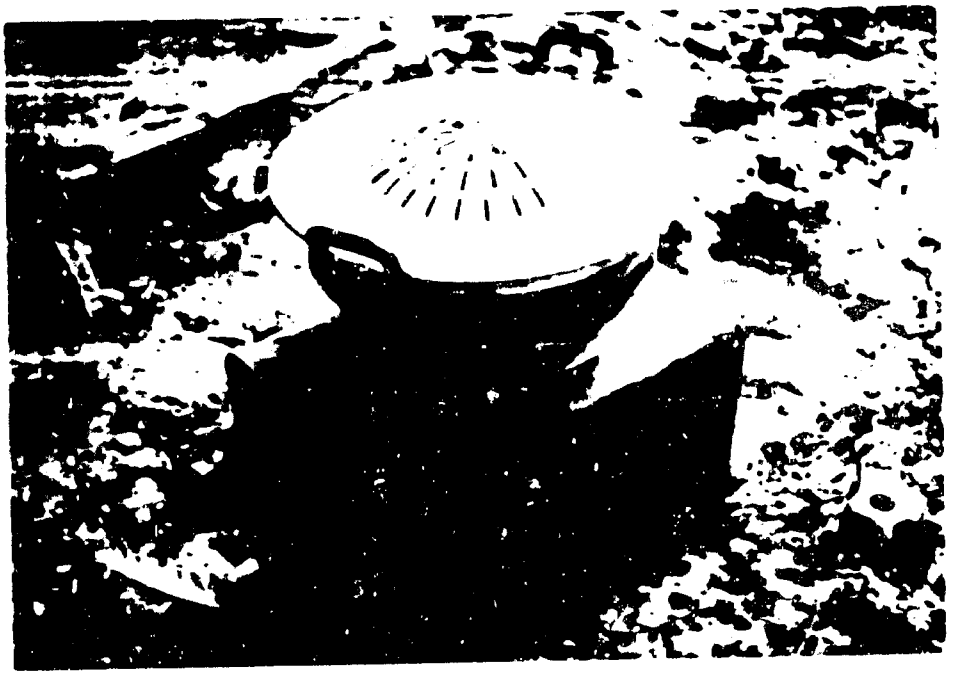
Bucket, two ports, on floor - Songkla



Bucket, two ports, raised - Kampangphet



Special bucket, pieces - Kampangphet

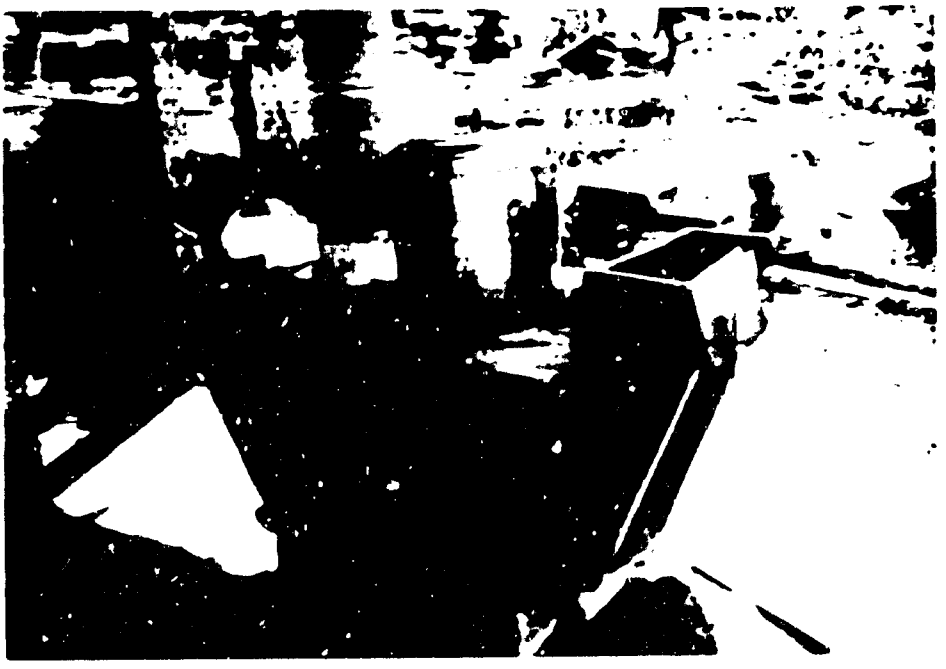


Special basket for frying meat - Udorn Thani

PHOTO SEQUENCE III
SPECIAL STOVES

Sawdust stove - Poi-et

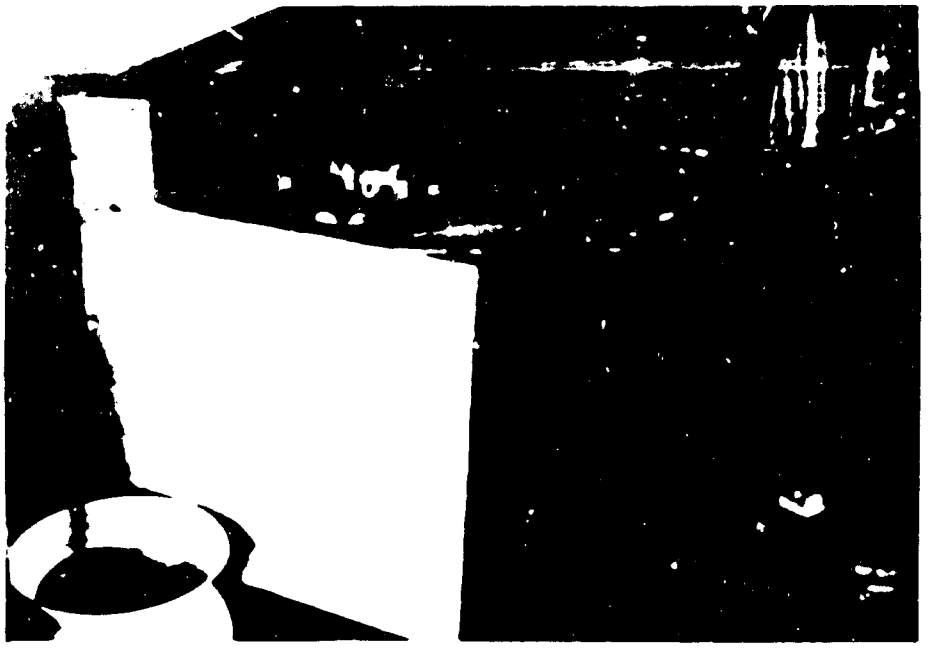
Sawdust stove -
Udorn Thani



Economical stove - Chanthaburi

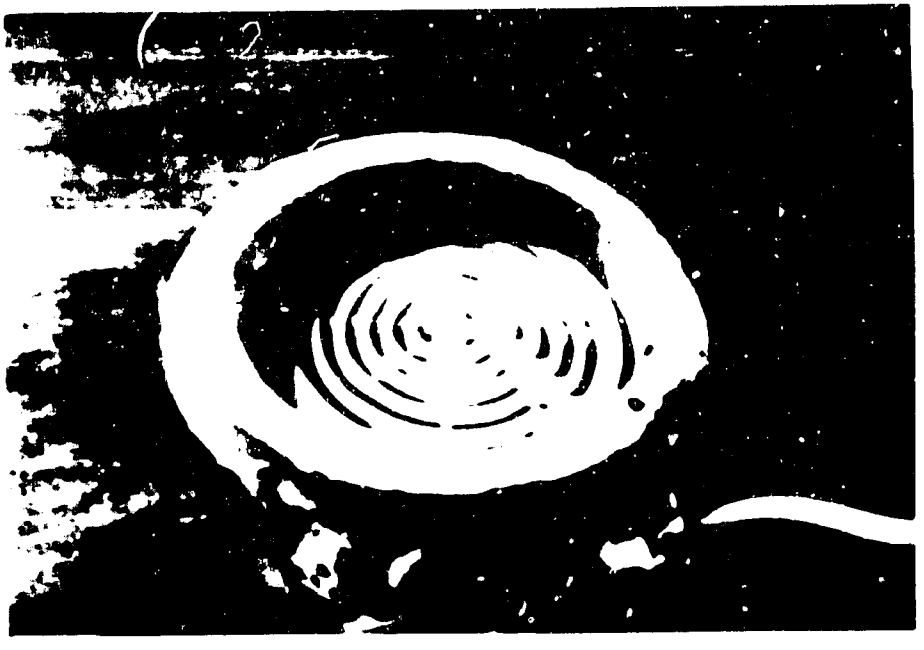
Economical stove, palm leaf fuel - Kampangphet

Biogas burner - Udorn Thani



Biogas double burner - Khon Kaen

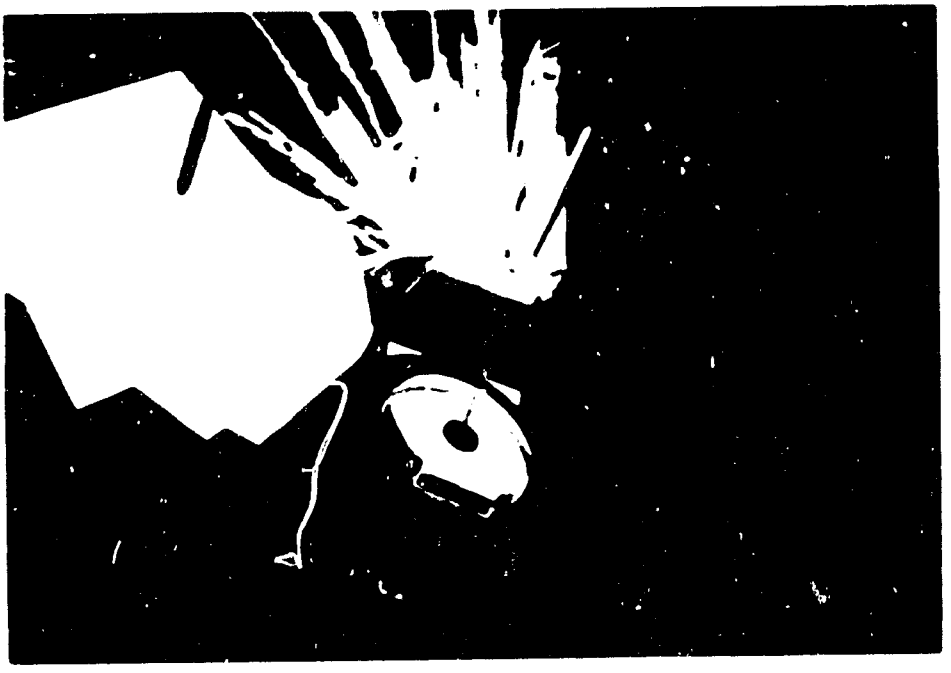
Gas bucket stove - Pattaya



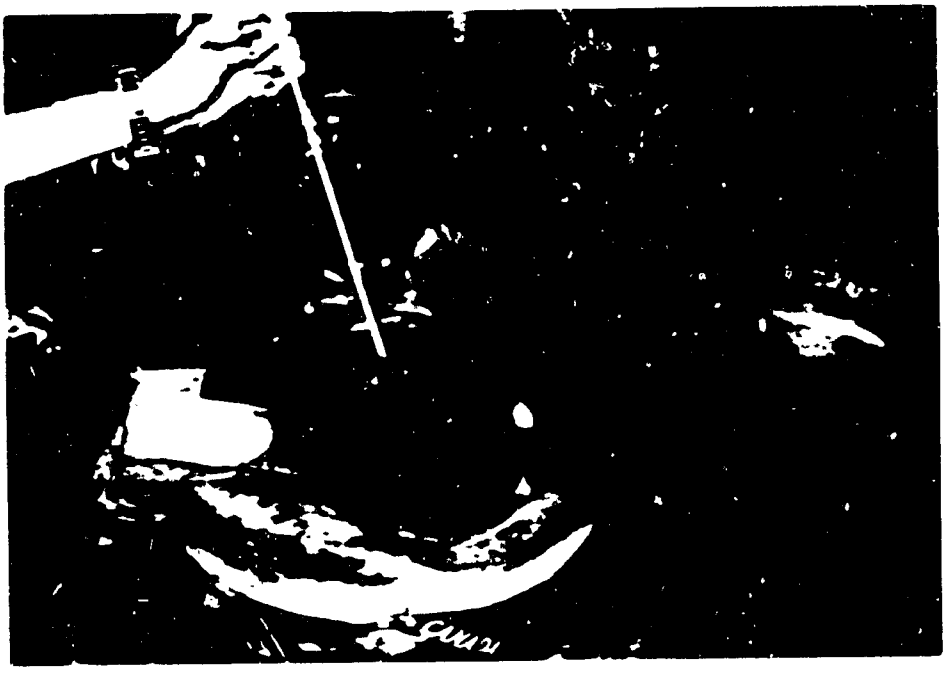
Electric bucket - Lampang

Car part stoves - Udorn Thani

PHOTO SEQUENCE IV



Measuring weight



Measuring temperature

Measuring size

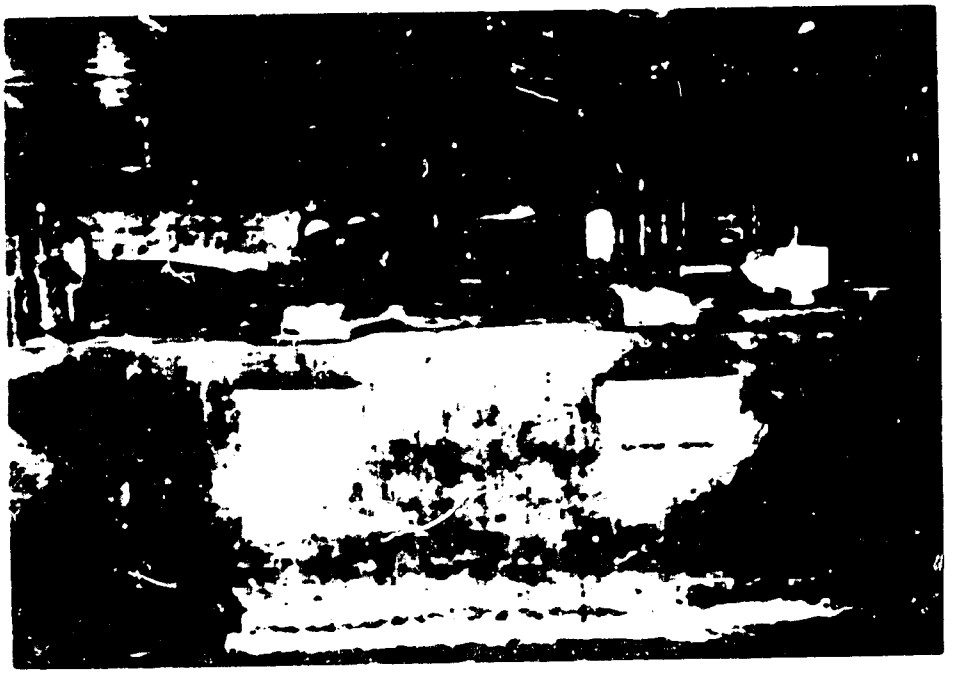
Steaming rice -
Bangkok

Steaming rice - Udorn Thani

Cooking position, squatting - Udorn Thani

Cooking position, standing - Songkla

Bucket stove on table - Songkla



Bucket stove in cement structure - Chiang Mai

Cooking utensils, charcoal cooking - Petchburi

Cooking utensils, wood cooking - Petchburi

Dousing pit -
Udorn Thani

PHOTO SEQUENCE V
INSUFFICIENT STOVE USE - ROI-ET

Tight fit

Loose fit

Fuel

Appendix A-4

The Water-to-Fuel Ratio and Efficiency

The relationship between the fuel loaded and water heated can be examined using formula 2 for efficiency:

$$E = \frac{w(T+54)}{(1-M_c)eW}$$

The ratio of water loaded to fuel loaded is expressed as:

$$R = \frac{w_i}{W_i}$$

using the notation on page 3, formula 2 can be written as follows:

$$E = \frac{w_i - w_f}{W_i - W_f} \times \frac{(T+540)}{(1-M_c)e}$$

The second term on the right-hand side of the quation has relatively little variance. The temperature change, T, was 73±2. The energy content of the charcoal, e, was 6.4 ± .75 kilocalories per gram. The moisture content factor, $(1-M_c)$ was .92 ± .05. If the final term is assumed to be constant then the efficiency will vary with the ratio of the quantity of water vaporized to the quantity of fuel burned.

$$E = K \frac{w_i - w_f}{W_i - W_f}$$

The analysis in figure 7 indicated that:

$$E = \frac{K\, w_i}{W_i} + E$$

which does not follow from the previous equation since both w_f and W_f are non-zero and not proportioned to w_i and W_i.