An Evaluation of Thai Cooking Fuels and Stoves[1]

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ABSTRACT

This report documents investigations of the energy unit cost of sixteen cooking fuels and the tested performance efficiency of twenty six different cooking stoves. A total of 122 tests were conducted on 46 fuel/stove combinations in Kao-I-Dang refugee holding center. Results show that the fuels with least cost are agricultural waste products including rubberwood, corn-cobs, rice husk and sawdust. The most efficient stove for burning solid fuels like charcoal, wood and corn-cobs is the traditional Thai bucket. A packed gallon can is best for cooking with sawdust. A good improved two hole mud stove with feed box is best for cooking with rice husks. Use of these alternatives by refugees is recommended as a feasible and ecological alternative to cooking with charcoal or local wood.

INTRODUCTION

Using Cooking Fuels More Effectively

The cooking fuel situation in Thailand can be improved by the planting of more trees and by better management of existing forest resources. However a parallel approach that should be followed is reducing the demand for firewood through introduction of alternative fuels, conservation and introduction of more efficient burning equipment. The possibilities of this approach seem particularly attractive because firewood is most scarce in those regions of the world where it is burned most inefficiently.

Roughly 80 percent of the fuelwood consumed in developing countries is used for domestic purposes: cooking, space heating, and hot water. Many traditional cooking stoves and open fireplaces waste fuel mainly because they focus the flames poorly on the cooking surface. Improving cookstoves is one of the ways to alleviate the double problems of cooking fuels scarcity and forest depletion. Often, all that is required is minor redesigning of existing stoves.

Improved stove models are insulated to prevent heat loss through the walls. The burning area can be closed to regulate air intake and improve combustion conditions. The flow of air and hot gases is directed through the stove to concentrate heat on the cooking surface. A chimney is

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[1]This text was originally prepared as a report for the United Nations High Commission for Refugees (UNHCR), and was submitted on May 31, 1981. Some of the details from the original report have been omitted in the version presented here.

often incorporated into the design to improve draft and provide the motive power that eliminates exhaust smoke and draws in fresh air for combustion. However, poorly designed chimneys can decrease efficiency by creating excessive draft. Cooking pots are arranged to fit deeply in the stove top, minimizing leaks and heat loss and increasing the pot area exposed to heat.

An overall efficiency of between 20 and 30 percent can be achieved by improved stoves. They have the potential for significantly reducing cooking fuel requirements for those who adopt their use. In addition to reducing the consumption of Thailand's forests, the wide dissemination of such stoves would help eliminate smoke-filled homes, sooty hands and the respiratory and eye defects caused by smoke, fumes and sparks. Burn hazards to children may be reduced.

However, the claims about efficient stove designs have seldom been substantiated in unequivocal tests. Therefore it is important that any new stoves be field tested on site before they are widely promoted for local use. An excellent measure of performance is the weight of fuel needed to cook a number of typical meals. The results should be compared with those of other stoves, including traditional ones.

Many factors other than efficiency complicate the acceptability of a cooking stove: cost, availability of materials, type of fuel available, family size, cooking practices, and types of meals to be prepared. These vary greatly from area to area, which means that it cannot be assumed any given stove design will be accepted or used effectively outside the area where it was designed.

In many cases cooking fuel savings can be realized even without changes in equipment. Perhaps the best way to do this is simply to dry or season wood before burning. Moist wood produces less useful heat and more smoke when burned. Fig. 1 presents the effect of wood' moisture content on its heating value. To ensure that wood is dry, it should be split and dried below 20 percent moisture content (wet basis). Though economic pressures often prevent proper seasoning of wood, some drying and storage facilities should be provided. In adopting these mea-

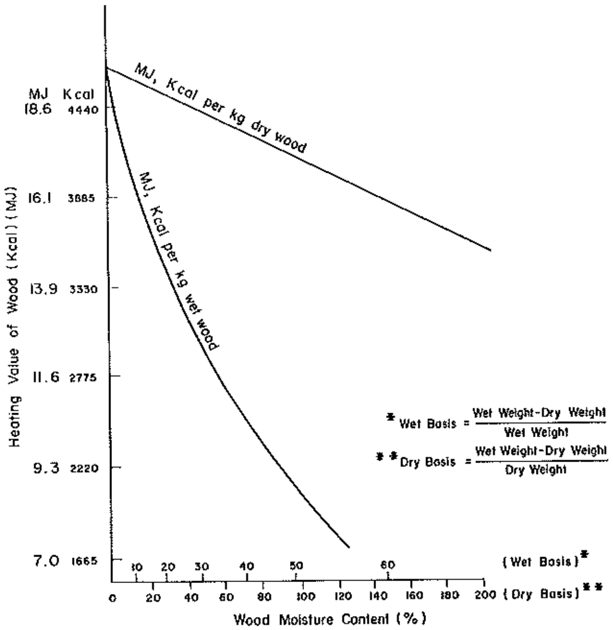

Fig. 1 Effect of wood moisture content on its heating value (14)

sures the population in Thailand may be able to save thousands of tons of cooking fuel annually.

Cooking Fuel Consumption at Refugee Camps in Thailand

The 220,000 Southeast Asian refugees now in Thailand burn mostly wood charcoal in traditional Thai bucket stoves for their daily cooking needs. Each refugee is provided a daily ration of 170 grams of charcoal and 250 grams of rice and lesser amounts of vegetables, meat, oil and other critical staples. This results in a total monthly consumption of about 1,100 metric tons of charcoal and 1,650 metric tons of rice.

Due to increasing deforestation and the resulting diminished availability of charcoal cooking fuel, the Thai Supreme Military Command requested the UNHCR to decrease or stop charcoal use by refugees. UNHCR requested refugee relief agencies and VITA to assist this effort.

Prior to this study it was known that there were several alternative fuels and many types of alternative stoves in use in Thailand.[1, 2] Some of these stoves and fuels have been widely promoted at public exhibitions and demonstrations. However, little quantitative information on their performance, costs and public acceptance was available.

OBJECTIVES

The immediate goal of this fuels/stoves evaluation is to provide useful comparative information on the performance, economics and user acceptability of several types of cooking fuels and stoves. This information is required during planning and implementation of a fuel substitution program. It will be useful to government and non-government agencies seeking to cope with the supply of cooking fuels and/or the reduction of deforestation.

This evaluation seeks to determine which alternative fuel/stove combinations are most economial and appropriate to replace use of charcoal and local wood in the refugee camps. The primary information sought in this study is:

- Unit cost of potential heat energy supplied by several cooking fuels.
- The most practical and economical stove for cooking with each fuel.
- Total user-cost per person per month of using each type of fuel/stove combination.

STANDARD COOKING PRACTICE OF KYMERS

The standard cooking practice of Kymers was determined before the fuel/stoves testing. Nine Kymer families were observed preparing their evening meals on Thai bucket stoves in Sakaeo and Kao-I-Dang camps.

At Sakaeo, three cooks were visited and their procedure for cooking rice was observed and measured. These cooks used 9 litre cast aluminum pots 27 cm in diameter, 16 cm deep, with a lid for cooking rice. A stamped aluminum # 22, 5 litre pot without lid is used for simmering soups. A stamped steel frying pan (katha or wok) is used to stir-fry vegetables and some meat. Rice is prepared by washing dry rice in cold water, heating water almost to a boil in the pot, adding the rice, bringing again to a boil and simmering about 20 minutes over reduced heat till the rice is done. After cooked rice is removed from the fire, vegetables and/or meat are stir-fried in less than 5 minutes. Soups are often prepared by simmering for 30-90 minutes on a slow fire. Measurements of rice cooking are summarized in Table 1.

Table 1
Measurements of Kymer rice cooking at Sakaeo

Fuel name	Dry rice weight (g)	Water weight (g)	Cooking time (min)	Fuel use (MJ/kg rice)	No. of people served	Rice/person (g)
wood	1,505	1,545	20	5,290	7	215
bamboo	1,705	2,485	17	6,950	8	213
charcoal	827	1,735	20	9,112	5	165
average	1,346	1,922	19	7,327	6.7	198

At Kao-I-Dang, 6 cooks with families of 5-8 people were visited and interviewed. Differences from the methods at Sakaeo were apparent. All cooks used 22 cm, 5 litre stamped aluminum pots with lids for cooking rice, soups and boiled vegetables. A stamped steel or aluminum frying pan (katha or wok) is used for quickly stir-frying vegetables and meat over a high flame. Rice is first washed, then put in a pot with enough water to cover the rice by 3 cm. The rice and water are brought to a boil quickly and then slowly simmered so that all the water is evaporated and the rice is not burnt. Soups and boiled vegetables are also brought to a boil and then simmered for longer periods than the rice. Food is generally cooked once in the morning and once in the evening. Total burning time (without soups) is normally less than one hour.

FUELS

The first part of this evaluation is to determine the cost and availability of all cooking fuels

Table 2
Availability and costs of alternative fuels

Fuel name	Source place	Tons available per month	User camp	Dist. (km)	Truck cost (฿/day)	Load/ truck (kg)	Trans. cost (฿/kg)	Source cost (฿/kg)	Final cost (฿/kg)
Rice husk	Chachoeng Sao	216	Ban Kaeng	20	240	6,000	.04	.07	.11
Rice husk	Tapraya	72	KID*	20	240	6,000	.04	.07	.11
Rice husk	Watana Nakorn	432	KID	60	720	6,000	.12	.07	.19
Rice husk	Prachinburi		KID	250	3,000	6,000	.50	.13	.63
Sawdust	Bangkok		KID	350	4,200	6,000	.70	.06	.76
Charcoal	Aran street		KID						1.70
Charcoal	Aran contract		KID						2.70
Rubberwood			Panat Nikom						1.6
Corn cob	Pakchong		KID	500	6,000	6,000	1.00	.45	1.45
Corn cob	?	25	?	100	1,200	6,000	.20	.45	.65
Sawdust log	Bangkok	278	KID	350	4,200	12,600	.33	1.70	2.03
Rice husk log	Saraburi	100	KID	350	4,200	12,000	.35	1.50	1.85

* KID = Kao-I-Dang Camp. US$ 1.00 = 23.00 ฿

to be considered as possible alternatives to charcoal and local wood. All cooking fuels presently known to be used in Thailand were considered. Data were collected from many fuel suppliers to determine cost at source including processing and packing, and the delivery cost to Kao-I-Dang was determined on the basis of ฿ 6.0 (US$ 0.26) per km per 6,000 kg. This information is presented in Table 2.

Analyses of the moisture content of small samples of the actual test fuels were made because the useful heat released from any fuel is partially dependent upon the free moisture it contains. Each sample was accurately weighed. All samples were simultaneously dried in a gas oven at 140°C for 10 hours and then weighed again. It was assumed that this oven-dried weight indicates a condition of zero moisture content. Since the samples were dried at 140°C rather than the standard drying temperature of 105°C, it is possible that some volatile components of wood resin may have evaporated, thus resulting in a slight overcalculation of moisture content. The difference in weight before and after drying indicated the moisture content of each fuel sample. The moisture content of the samples was determined as follows:

$$\text{moisture content (dry basis)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}}$$

The results are summarised in Table 3.

Table 3

Summary of moisture content test results

Fuel tested	Wet weight (g)	Dry weight (g)	Moisture content (per unit, dry basis)
Rice husk	60.60	55.80	.086
Sawdust	79.55	72.00	.105
Rubberwood	178.20	116.30	.532
Seawood	118.70	100.30	.184
	Rice husk logs and sawdust logs were freshly produced and assumed to be near their tested moisture content of:		.040

These moisture content results were used to recalculate the standard high heat values[3] of each fuel (0% moisture) in order to compensate for the actual free moisture content of the test fuels. The latent heat energy required to evaporate the free moisture was subtracted from the amount of equivalent dry fuel high heat value per kg. The corrected high heat value of each fuel was calculated as shown below and is indicated in Table 4.

$$\text{fuel value (wet)} = (\text{high heat value}) \times (1 - \text{moisture content}) - (\text{latent heat of water}) \times (\text{moisture content}),$$

$$\text{latent heat of water} = 2.26 \text{ MJ/kg}.$$

Table 4
High heat values of tested fuels corrected for moisture

Fuel name	High heat [a/] value (MJ/kg)	Moisture [a/] content	High heat value (MJ/kg)	Actual	
				Moisture content (per unit)	High heat value (MJ/kg)
Tropical hardwood	19.6	.000	19.6		
Rubberwood			20.4	.532	12.8
Seawood			21.8	.184	18.1
Sawdust			19.6	.105	17.7
Sawdust logs	16.3	.048	19.8	.048	18.8
Bamboo			19.6	.100	17.3
Wood charcoal	31.4	.050	33.0	.050	31.4
Ricehusks	13.9	.020	14.2	.086	12.9
Rice husk logs					12.9
Corncobs	16.4	.170	19.6	.133	17.0

a/ [3, 4, 5]

Some fuels were not considered in this study because of the reason indicated in Table 5. Charcoal was retained as a control and reference standard.

About 100 kg samples of each fuel not eliminated were obtained and transported to Kao-I-Dang camp for use during the fuels/stoves testing. Table 6 presents the cost of energy from different fuels.

STOVES

Because of the lack of comparable information on different traditional and "improved" stoves and a total lack of information on the use of agricultural wastes for domestic cooking, a thorough testing program of many stove/fuel combinations was necessary. A total of 35 stoves were evaluated for possible testing and 31 were actually acquired and transported to the test site or built on the site (Table 7, Figs. 2, 3, 4, and the Appendix). Due to economic and logistic reasons several stoves were eliminated from serious future consideration and testing (see Table 8).

Table 5
Elimination of fuels

Eliminated fuel	Reason for Elimination
Local wood	Refugees not allowed out of camp to collect wood. Supply by local entrepreneurs would cause serious local deforestation.
Wood Shavings	Normally used by some Thais, but not available in quantity.
Biogas	Several years required for amortization of equipment. Difficult and time consuming to implement.
Lignite logs	Sulpherous smoke. High production and transport costs. No longer in production.
LP gas	High cost burners and storage systems. Unfair to surrounding Thai villagers.
Electricity	High cost of production, distribution and electric burner. Only available from portable diesel generators. Other uses have higher priority.
Rice straw	Does not burn well in any stove tested. Ash quickly clogs stove.

Table 6
Cost of energy from different fuels

Fuel name	Final [a/] delivered cost (฿/kg)	High [b/] heat value (MJ/kg)	Cost of energy (฿/MJ)
Rubberwood	.16	12.8	.013
Ricehusk	.19	12.9	.015
Sawdust	.76	17.7	.045
Charcoal	1.70	31.4	.054
Corncob	1.45	17.0	.085
Sawdust log	2.03	18.8	.108
Ricehusk log	1.85	12.9	.143

[a/] data from Table 2 [b/] data from Table 4

Table 7 Names, costs, and sources of evaluated stoves

Name of Stove	Source	Cost ฿			Life time (Month)	No. of Users	Cost per User (฿/Month)
		Buying	Fixing	Total			
Ayudhya 23 cm.	Aranyapratet	24	6	30	24	8	.16
Ayudhya 18 cm.	Aranyapratet	22	6	28	24	6	.19
Hexagon 18 cm.	Samutprakarn	30	6	36	24	6	.25
Vichai 13 cm.	Samutprakarn	30	6	36	24	4	.17
Khon Kaen 13 cm.	Khon Kaen	20	6	26	24	4	.27
Vichai rice feed	Samutprakarn	75	25	100	24	6	.69
Vichai wood feed	Samutprakarn	75	25	100	24	6	.69
1 hole log feed	Samutprakarn	130	21	151	24	6	1.05
2 hole log feed	Samutprakarn	160	27	187	24	8	.97
1 hole rice feed	Samutprakarn	130	25	155	24	6	1.08
2 hole rice feed	Samutprakarn	160	25	185	24	8	.96
NFED cone	NFED, Bangkok	60	–	60	18	4	.83
Noi large can	NRC, Bangkok	600	12	612	24	8	4.25
Noi insulated can	NRC, Bangkok	800	44	844	24	8	4.40
1 gallon can	paint store	1	–	1	6	6	.03
Sayan 1 hole	Bangkok	280	41	321	48	6	1.11
Suksan 2 hole	Thonburi	330	34	364	48	8	.95
Rangsit 1 hole	Patumthani	350	48	398	48	6	1.38
Rangsit 2 hole	Patumthani	450	48	498	48	8	1.30
Rangsit 40 cm.	Patumthani	550	96	646	48	50	.30
Kymer pottery # 1	Sakaeo, CBERS	90	9	99	24	6	.69
Kymer pottery # 2	Sakaeo, CBERS	90	9	99	24	6	.69
Agri. Dept. 2 hole	Kasetsart U.	380	24	404	48	8	1.05
IRRI Rice feed	Philippines	480	43	523	48	8	1.36
Kymer 2 hole	Sakaeo, CBERS	10	–	10	24	8	.05
Hole in ground	KID	6	–	6	24	6	.04
Hole with vent	KID, Sakaeo	12	–	12	24	6	.08
Hole with chimney	KID, Suksan	36	30	66	24	6	.46
Stewart 1 hole mud	Sri Lanka	26	11	37	24	6	.26
Suksan 2 hole	KID	32	7	39	24	6	.26
VITA 2 hole I	KID	32	11	43	24	8	.22
2 hole ricefeed	KID, Bangkok	32	11	43	24	8	.22
Lorena	Reference 13	36	30	66	24	8	.34
Sakaeo market	Sakaeo	20	–	20	24	8	.10
VITA 2 hole II	VITA, NFED	16	11	27	24	8	.14
Suksan 1 hole	Bangkok	26	7	33	24	6	.23

Table 8
Elimination of stoves

Eliminated Stove	Reason for Elimination
Noi large can	No insulation and lack of secondary air feed indicated probable less efficiency than similar insulated can. Excessive volume and cooking time. Originally intended for space heating in northern climates.
Kymer pottery # 2	Better version of this stove wouldn't boil water, pot hole too small and too high above burning area. Flames never touch pot.
Agriculture Department two hole	Logistics. Can't transport, build on site, or test at Agri. Dept. Design deserves testing however.
Kymer two-hole	Normally used by refugees in their homes for steaming thin rice cakes. Not used for cooking rice. Uses local wood. May be improved for traditional use and deserves testing.
IRRI rice feed	Complicated sheet metal construction developed by International Rice Research Institute appears expensive, difficult to make, hard to maintain or repair. The unique stepped burning grate may be adaptable to clay stoves. Deserves testing.
Hole in ground with vent	Kymer ladies preferred venting around pot. Examples seen at Kymer market in Sakaeo camp should be tested.
Hole in ground with chimney	Example seen at home of Khun Suksan would not start. Intended for burning wood. High probable heat loss to ground. Should be tested at Sakaeo market by adding chimney to vented hole in ground.
VITA two-hole mud II	Development not yet completed. Several improvements will be made. May perform better than VITA two hole mud with rice husk feed box.
Sakaeo market high mass Two hole mud	Seen at Sakaeo Camp market for steaming rice cakes. Uses local wood. Required large earth volume. Maker could not come to make example for testing. Market example should be tested.
Lorena	Some have been built at Mairoot Camp for burning rubberwood. No longer being used. No other built. Same reasons as high mass two-hole mud. Could be tested at Mairoot.

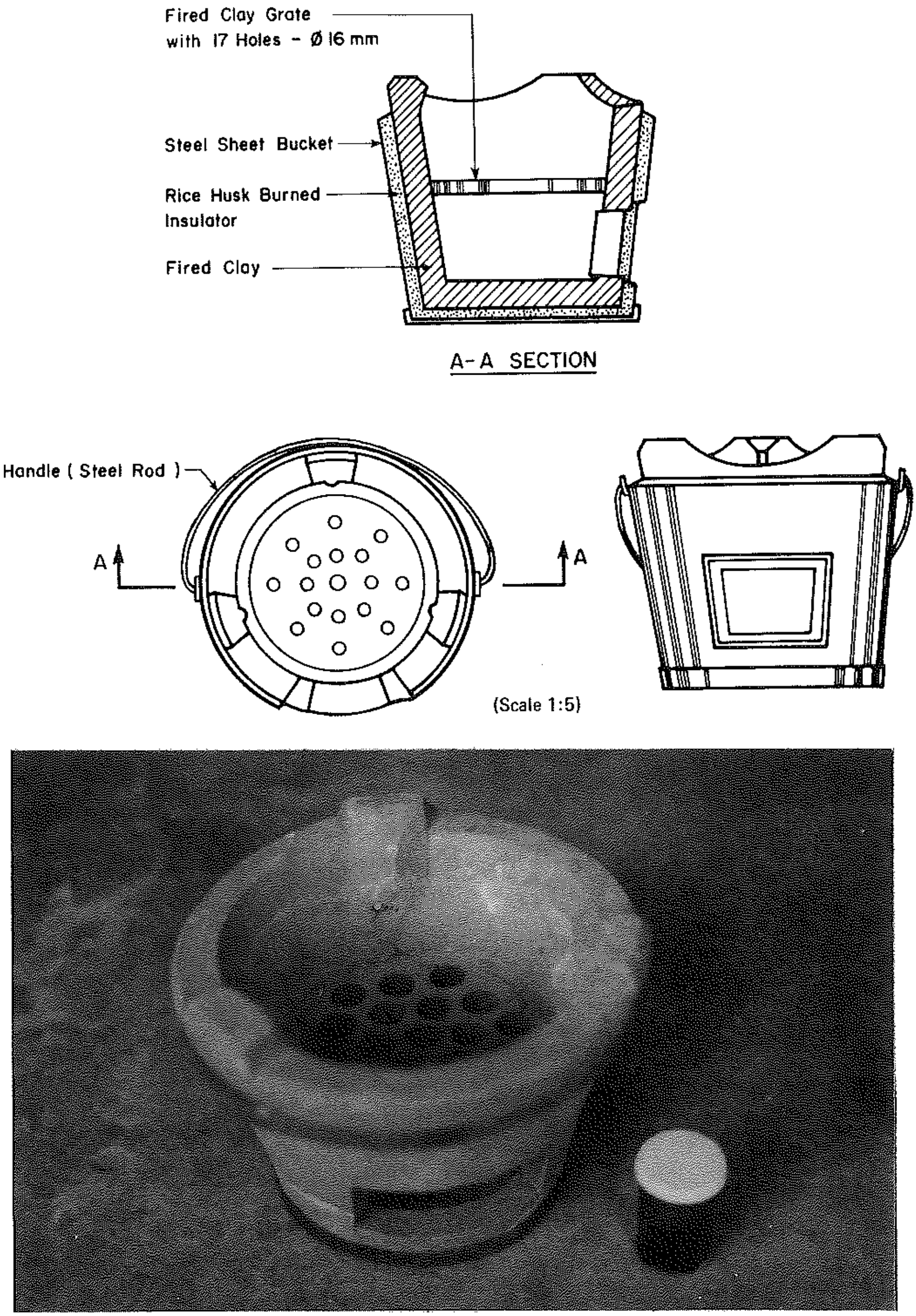

Fig. 2 The Thai pottery bucket stove

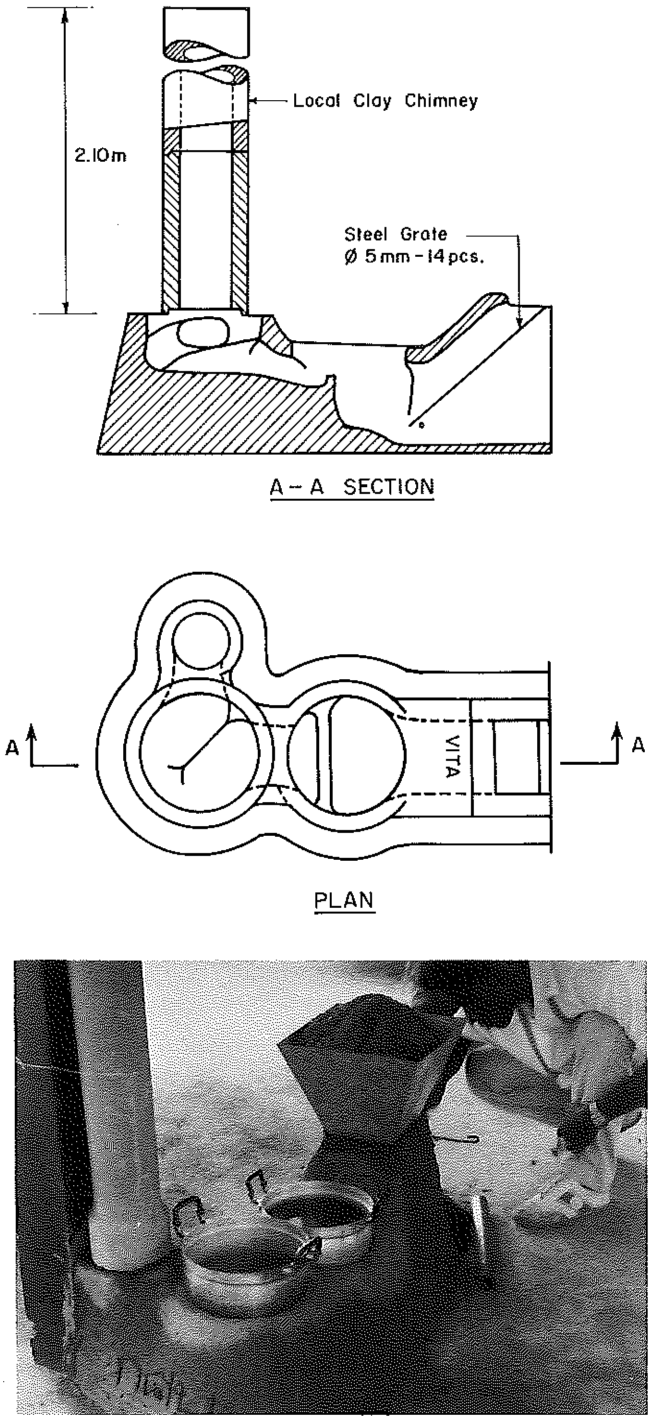

Fig. 3 A two-hole mud stove with rice husk feed box

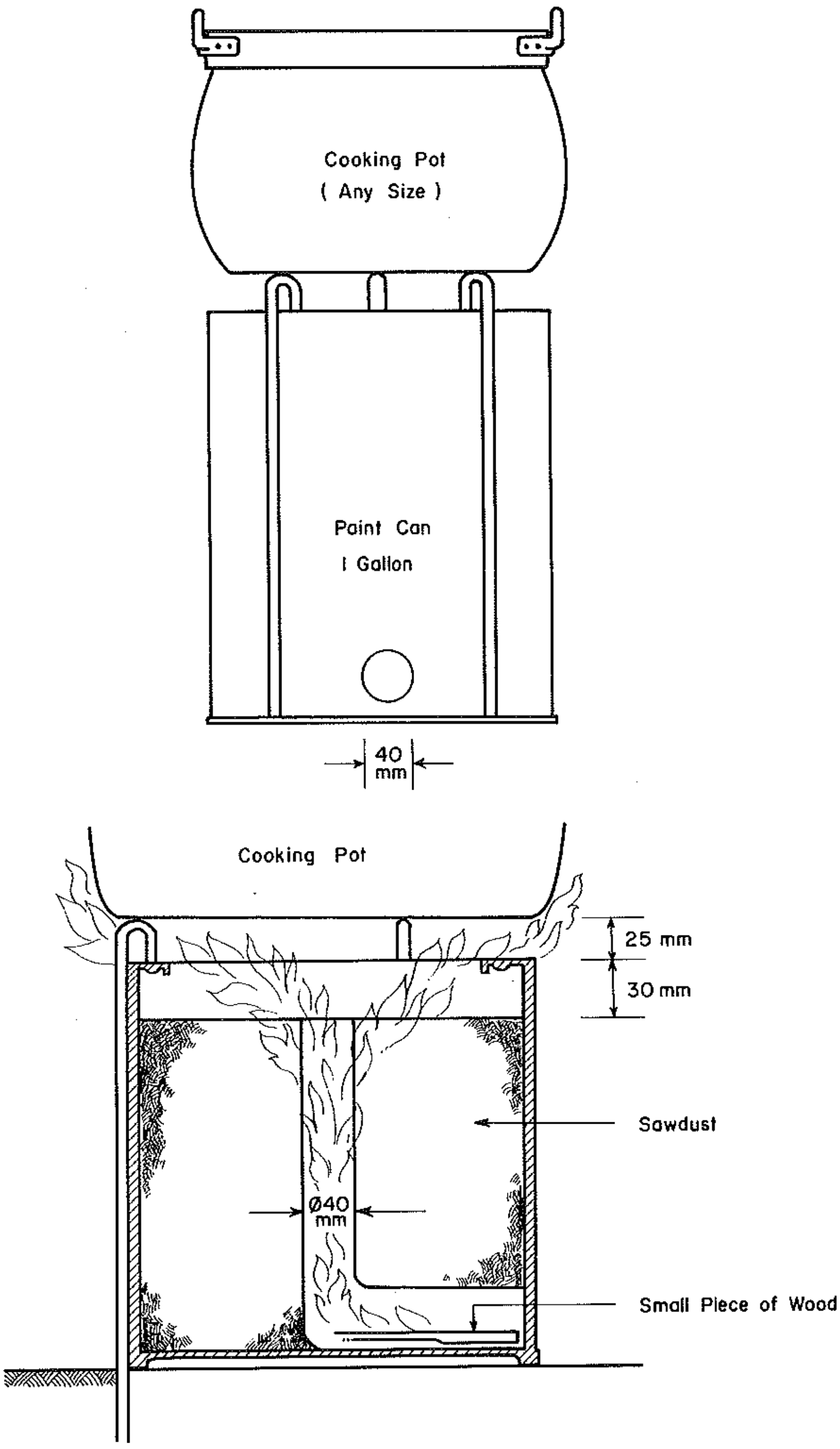

Fig. 4 Drawing of a 1 gallon can for cooking with sawdust. (Not to scale)

A testing program for the 17 selected stoves and 9 fuels was organized and implemented. Of the 153 possible fuel stove combinations, 47 were tested; 106 combinations were not tested due to obvious incompatability of fuel and stove or because preliminary tests indicated poor performance of the fuel or stove.

METHODS OF FUELS/STOVES TESTING

1. Research Plan

In order to have fuel information to conduct an economic evaluation of the alternative fuels, it is necessary to determine which stove burns each type of fuel most efficiently and how much fuel is used to cook typical meals. Simulated cooking tests, in which water was boiled and simmered, were performed to determine the most efficient stove for each type of fuel. Rice cooking tests were performed to determine fuel utilization efficiencies of the best fuel/stove combinations to be used for cooking a simple meal. When this efficiency is analyzed together with the cost and lifetime of the stove, the cost of fuel and the number of meals prepared per month, the total cost of cooking per man per month will be known for each fuel under consideration.

2. Procedure

a. All cooking tests were conducted from April 30 to May 16, 1981 by William Stewart, United Nations volunteer stove expert, Marcus Sherman and Banyat Srisom of the VITA Asia Field Office, and three Kymer cooks who were employed to tend fires and build mud stoves.

b. All tests were conducted and recorded using standard procedures and similar conditions.[6,7,8]

c. All cooking tests were conducted inside a bamboo and thatch building at Kao-I-Dang refugee holding center. Windows and doors were kept closed to minimize the variable factor of wind-induced drafts in the stoves.

d. Equipment and supplies used during the tests included the following: single beam balance (0-10 kg $\pm$ 5 g) for weighing kindling, fuel, water, pots and char; double pan postage scale (0-200 g $\pm$ .05 g) for measuring wood sample weight in moisture content tests, mercury thermometers (0-100°C + 0.5°C) for determining approach of boiling, and initial water temperature; portable electric thermocouple temperature indicator (0-1,000°C $\pm$ .1°) to measure exhaust gas temperatures; electric wall clock with second hand for all timing of tests; large metal spoons for removing ashes, stirring rice, and carving the interior of mud stoves; small axe and a large knife for cutting wood; two Duralex plates for observing flame flow inside stoves; 1-# 30, 1-# 24, 4-# 22, 2-# 16 stamped aluminum pots with lids; charcoal tongs, fire poker; fire blow pipe; several sizes of water bucket for storage and transport of water.

e. An effort was made to boil the same quantity of water in the same size pot during all tests. However some stoves were either too small or too large to accommodate the standard # 22 pot, so other sizes were used when necessary as indicated in Table 9.

f. Time measurements – Time of ignition was observed as that moment when the flame on a piece of kindling or fuel becomes self-sustaining. Time of ignition of kindling and fuel were recorded separately.

During the simulated cooking tests, the approach of the time of boil was determined, without having to remove the lid, by observing a mercury thermometer inserted in a hole in the

Table 9 Pot sizes used

Pot #	Pot size (cm)	Pot weight (g)	Water used (g)	Number of tests	Percentage of tests
16	16 x 9	280	1,285	14	10.2
22*	22 x 13	480	3,000	76	55.6
24	24 x 14	600	4,000	5	3.6
30	30 x 17	920	5,500	41	29.9
40	40 x 25	2,355	24,000	1	.7

* #22 pots were used exclusively during the 22 rice cooking tests.

pot lid. Actual boil was confirmed by sound and by removing the lid to see steam bubbles on the water surface.

g. Weight measurements – Each pot was marked with its weight so the weight of water or rice could be easily determined. The weight of water or rice and water was measured before and after each test. The kindling and fuel were weighed at the beginning of each test and the remaining kindling, fuel and char were weighed at the end of each test.

h. Temperature measurements – The temperature of water in each pot was recorded with a mercury thermometer before each test, monitored to determine approach of boil time and monitored during simmering of the simulated cooking tests. On tests of two-hole stoves, if the second pot of water did not boil, the water temperature was measured and recorded.

An electric thermocouple thermometer was used sporadically to monitor the temperature of the stove exhaust gases (stack temperature), on those stoves with chimneys, at a point in the chimney 15 cm above the level of the stove top. Stack temperature gives a good indication of the characteristics of combustion inside a stove and how much heat is lost up the chimney. Stack temperatures can vary widely during a test period and were only occasionally recorded on the raw data sheets to give a general idea of the combustion temperature and chimney heat loss. Burning characteristics are shown in Table 10.

Table 10
Burning characteristics of wood and agricultural wastes, as indicated by exhaust temperature

Stack Temp. (°C)	Burning Characteristics
600 +	Too hot, flames inside chimney, may start roof fire, will damage chimney, poor heat transfer to pots.
300 – 600	Too hot, much heat lost out of chimney, will damage chimney, poor heat transfer to pots.
200 – 300	Optimum stack temperature, efficient combustion, no creosote formation, good heat transfer to pots.
less than 200	Too cool, creosote formation in chimney may lead to chimney fire, incomplete and inefficient combustion, much smoke.

3. Simulated cooking tests

The objectives of the simulated cooking tests were to:

a. Determine useful comparative performance figures for each tested stove.

b. Provide quantitative performance figures that can be compared with other results in Thailand and other countries.

c. Eliminate from further testing those fuels, stove and fuel/stove combinations that were obviously inefficient, uneconomic or inappropriate.

d. Select the optimum stove for each fuel under consideration.

Each test was conducted on a cold stove with known quantities of water in covered aluminium pots. Kindling and fuel were placed in the stove and lit. The water was brought quickly to a boil and then simmered at 96-100°C for 30 min. All raw test data for each test was recorded on separate data sheets. A total of 108 individual simulated cooking tests were conducted on 46 different promising fuel/stove combinations. The results are summarised in Table 11.

Table 11
Summary of simulated cooking tests, average results for the optimum fuel/stove combinations

Fuel name	Stove name	No. of tests	Water volume (1)	Fuel burnt (kg)	Fuel energy used (%)
Ricehusk log	Bucket 23 cm	5	5.20	.797	24.9*
Rubberwood	Bucket 23 cm	3	5.50	.593	24.2
Charcoal	Bucket 23 cm	3	3.44	.300	20.0
Sawdust log	Bucket 23 cm	5	4.50	.730	18.3*
Corncob	Bucket 23 cm	3	5.50	.692	21.0
Ricehusk	Rangsit 40 cm	2	19.78	6.301	15.9*
Sawdust	1 gallon can	3	3.00	.546	14.0
Seawood	Suksan 2 hole	1	6.66	2.125	13.3*
Ricehusk	2 hole mud	5	6.00	1.462	12.4
Ricehusk-sawdust 1:1 mix	1 gallon can	6	3.25	.888	12.3*

* eliminated from further testing.

4. Rice Cooking Tests

The objective of the rice cooking tests was to measure the performance of the best stove for each fuel under typical cooking practices. A mass of 1,270 g of dry rice was cooked with 1,510 g of water in a covered # 22 pot till judged to be done by the Kymer ladies doing the cooking. The amount of dry rice is the daily ration of 5 people: 5 milk tins full. The amount of water was determined initially by the Kymer ladies as the amount necessary to cook the rice. These amounts were measured in the first cooking test and kept the same for all the tests.

After the rice was cooked, another # 22, pot with 2,780 g of water was also brought quickly to the boil. On one-hole stoves the second pot was boiled after the rice was done. On two-hole stoves, it was heated on the back hole and then switched to the front hole to boil while the rice was simmered. The volume of water was chosen by the Kymer women to be a typical amount for boiling soup or vegetables. The boil-simmer-boil cycle of this test was useful to observe the control ability of the heat output of each stove.

A total of 22 rice cooking tests were conducted on the 5 best fuel/stove combinations determined by the simulated cooking tests.

STOVE DEVELOPMENT

Modified versions of the traditional pottery Thai bucket stove (Fig. 2) and mud rice husk burning stoves (Fig. 3) were made and tested during this evaluation. Development of these stoves is not complete, and more details will be given in a later report. The test results on the latest version of the VITA two-hole rice husk burning stove show good potential for this cheap and easy-to-make stove. Several good references on stove development are being used during the refinement of these designs.[9-13]

DATA ANALYSIS

All preliminary data reductions were performed and recorded on the raw test data sheets.

– The time to ignite was determined by calculating the interval between kindling ignition time and fuel ignition time.

– The time to boil was determined by calculating the interval between kindling ignition time and time to boil.

– The high heat value (Table 6) of each fuel was determined initially from standard reference values, and some calorimetry tests completed by the Thailand Institute of Scientific and Technological Research.[4]

– The net fuel energy released was determined by multiplying the heat values of the kindling and the fuel respectively, by the burned weight of each, adding the results and subtracting the heat value of the weight of remaining char, if any:

$$\begin{aligned}\text{net fuel energy released} = {} & (\text{kindling heat value}) \times (\text{kindling weight}) \\ & + (\text{fuel heat value}) \times (\text{fuel weight}) \\ & - (\text{charcoal heat value}) \times (\text{charcoal weight})\end{aligned}$$

– The evaporated water weight was determined by subtracting the weight of the water remaining at the end of the test from the weight of the water at the beginning of the test.

– The energy used to boil was determined by the following multiplication: weight of water at start times the number of degrees (°C) the water was raised from start to boil, times the specific heat of water (4.184 kJ/kg°C).

– The energy used to evaporate the water was determined as follows: the weight of the water evaporated times the latent heat of the water (2.26 MJ/kg).

– The energy used to cook rice was determined by multiplying the weight of the dry rice by its heat of gelatinization (171.7 kJ/kg).[7]

– The total energy used was determined by adding the energy used to boil, the energy used to evaporate, and the energy used to cook.

— The energy utilization efficiency was determined by dividing the total energy used by the net fuel energy released. The efficiency of energy utilization is an important determinant of the overall economy of any fuel/stove combination.

— The results are summarised in Table 12.

Table 12
Summary of rice cooking tests, average results

Fuel name	Stove name	No. of tests	Cooking time (min)	Fuel burnt (kg.)	Energy used (%)
Rubberwood	Bucket 23 cm	4	29	.668	23.1
Corncob	Bucket 23 cm	4	31	.726	16.7
Sawdust	1 gallon can	4	32	.680	16.4
Charcoal	Bucket 23 cm	5	33	.459	13.6
Ricehusk	2 hole mud	5	36	1.146	13.3

— It was determined that the standard monthly allowance for delivered cooking heat is 5.2 kg x 31.4 MJ/kg x .136 = 22 MJ, given that refugees currently receive 5.2 kg of charcoal per month, that the high heat value of charcoal is 31.4 MJ/kg, and that the efficiency of presently used Thai bucket stoves is 13.6%. It is assumed that 22 MJ is the amount of heat required to be delivered to cooking pots, no matter what type of fuel or stove is used.

— The amount of other fuels needed was determined by taking into account the high heat value of other fuels and their efficiency of utilization in their respective stoves, as follows:

$$\text{fuel need (MJ)} = \frac{22\ \text{MJ}}{\text{utilization efficiency}}$$

$$\text{fuel need (kg)} = \frac{\text{fuel need (MJ)}}{\text{high heat value (MJ/kg)}}$$

— The costs of supplying amounts of fuel that would give an equivalent amount of useful cooking heat were determined by multiplying the amount of each fuel required by the cost of the fuel.

— The total cost per month of using each fuel/stove combination was determined by adding the monthly cost of the fuel and the stove.

— The costs are summarised in Table 13.

— A guideline for fuel buyers (Fig. 5) was prepared by plotting a graph of fuel cost per kilogram versus total user cost. This graph takes into account the fixed factors of fuel heat value and stove efficiency. It allows comparisons to be made between total user costs which result when fuels of different prices are used.

Table 13

Summary of results and total costs per refugee of using various fuel/stove combinations

Fuel name	Stove name	Energy a/ use Efficiency (%)	Fuel need for 22 MJ (MJ)	Fuel need for 22 MJ (kg)	Fuel cost (฿/ kg)	Fuel cost (฿/month)	Stove b/ cost (฿/month)	Total cost (฿/month)
Rubberwood	Bucket 23 cm	24.2	90.9	7.10	.16	1.14	.16	1.30
Rubberwood*	Bucket 23 cm	23.1	95.2	7.44	.16	1.19	.16	1.35
Ricehusk	Rangsit 40 cm	15.9	138.4	10.73	.19	2.04	.30	2.34
Ricehusk*	2 hole mud	13.3	165.4	12.82	.19	2.44	.22	2.66
Ricehusk	2 hole mud	12.4	177.4	13.75	.19	2.61	.22	2.66
Ricehusk-sawdust mix 1:1	1 Gallon can	12.3	178.9	11.69	.48	5.61	.03	5.64
Sawdust*	1 Gallon can	16.4	134.1	7.58	.76	5.76	.03	5.64
Charcoal	Bucket 23 cm	18.3	120.2	3.80	1.70	6.46	.16	6.62
Sawdust	1 Gallon can	14.0	157.1	8.88	.76	6.75	.03	6.78
Charcoal*	Bucket 23 cm	13.6	161.8	5.2	1.70	8.84	.16	9.00
Corncob	Bucket 23 cm	21.0	104.8	6.16	1.45	8.93	.16	9.09
Corncob*	Bucket 23 cm	16.7	131.7	7.75	1.45	11.24	.16	11.40
Ricehusk log	Bucket 23 cm	24.9	88.4	6.85	1.85	12.67	.16	12.83
Sawdust log	Bucket 23 cm	18.3	120.2	9.32	2.03	18.92	.16	19.08

*Indicate rice cooking test. All others are simulated cooking tests
a/ Data from Tables 11 & 12, b/ Data from Table 7

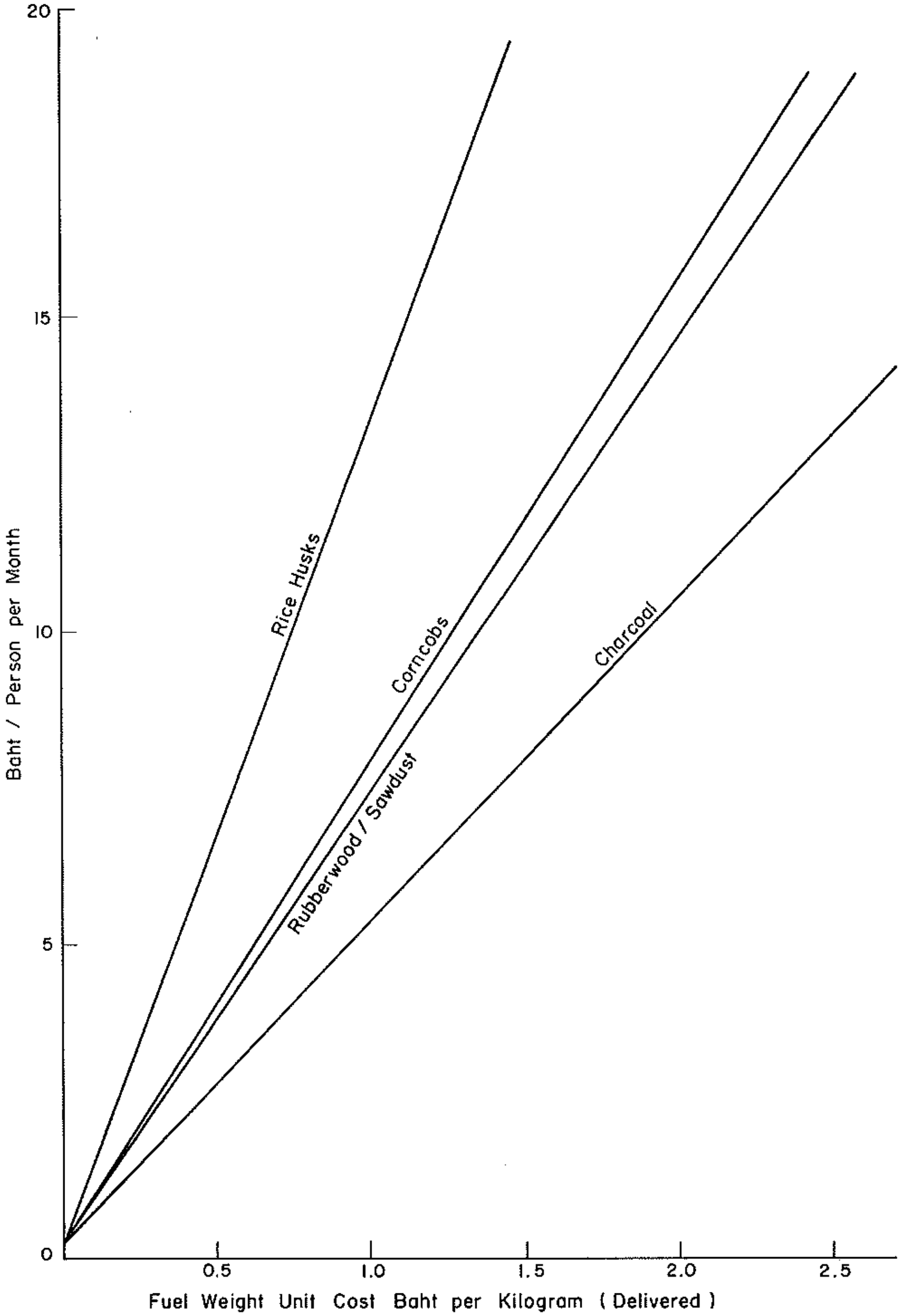

Fig. 5 A guide to buyers of cooking fuels: graph of total user cost versus weight unit cost of fuels

RESULTS AND DISCUSSION

1. Measurements of Kymer cooking at Sakaeo (Table 1) indicated that the normal time to cook rice is 29 minutes. Considering that some frying is also done afterwards, and also that a standard simmering time used in the ITDG Stoves Testing Program is 30 min[6], it was decided to use 30 min as the standard simmering time for the simulated cooking tests.

2. Agricultural wastes, including rubber wood, rice husk, corn-cobs and sawdust appear to be availble in significant quantities and at low cost. The delivered price of alternative fuels is mostly dependent upon transport costs and thus highly sensitive to distance between supply and use (Table 2).

3. The moisture content of rubberwood (53.2% dry basis) was particularly high (Table 3). The useful heating value of this fuel will double if it is properly dried to below 10% dry basis moisture content before it is used.

4. The cost of energy expressed in ฿/MJ* from rubberwood, rice husk and sawdust is less than the cost of energy from charcoal. Corn-cob from 500 km away is only slightly more expensive than local charcoal.

5. Results of 36 simulated cooking tests on the 10 best fuel/stove combinations are shown in Table 11. Five of these combinations were eliminated from further consideration or testing.

– The fuel utilization efficiency of rice husk logs (24.9%) and sawdust logs (18.3%) when burned in a Thai bucket stove is quite good. However, because the energy unit cost of these fuels is significantly higher than any other, they were eliminated.

– Seawood was eliminated because of its limited availability and poor fuel utilization efficiency when compared with other solid fuels.

– Burning rice husk in any concrete "Rangsit type" stove was eliminated because of the high relative cost of the stove when compared to the two-hole mud rice burning stoves.

– Further testing of rice husk/sawdust mix in the 1 gallon can stove was stopped because it was difficult to keep the stove burning evenly and consistently. The burning area in the center of the packed fuel would often collapse, and either burn unevenly or just smolder. Some tests with this combination could not bring water to a boil.

6. Five optimum fuel/stove combinations were selected for further testing under conditions of actual rice cooking. The average results of 22 rice cooking tests are summarized in Table 12.

7. The rice cooking tests for the five best fuel/stove combinations gave slightly different results than tests in which only water was boiled and simmered. The largest differences are for charcoal and corncobs burned in the 23 cm Thai bucket. The main reason for the drop in efficiency is that during simmering of the rice, the heat output can only be reduced by removing fuel, which the cooks will do only to prevent severe burning of rice in the bottom of the pan. Scorching and sticking to the bottom of the pot are normal practice. An air inlet door is a simple stove improvement that would allow the heat output to be decreased quickly and easily, and would result in reduced fuel consumption.

The two-hole mud rice husk stoves showed the smallest difference in efficiencies, demonstrating that the design was well adapted for both boiling and simmering and was less effected by wind. Further improvements in this stove are being made that will increase its fuel utilization efficiency. The use of this stove when only one pot is needed would be more functional but

* ฿1.00 = US$0.05

less efficient.

The wet rubber wood burned effectively in the bucket stove because the grate allows excellent air mixing and the longer pieces of wood can be moved to control the fire more easily than is possible using corn-cobs or charcoal. The indication of higher energy utilization for rubber wood during the rice cooking tests resulted partially from the fact that the wood used had dried since the moisture analysis was conducted.

The significant increase in the energy utilization of sawdust burned in the 1 gallon can demonstrates that its heat output can be adjusted to low simmering rates more easily than any of the other fuel/stove combinations.

The two-hole mud rice husk burning stove can be adapted to burn larger sized fuels by removing the steel rods of the rice burning grate. This useful feature will increase the versatility of the stove, however it was not tested in mode.

8. The traditional Thai insulated pottery bucket stove is the most economical and efficient for cooking with all solid fuels such as wood, charcoal, corn-cobs, sawdust logs and rice husk logs. Though the Thai buket is virtually the cheapest and most versatile stove available, some improvements can be made:

– Adopt the use of a clay air inlet door to control the heat of the stove and extinguish the remaining fuel after cooking.

– Adopt the use of a tight fitting clay lid to totally extinguish the remaining fuel after cooking.

– The packed gallon can (Fig. 4) is the most efficient and economical for burning sawdust. This fuel/stove combination has been widely used in Kampuchea and would be easily accepted by the refugees.

A properly designed and well made two-hole stove with a rice husk burning grate (Fig. 3) is the most efficient and economical for cooking with rice husks. There is a tradition of cooking with rice husks in Kampuchea. Given simple hand tools and proper instruction, refugees can easily and quickly make these stoves from a mixture of Kao-I-Dang dirt and rice husks.

9. One series of tests carried out under windy conditions shows the negative effect of wind on the utilization of the different fuel/stove combinations (Table 14).

Table 14
Effect of wind on energy utilization efficiency

Fuel/Stove name	Energy Utilization Efficiency		Deviation
	Average	Windy	
Corn cobs Bucket 23 cm	16.7	9.2	.45
Charcoal Bucket 23 cm	13.6	11.2	.17
Ricehusks 2 hole mud	13.3	12.2	.08
Sawdust 1 gallon can	16.4	13.7	.16

The corn-cobs in the bucket performed less satisfactorily than any other combination under windy conditions, because the flames were easily dispersed by the wind. The rice husk stove with its totally enclosed combustion chamber was least affected by the wind. The radiant heat transfer of the charcoal and the central flame of the sawdust stove were also adversely affected by the wind but not as much as the corn-cobs.

10. A practical method was developed for field staff to evaluate the overall cost effectiveness (total user cost) of different fuels at different local prices. Figure 5 presents purchase guidelines for buyers of alternative cooking fuels. These guidelines reduce the number of variables to be considered to only the delivered price of fuel, expressed in ฿/kg. The variability of all factors considered in this evaluation has been incorporated in the differing slopes of the various diagonal lines representing each fuel.

RECOMMENDATIONS

Fuels

1. The types of fuels used in each camp should be diversified, in order to reduce dependence of any single source.
2. Charcoal use should be reduced in favor of cheaper fuels. Present stockpiles of charcoal should be conserved.
3. Use of properly dried rubberwood in Thai bucket stoves should be increased. Purchase rubberwood by volume not weight.
4. Cost evaluations of agricultural waste fuels should be conducted in the area of each refugee camp.
5. Fuel purchasing agents should use Fig. 5, *A Guide to Buyers of Cooking Fuels,* as an aid to comparative local pricing of alternative fuels.
6. Local purchase programs for selected local agricultural waste fuels including rubberwood, corn-cobs, rice husks and sawdust should be begun.
7. Further evaluation of current Kymer cooking practices should be conducted.
8. Seek and implement opportunities for fuel conservation through drying fuels before use and improved cooking practices such as constant use of lids, slower cooking, proper fitting of pots to stoves, always having a pot on a burning fire and extinguishing fuel at end of cooking to save it for use in cooking the next meal.

Stoves

1. Incorporate suggested improvements in any new bucket stove to be distributed in any camps.
2. Conduct maintenance of bucket stoves currently in use.
3. Consider manufacture of improved bucket stoves by Kymers living in the camps.
4. Conduct further evaluation of traditional Kymer methods of making, using and maintaining cooking stoves. Incorporate these findings in the selection, adaptation and manufacture of new stoves.
5. Acquire used one gallon paint cans for conversion to sawdust burning stoves, at those camps where sawdust is available.
6. Accelerate the rice husk burning mud stove development program in preparation for later use of rice husk as a major cooking fuel.

7. Evaluate the feasibility of a pilot training program on the fabrication, use and maintaince of rice husk burning mud stoves. This program would be for training of refugees and staff of the voluntary agencies.
8. Investigate and share solutions to fuels/stoves and related problems in other countries and regions.

ACKNOWLEDGEMENTS

The authors are most grateful to the UNHCR for its support of this project, to Mssrs. Glen Dunkly and Udo Janz of the Kampuchea Program Division for their encouragement and assistance, to John Williamson and Khun Williawan of Social Services Division for initiating the project and undertaking background research on fuels, to UNDP-Sri Lanka for allowing William Stewart to participate in the project. Many thanks are also due to the staffs of the International Rescue Committee (IRC), the Community Based Emergency Relief Services (CBERS), Red Barners, CARE, and Task Force 80 for their practical support in the Kao-I-Dang Camp.

Several useful additions to the report resulted from the thoughtful comments of Diana Donovan, Howard Gellar and Steven Joseph, who reviewed the first draft. The generous cooperation of many suppliers and developers of fuels and stoves is appreciated. Special thanks are due to three Kymer ladies for their faithful daily assistance and positive reaction to our work.

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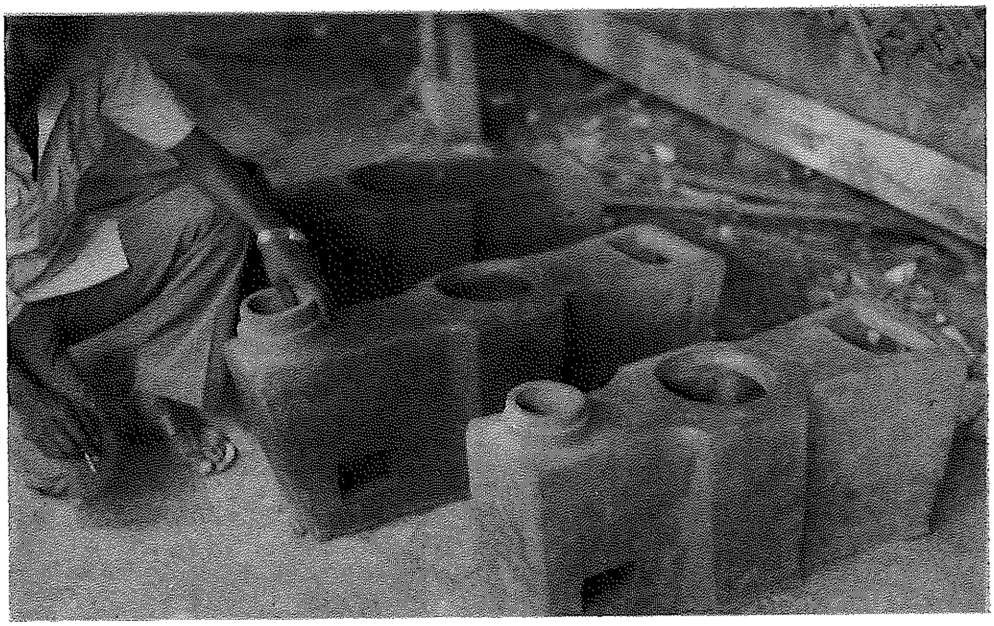
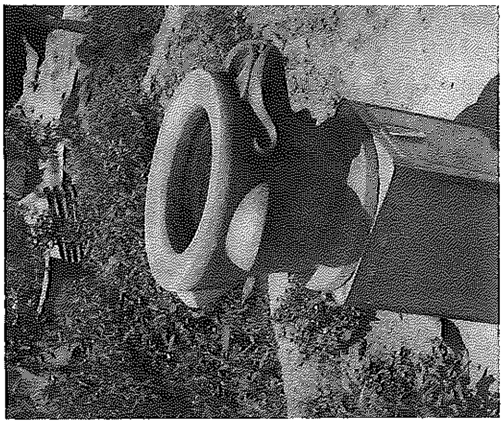
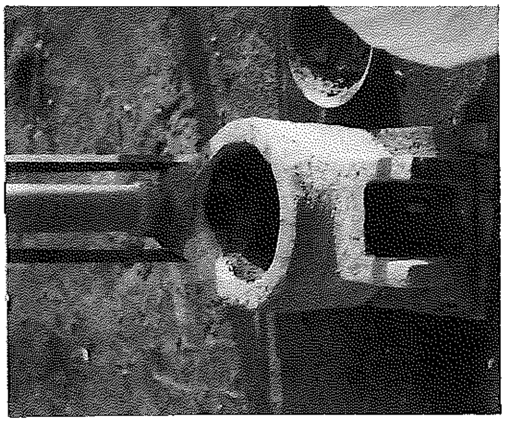
APPENDIX
Various Types of Evaluated Stoves

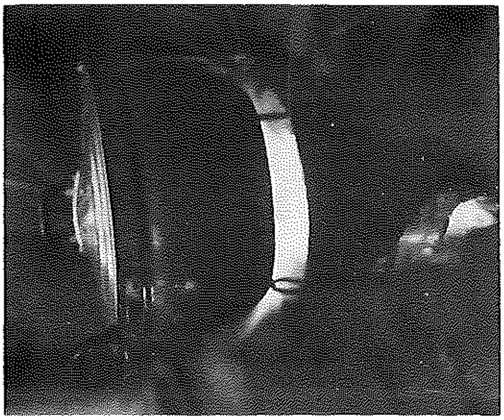


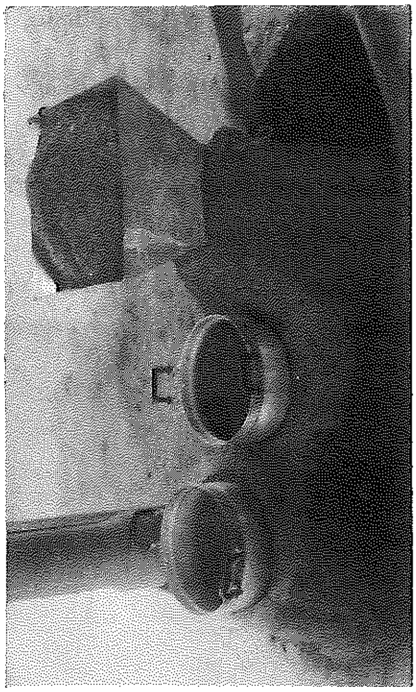
Kymer 1 hole stoves

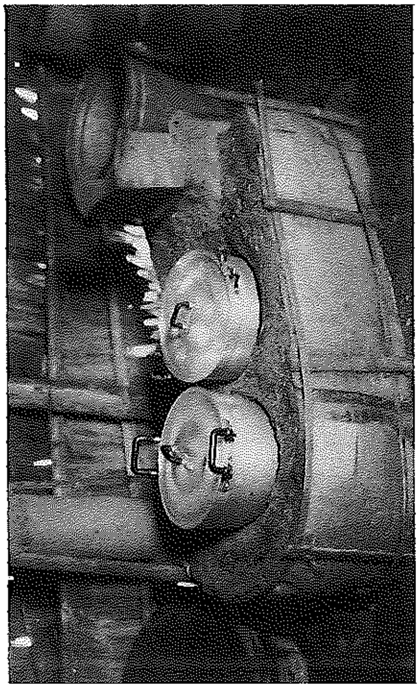
Thai traditional bucket stoves

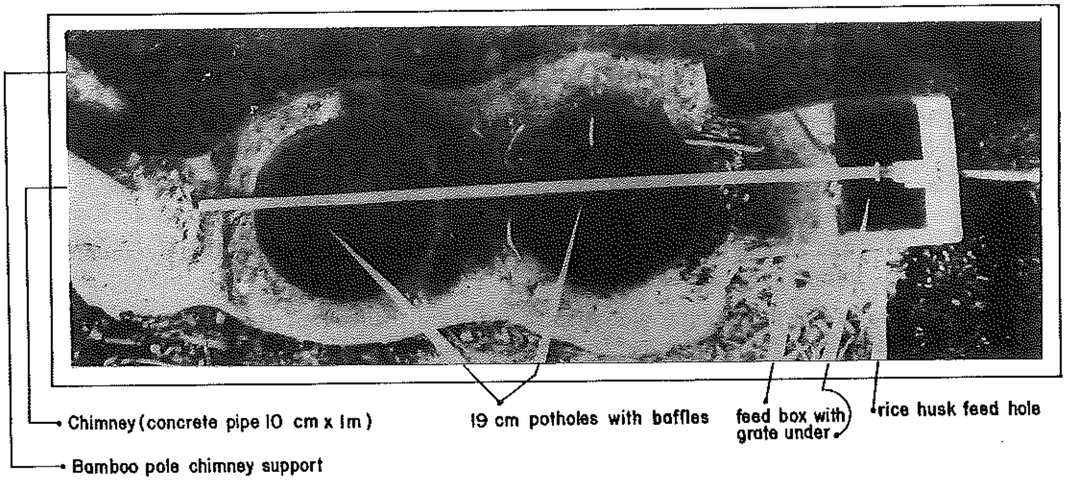

Vichai wood feed stove


Suksan 1 hole mud stove before transporting


One gallon can for cooking with sawdust


VITA rice husk stove


UNHCR stove



Composite top view of two hole mud stove with pottery rice husk feed box. (Scale: 1:5)