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COOKING STOVES: the state of the art

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1. INTRODUCTION

Cooking represents an important item in the energy budget of most people living in the less developed countries. This is not evident in monetary accounts because the fuel in rural areas is frequently collected in nearby forests in the form of wood or charcoal or is made up of agricultural wastes and manure; usually these fuels are labelled as non-commercial because they are not fully registered in commercial activities (and are not taxed) or because they involve only exchanges for other goods and services.

From the point of view of the consumption of natural resources the use of these fuels is, however, an important activity that has had negative effects on the environment in many parts of the world.

The main fuel used for cooking is wood from forests ; this is a renewable resource and if properly used could supply for long periods the needs of the people in rural areas. Forests have a natural growth that produces a given increment of wood per year and if consumption remains below this increment no damage is done to the forest. This is not always the case and has led to serious devastation of forests.**

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* On leave from Eisenhower College, Seneca Falls, N.Y.

** Devastation of forests is not due in general to its use for firewood consumption except in some particular areas of the world; most generally the inordinate clearing of forests for agriculture and pulp production are the main causes. Adequate control of these activities (in addition to the fuel conservation measures discussed here) are fundamental to avoid further damage to the environment.

Table I shows the main characteristics of the world forests.

TABLE I

CHARACTERISTICS OF THE WORLD FORESTS

	Area $x10^6$ha	Growing stock* $x10^9m^3$	Annual increment $x10^9m^3$	Used for fuel $x10^9m^3$	Used for industrial purposes $x10^9m^3$	Annual increment per hectare** m^3
Developed Countries		242	8,8	0,3	1.1	
Less Developed Countries		382	9,0	0,18	0.2	
Total	3800	624	17.8	1.1	1.3	4.7

Source: Earl[1]

* Estimated to include all wood above ground
Density of wood 400 kg/m^3
Heat content 2100-4500 kcal/kg

** In forest plantations annual increments of 5 to 45 m^3/ha have been reported.

From the point of view of the poor rural or urban people which depend on the use of wood or charcoal this had lead to increased burdens on an already burdened existance. In some sub-Saharan african countries long trips (of the order of 50 kilometers) have to be taken by families to gather wood for domestic uses. It is estimated that 200-300 man-days of work are spent per family in India in the process of collecting wood[2]. This activity consumes time and energy that could be spent in more useful ways and in education of children who are frequently engaged in the demanding job of gathering wood for cooking. In other countries such as China and parts of India forests are long gone and manure is used extensively for cook ing, burning up an important resource that could be used as much needed fertilizer. Even if fuelwood is plentiful, as it is in some areas of the world cooking represents a very important activity of the women in the house that often keeps them busy and working for a good part of the day.

Expressed in monetary terms, fuel for cooking can represent less than 5% of the expenditures of people in the rural areas (when one attributes a monetary value to non-commercial purchases). Expressed in energy units it corresponds to more than 50% of their total energy budget.

The situation in urban areas is completely different; in monetary terms fuel for cooking (in general gas and electricity) represents 1-2% of the income and in energy units less than 5% of the energy budget.

The needy people in rural areas actually use more energy and have to devote a larger fraction of their time, effort and economic means than the more affluent urban dwellers.

The reason for this lies in the low efficiency of cooking methods used in rural areas. As will be shown below the efficiency of gas and electric ranges in use in urban areas is of the order of 40% while primitive cooking stoves in use in rural areas have efficiencies of the order of 10%, consuming therefore 4 times the amount of fuel used in modern cooking stoves.

Primitive stoves in use in rural areas have not changed over the centuries and have not been the object of much recent systematic investigation.

Improvements however are possible and would have an immediate impact in the family budgets of poor rural people on the burdens of the housewives and on the devastated environment in which they live.

2. COMPARISON OF THE ENERGY NEEDS FOR COOKING IN DEVELOPED AND LESS DEVELOPED COUNTRIES.

In a high technology developed country such as the United States less than 1.5% of the total energy consumed goes into cooking as can be seen in Table II.

TABLE II

PRIMARY ENERGY CONSUMPTION IN THE UNITED STATES AND INDIA

Activity	UNITED STATES(%)	INDIA(%)
Transportation	25	3.5
Miscellaneous electric	19.5	4.5(lighting)
Feedstock and agriculture	7	22
Water heating	4	-
Space conditioning	19	-
Industrial processes	24	7
COOKING and clothes drying	1.5	63 (cooking)
Total	100.0	100.0

Source: Ross and Williams[3] and Revelle[4]

In energy units cooking in the United States corresponds to 2,000 kcal/day/capita (0.82% out of a total of 243,000 kcal/day/capita of total energy consumed).

Shown in the same Table is the energy consumption in a typical Indian village.

In energy units, cooking in a village in India corresponds to 4,500 kcal/day/capita (63% out of a total of 7,110 kcal/day/capita).

Figure 1 shows the situation as far as the use of cooking fuels is concerned in one of the states of Brazil[5]. In the rural areas people consume almost as much wood (and charcoal) as gas; as one moves to urban and metropolitan areas the use of gas becomes dominant.

FIGURE 1

Table III shows the variation in money and energy expenditures as one moves from rural to metropolitan areas. To organize this Table assumptions were made about the indirect energy costs of family expenses in a manner consistent with family income and average per capita energy consumption. These indirect costs and the direct energy costs for the families of different income levels were added up.

TABLE III

EXPENDITURES IN THE STATE OF RIO DE JANEIRO, BRAZIL (1974)

REGION	Expenditures in cooking fuel US$	Average annual family income US$	% of money spent in cooking fuel	% of energy spent in cooking
Rural	47	2,050	2.3	30
Urban	53	4,200	1.3	6
Metropolitan	55	6,400	0.86	3

Source: Goldemberg and Moreira[5]

Approximately 30% of the rural per capita energy consumption goes into cooking (most of this energy comes from wood). While the rural sample resembles the Indian village in its energy use pattern, the metropolitan average of 3% of total energy use associated with cooking is close to the U.S. average.

The amount of money spent for cooking is about constant so in less prosperous regions a larger fraction of income is spent for cooking fuels.

3. EFFICIENCY OF VARIOUS METHODS OF COOKING

We will discuss here some information on the efficiency of gas and electric ranges[6] and wood cooking stoves.

GAS RANGES (FIGURE 2) - In the U.S. the average energy required to cook food per family on the surface of a gas range is 900 kcal/day and the energy required to cook food in the oven is 120 kcal/day with a total of 1,020 kcal/day, enough to boil approximately 10 liters of water. The total energy input in a gas range is 6,900 kcal/day which means that the overall efficiency of a gas range is 15%. The remaining energy is lost in pilot lights* (41%), thermal inertia, vents, wall and other losses.

An interesting point to notice is that the surface burners without pilots have an efficiency of 48%, and would therefore only require 1,850 kcal/day to accomplish the surface cooking which is almost 90% of the average cooking demand in energy terms. Oven efficiency even without its pilot is only 6%.

FIGURE 2

ELECTRIC RANGES (FIGURE 3) - The energy required to cook food on the surface or in the oven are, of course, the same as in the gas range, 900 and 120 kcal/day respectively for a total of 1,020 kcal/day. The surface burners of electric ranges have a higher efficiency (73%); the oven also is better with an efficiency of 25%. In combination this gives an overall efficiency of 59% clearly superior to the gas range if one ignores how one gets electricity.**

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*Pilot lamps can, of course, be eliminated which by itself would increase the efficiency for all gas cooking to 25%; the total energy input needed becomes in this case about 4,000 kcal/day.

**If the electricity is produced from gas, oil or coal the efficiency for production is only 30% which means that the primary energy needed is 5,700 kcal/day or an overall cooking efficiency of 18% for electric ranges.

FIGURE 3

PRIMITIVE WOOD COOKING STOVES (FIGURE 4) - Frequently cooking is done in an open fire protected by a few stones on top of which the cooking pots are supported. Closed fires are also used with no draft control and chimney. As discussed in section 2 a primitive cooking stove using wood requires 4,500 kcal/day/capita or more which corresponds to 20,000 to 25,000 kcal/day for a typical family of 4 or 5. Out of this energy only approximately 1,000 kcal/day are needed to cook the food; this corresponds to an efficiency of 5%.

FIGURE 4

The amount of wood needed to supply 20,000 kcal/day corresponds to approximately 6-7 kg of dry wood/day or 2.0-2.5 ton per year to satisfy the needs of a family.

Table IV compares the three methods of cooking discussed above.

TABLE IV

COMPARISON OF COOKING METHODS

	US 1976 Gas range	Electric range	Rural (Wood)
Primary energy input	6,900 kcal/day	1,810-5,700 kcal/day*	20,000 kcal/day
Overall efficiency	15%	18 - 59%	5%
Efficiency of surface burners	48%	73%	-
Reason for low efficiency	Pilot lights	-	Small solid angle
Approximate price of stove	US$ 294	US$ 344	Less than US$10**

*Depends on whether primary input is thermal or hydropower. Efficiency of thermal plants was taken as 30%. If transmission losses are also included the actual range is about 16-47%.

**US$ 10 was taken as the maximum cost of a rural wood cooking stove; in general no money is involved in the construction of such stoves and this is a very rough estimate.

4. METHODS FOR IMPROVING THE EFFICIENCY OF WOOD COOKING STOVES

Primitive wood cooking stoves generally have poor performance. One typical problem is lack of control of the air supply to meet combustion needs; another is that the air to fuel ratio cannot be maintained at a constant level everywhere in the burning mass. For example, if air enters at the bottom of the burning mass then the air/fuel ratio decreases as the air moves up and may fall in some places below the level needed to ensure combustion. In this case carbon monoxide is produced; a visual indicator of incomplete combustion is the emission of black smoke made up of fine carbon particles.

The result is that in most stoves used in rural areas one finds a smoky low temperature flame which is both inefficient and unhealthy. The fuel varies in its combustion properties from day to day and even in the course of a day because the humidity content in the fuel can change from batch to batch.

This description of the characteristics of primitive wood cooking stoves indicates clearly why people (even in rural areas) move to the use of bottled gas or kerosene as soon as they can afford it: combustion of these fuels is easy to turn on and off; it is simple to control the intensity of the flame and the fuel burns uniformly. The production of biogas from agricultural, animal and human wastes through anaerobic digestion is another important option to pursue to solve the energy needs of rural people[2]. Charcoal* is still another option to be considered since it has different characteristics than either biogas or wood.

A basic reason for the low efficiency of open fire wood cooking stoves is to be found in the unavoidable large distance between the burning mass and the cooking pots; the sheer size of the logs or irregular size wood pieces and branches used in the fire is the main reason for that. In gas and electric ranges this distance is much smaller.

An increased efficiency is therefore largely a result of good design; a series of experiments conducted at Princeton University[7] helped clarify the basic problems and point to the following three basic points as fundamental ones to achieve a higher efficiency:

1. a closed hearth with a limited and controllable intake of air for the combustion.
2. flues to bring (through convection of the hot gases) the heat to the cooking pots.
3. a chimney to set up the draught which sucks the intake air needed for combustion and remove the unburnt gases.

For a discussion of the physics of cooking stoves see Appendix I.

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*Transforming wood into charcoal is one important method of extending the wood-based fuel use.[1] Charcoal can be transported economically over larger distances than wood and is therefore used in many poor urban districts of cities around the world. Charcoal has a calorific content more than twice that of wood (7,000 kcal/kg) and is easier to transport.

That is the comparative advantage of charcoal. The efficiency of the production process however is in the range 20-50% which offsets any advantage in energy terms. Charcoal can be burned more efficiently than wood because permits the building of a more concentrated fire which is a clear advantage. As a consequence it is difficult to improve the overall efficiency of charcoal stoves.

The area where progress can be made is in the design of more efficient kilns, such as the use of retorts which permit also the capture of gas and destillable by-products.

5. REVIEW OF THE LITERATURE ON WOOD STOVES FOR WARM CLIMATE COOKING.

A fairly large amount of literature (See Appendix II) has accumulated in the last decades describing improved stoves. Much of the literature doesn't go beyond stating that the stove being described is more efficient than the traditional stoves but there are a number of exceptions.

Basically the stoves described in the literature are of two kinds: the first one are the stoves made of cans or old drums which improve convection compared to open fires and which can burn a variety of waste materials like sawdust, rice-hulls (even damp) as well as wood.

FIGURE 5

These stoves are suitable for social patterns where cooking is done outdoors and they provide the means to take advantages of combustible materials that otherwise might be wasted.

The second type of stove is by far more interesting. It is a permanent stove with chimney that can be used inside or out and which can also burn a variety of waste combustibles as well as wood.

FIGURE 6

It offers high efficiency, multiple use patterns, little or no smoke, and nearly continuous hot water. This stove exists in many variations. It can be constructed by the users with local materials or it can be mass produced by cottage industries.

The better known are the Hyderabad Smokeless Chulah in India[8], the Improved Egyptian Rural Stove in Egypt[9], the Ghana Smokeless Stove[10], the Lorena Cookstove in Guatemala[11] and the Singer Stove in Indonesia[12]. They are basically designed according to the principles outlined in Section 4.

Most of these stoves have in common, multiple cooking holes and a hot water container connected in series to increase the efficiency of extraction of heat from the hot combustion gases.

Table V gives our estimates of wood fire efficiencies according to type of burning arrangement.

TABLE V

WOOD FIRE EFFICIENCIES

Type of fire	Efficiency	Basis of estimate
Open fire	5-10%	Measurements: C. Franklin[7] (ref.7) Calculations of solid angle (Appendix II)
Closed fire (one cooking hole, no chimney)	10-20%	Measurements: C. Franklin[7] Ahuja[13]
Closed fire (two or more cooking holes, chimney draft control)	25-38%	Measurements: Ahuja[13]

It is interesting to compare the numbers in this Table to the efficiency in the utilization of other fuels. This is done in Table VI where one compares efficiencies obtained in practice in India using stoves in common use. The cooking task in these experiments is defined as heating water from

18 to 90°C *.

TABLE VI

EFFICIENCIES FOR VARIOUS FUELS

FUEL	Calorific content kcal/kg	Efficiency(%)
Soft coke	6,492	28
Charcoal	6,790	28
Wood	4,750	17.3
Cow-dung	2,146	11
Kerosene	10,880	48
Electricity	-	76
Gas	4,060 kcal/m^3	60

Source: Reference 14

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*This task is not representative of the cooking sequence which might require a variety of heat output rates from the fire and a sucession of boiling and simmering activities (Dutt[15]). The overall efficiency for cooking may be defined as

$$E = \frac{\text{energy transferred usefully to food}}{\text{total energy expended}}$$

where the total energy expended is the chemical energy content of the fuel.

This efficiency E can be expressed as the product

$$E = E_s E_H$$

where E_s is the stove efficiency and E_H is the efficiency of heat transfer defined as

$$E_H = \frac{\text{energy transferred usefully to cooking pot}}{\text{total energy input to cooking pot}}$$

While E_s depends on the physical design of the cooking stove E_H depends of the cooking sequence and temperature of the fire that takes into account the tightness of the pots and the abilities and intentions of the cooker.

It would be quite convenient to define a "reference cooking sequence" and compare the efficiency of different cooking stoves around the world for that sequence.

It is clear from the discussion above that although some technical information is lacking on the scientific design of wood cooking stoves, enough is known to build stoves more efficient than the ones in present use.

Stoves can be built by the users themselves with local materials at costs of the order of US$ 10 (or equivalent in non-monetary transactions) or with the assistance of cottage industries at higher prices but still acceptable. Such stoves are capable of 30-40% efficiency in laboratory tests. Perhaps, half of this, i.e. 15-20%, could be achieved in rural households . This would be at least twice the present rural average. In other words it should be possible to reduce rural wood consumption to about half of its present level. In the late 60's it was estimated[13] that 20 million tons of coal equivalent would be saved in India by the introduction of these stoves. This is about 50 million tons of wood or about half of the total wood used for cooking in that country.

S. P. Raju,[8] already in the 1950's stressed the importance of improved stoves in the areas of "housing, health, fuel economy and forest economy". He also made a special point of the beneficial impact that improved stoves would have on the lot of women who are most exposed to the heat and smoke* and whose "man-days" comprise most of the time spent in the search for wood in wood-poor regions of the world. In addition to that as mentioned earlier most of the improved stoves offer nearly continuous hot water. Hence the improved stoves offer significant advancement in living standards to the rural poor as well as reducing pressure on forests, while reducing the time spent in cooking by an appreciable amount.

Why then almost thirty years later has there been so little success in introducing stoves of improved design in poor rural areas?

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*In some places the smoke produced by inefficient stoves seems to play the role of bug and thermite exterminator and is accepted for that reason.

THE ROLE OF EXTENSION PROGRAMS

The most obvious reason for this failure is the absence of extension programs to disseminate better stoves. In addition it is usually not possible to improve cooking methods of the poor without simultaneously dealing with a host of cultural and environmental factors that determine the quality of life. Improvement in one factor very easily can lead to deterioration in another with no gain in the quality of life. Hence the introduction of better cooking stoves must be consistent with a general improvement in the lot of the poor.

Many planners and economists believed that the lot of the poor would more or less automatically improve through economic development and that the firewood crisis would be solved naturally as rising affluence allowed more people to switch from firewood to other fuels.

These expectations have not materialized in many countries and it is now evident that improved use of firewood is as essential a goal as it was a few decades ago. Although extension programs are slow in yielding results, in their absence there has been very little change at all.

The characteristics of rural cultures in less developed countries require successful local demonstrations of a new technology in order to stimulate a transition. Villagers will switch to a better stove if they see their neighbors enjoying the advantages of a new procedure. A significant impact can only occur if increasing numbers of villagers are brought into contact with improved stoves being used by other community residents.

Since no "universal" improved stove exists it is clear that any extension program will have to start by identifying in a given country (or region of a country) what modifications have to be introduced in the existing stoves. These changes (the addition of a chimney for example) will have to take into account local habits.

Once the changes (or eventually a new design) is agreed upon a few units should be built and a simple building manual should be prepared in the local language. The style of the manual must be consistent with the local level of literacy.

One possibility for greater success in reaching people and convincing them of the advantages of change would be to install the new stoves in health centers or schools where young mothers can see them in operation. Since health care and schooling are usually desired, the association of improved stoves with these activities should tend to reduce the psychological barrier to their acceptance.

In addition to efforts to bring the better stoves to the attention of the younger more adaptable members of a community, it is also necessary to demonstrate the advantages of the stoves to a set of community leaders.

As with agricultural extension programs, only when the advantages of a new technology are quite evident in local demonstrations carried out by local residents, will they be readily apprehended by the rural population. The potential user-benefits of improved stoves are elimination of smoke (not a clear advantage if insect control depends on smoke), reducing by as much as a factor of 2 the firewood needed and hence the time required to collect it, provision of extra hot water and cooking convenience. successful demonstrations with stoves should likewise lead to a fairly rapid acceptance of new stove designs.

In less populated areas, special units of "social foresters" may be required for the extension service. Such units have been established in Gujuran, India. Their tasks besides disseminating information on reforestation would be to demonstrate the advantages of improved stoves. For this activity forest guards would not be appropriate since they are too frequently associated with repression.

Even in urban areas there are some possibilities for firewood or charcoal stoves. In slum recovering programs, better stoves can be introduced in the new houses as a permanent fixture along with toilets and showers which induce the owners to adopt new living patterns that are superior from a sanitary and economic point of view.

The manufacture of the stoves will depend on the particular type chosen and in heavily populated areas (or in urban areas) it can give rise to small cottage industries.

STARTING EXTENSION PROGRAMS

An extension program for the introduction of better stoves\should therefore

- start with the visit of a World Bank expert (or consultant) that will identify - after studying the local situation - what is the most suitable model for that area.
- immediately afterwards a few units will be manufactured and a detailed building manual prepared.
- the visiting expert will then train a number of people engaged in agricultural extension work , social forestry or a newly created unit of high school students on the building and use of the stove.
- the local people will afterwards spread a few units to key centers (health clinics, schools, community centers, etc.) and convince some influential villagers to use them.
- in all cases either cottage industries should be created, or local blacksmiths or semiskilled laborers should be trained or "do-it-yourself" manuals should be distributed so anyone desiring to build or purchase better stoves should have no trouble in doing so.

The role of the WORLD BANK is to ensure that money be made available along with reforestation, urban slum recovery and health programs (among others) to bring into the country experts to start the extension program and train an initial core of local people. It seems to us that less than US$ 100,00 should be enough to start a given program in a small country or a State of the large ones.

Once started the upkeep of such an extension program should not be large. But it will be necessary to maintain a distinct responsibility for the new officers who are spreading improved stove technology. These officers may fit in diverse ways into existing or new extension programs but other extension experience suggests the task of introducing new stoves \cannot be just one more task on top of an already overburdened extension officer.

As in all extension services leadership is essential and the success of the program will depend on some local people strongly motivated by the problem that decides to face the challenge of the firewood crisis in their own plysical and cultural settings.

APPENDIX I

AVAILABLE PAPERS ON WOOD COOKING STOVES

(VITA* - March 31/1978)

1. OUTDOOR OVEN,
VITA, Village Technology Handbook - p. 339

2. WOODBURNING OVEN,
VITA, Technical Bulletin 11

3. DOUBLE-DRUM SAWDUST STOVES,
VITA, Technical Bulletin 29

4. LORENA MUDSTOVE,
Choqui Experiment Station, Guatemala

5. RICE HULL STOVE,
Volunteers in Asia, A.T. Sourcebook

6. THE $ 1.50 WOODBURNING STOVE,
Volunteers in Asia, A.T. Sourcebook

7. "RECENT EFFORTS TO DEVELOP SIMPLE WOODBURNING STOVES"
Georgia Institute of Technology, A State of the Art Survey of Solar Powered Irrigation Pumps, Solar Cookers and Wood Burning Stoves for Use in Sub-Sahara Africa.

8. "THE SMOKELESS STOVE-GHANA"
Canadian Freedom from Hunger Foundation and Brace Institute, Appropriate Technology Handbook.

9. "EXPERIMENTS WITH THE IMPROVED EGYPTION RURAL STOVE"
B. Theodorovis, Arab States Fundamental Education Center.

10. "JAPANESE COOKSTOVES"
Japanese Ministry of Agriculture and Forestry.

11. SMOKELESS FOGONES
Anonymous mineo

12. "WATER HEATER WOODSTOVE"
L. McKusick, Alternative Sources of Energy
December 1976

13. "ECONOMIC STOVE THAT BURNS SAWDUST AS FUEL"
E. Simon and P. Solis, Appropriate Technology, Vol.4,Nº 1

*Volunteers in Technical Assistance

14. "SMOKELESS KITCHEN FOR THE MILLIONS"
S.P. Raju, Christian Literature Society.

15. "IMPROVING THE DOMESTIC CHULA"
E.G.K. Rao *Indian Farming*, January 1962.

16. *A SMOKELESS CHULAH FOR EVERY HOME*
Farm Information Unit, Ministry of Food and Agriculture, New Delhi.

17. "IMPROVED CHULAH FOR KITCHENS"
Appropriate Technology Development Asssociation, *Appropriate Technology Directory*.

18. *MAGAN CHOOLA*
T. Kalluppatti

19. "CONSTRUCTION OF A SMOKELESS FIREPLACE"
G. Peters

20. "HOW TO MAKE A SMOKELESS STOVE"

21. "Device for Using Sawdust as Economic Fuel"
E. Simon and P. Solis, *Appropriate Technology*, Vol.3 Nº 2.

22. "The Village Bakery"
Rural Communication Service, Leaflet Nº 5
South Petherton, Somerset, ENGLAND

23. *A Study on the Efficiency of Chulahs*,
Government of India, National Buildings Organization, and United Nations Economic Commission for Asia and the Far East Regional Housing Centre.

24. *Smokeless "Herl" Chulah*
Hyderbad Engineering Research Laboratories.

APPENDIX II

THE PHYSICS OF COOKING STOVES

Heat is transfered from the fire to the cooking pot through three processes: radiation, conduction and convection.

Radiative heat (mainly infrared radiation) can be concentrated on the cooking pot by surrounding the fire with a shiny surface (such as an aluminum foil). The pot is usually blackened by the smoke and becomes a good absorber of radiative heat; this means that shiny pans (on the outside) should not be used in wood cooking stoves. Of course pans do not remain shiny when in use and quickly become covered by black layer ; however, if this layer is too thick it impedes good conduction.

Conduction occurs through the layer of air between fire and pot and should be optimized by providing good access to the bottom of the pot; it means also that the flow of hot gases around the pot should be turbulent since a laminar flow might allow some of the gas to go up around the cooking pan without contacting it and hence not transferring heat to the pan.

Convection of hot gases is the most important factor in woodstoves. Uncontrolled convection is the biggest problem in open fires where the wind can disperse the hot gases eliminating contact with the cooking pot. In stoves with several openings it is essential to create a flue system to conduct the heat from the fire to the pot; this implies the use of baffles which also increase the turbulence of the gas flow.

A combination of these ideas is essential to increase substantially the efficiency of cooking above that to be expected for just the radiative part of the heat transfer from an open fire.

The geometrical efficiency for intercepting radiation can be calculated from the solid angle subtended by the cooking pot[16], with respect to the extended fire. Figure 7 shows the results of such calculations. Note that for a pan whose diameter is the same as the diameter of the fire and whose separation from the fire is a distance equal to the pan diameter, the geometrical efficiency is only about 10%, which means only 10% of the radiant heat of the fire is directly intercepted by the pan.

FIGURE 7

An experiment at the University of Princeton[7] tested the efficiency of a fire-pan configuration with and without control of the convection of gases. The test device consisted of a shiny aluminum cylinder with some appropriate holes and partitions which could be used to enclose the fire and pan. Efficiencies were obtained by weighing the wood before and after burning and measuring the temperature change of a given amount of water. The results were 7% efficiency for the open configuration and 16% with the convection control. This demonstrates clearly the importance of convection control as a design consideration.

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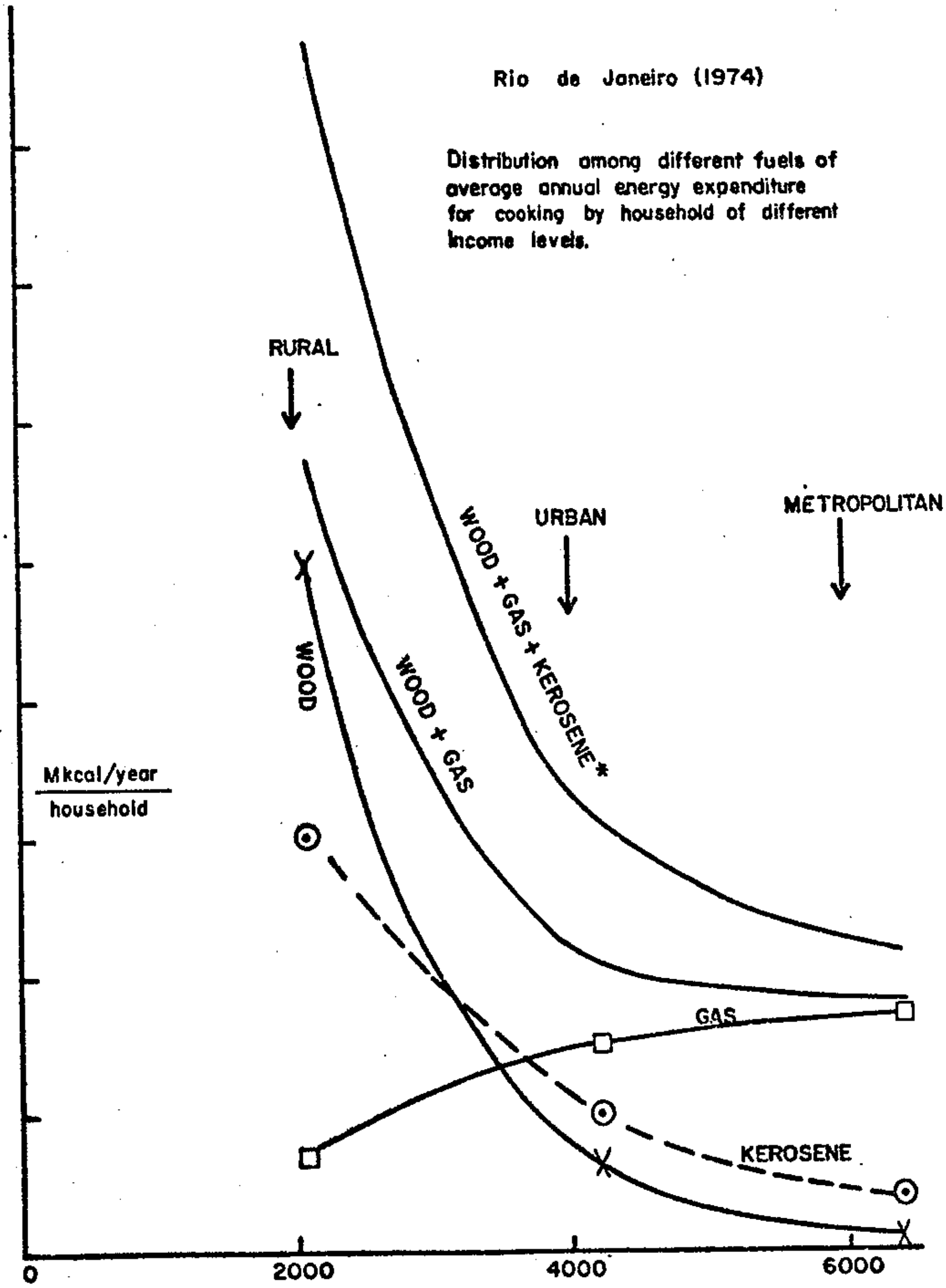


FAMILY INCOME $ US Dollars (1974)

* An unknown fraction of kerosene is used for lighting rather than cooking

Fig. 1

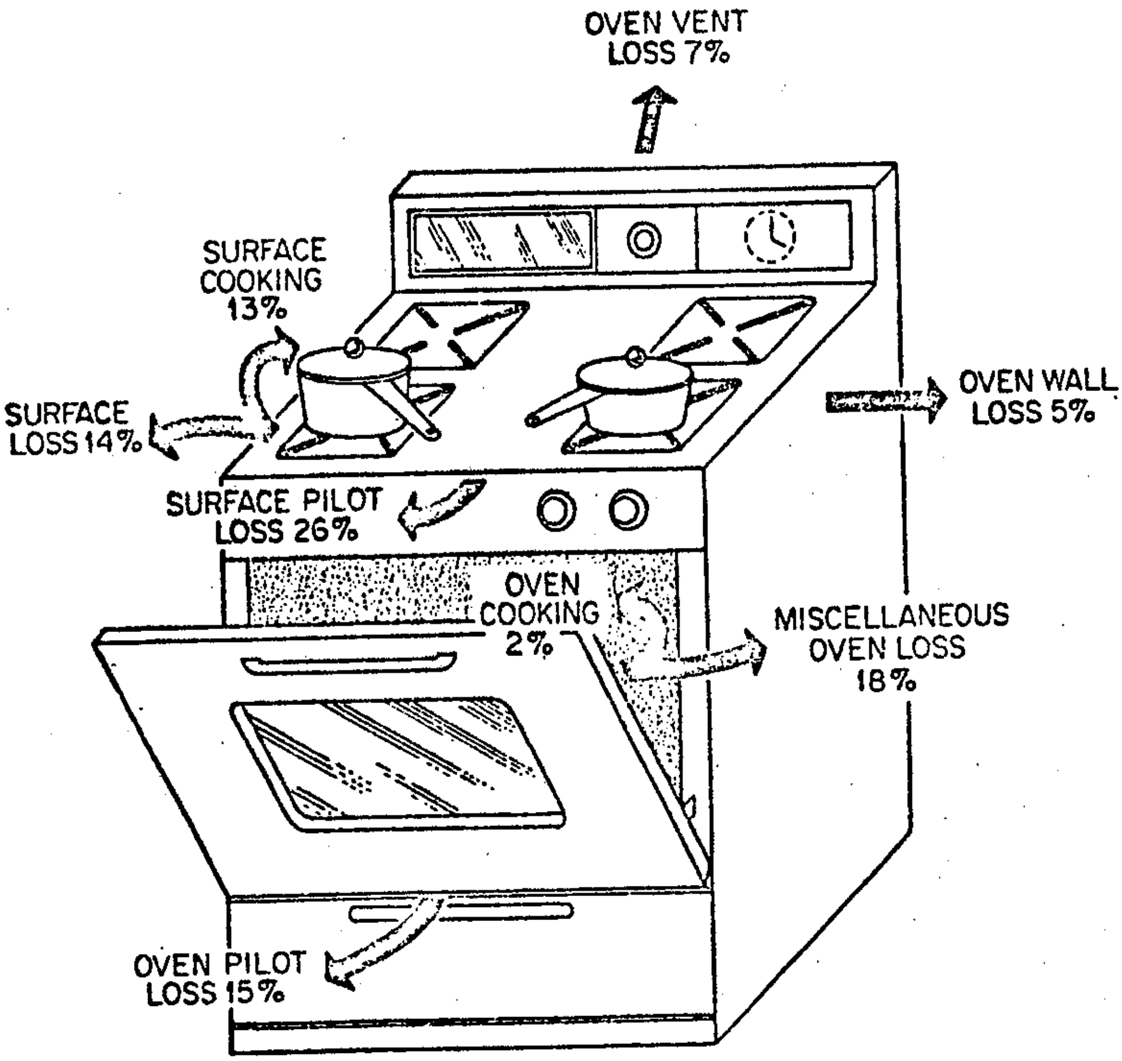


Fig. 2 Energy flows in a gas range. Total energy use is 10.5 x 10^9 J/yr.

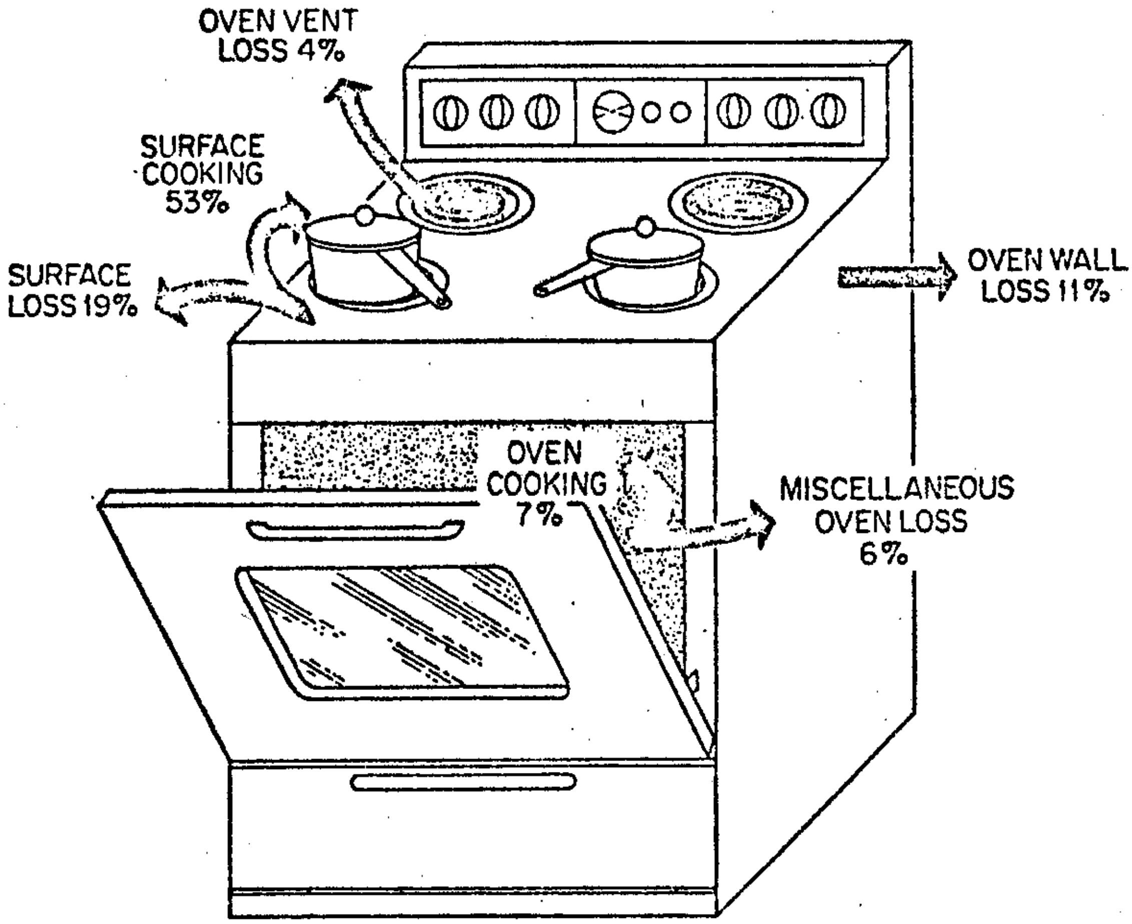


Fig.3 Energy flows in an electric range. Total energy use is 2.65×10^9 J/yr.

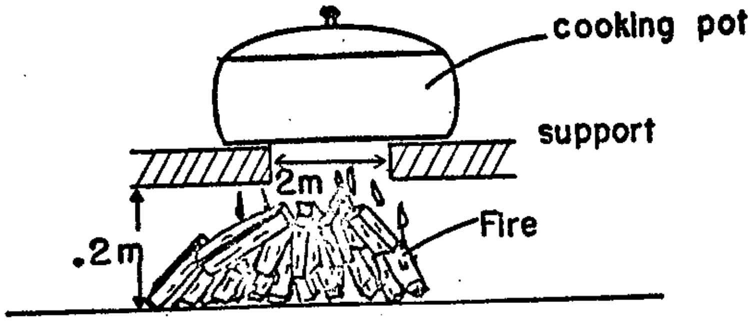
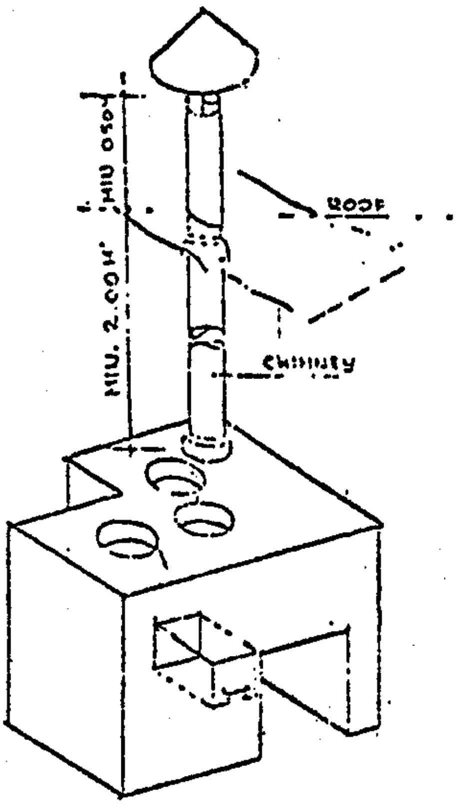


Fig. 4



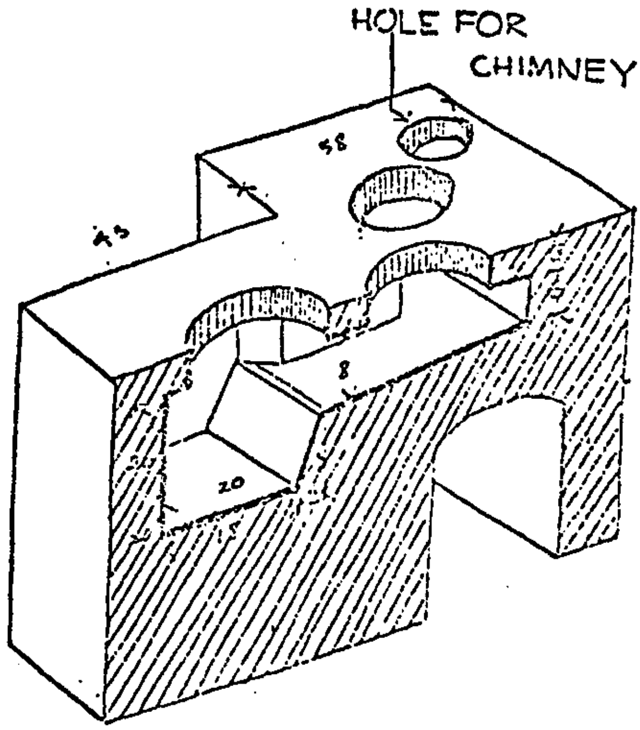


Fig. 6

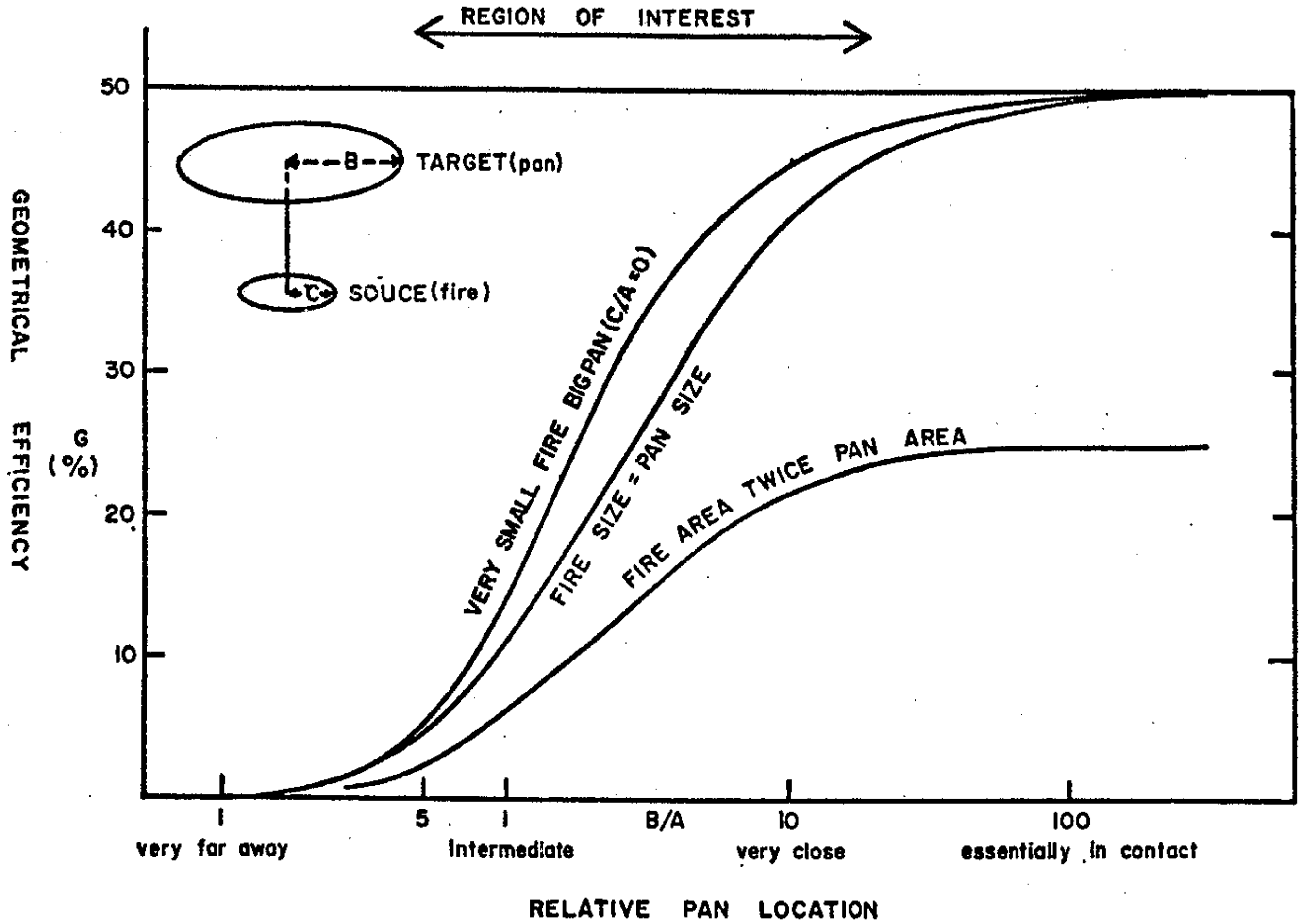

REGION OF INTEREST
TARGET(pan)
B
C
SOUCE(fire)
GEOMETRICAL EFFICIENCY
G (%)
50
40
30
20
10
VERY SMALL FIRE BIGPAN(C/A=O)
FIRE SIZE = PAN SIZE
FIRE AREA TWICE PAN AREA
1
very far away
5
1
intermediate
B/A
10
very close
100
essentially in contact
RELATIVE PAN LOCATION

Figure 7