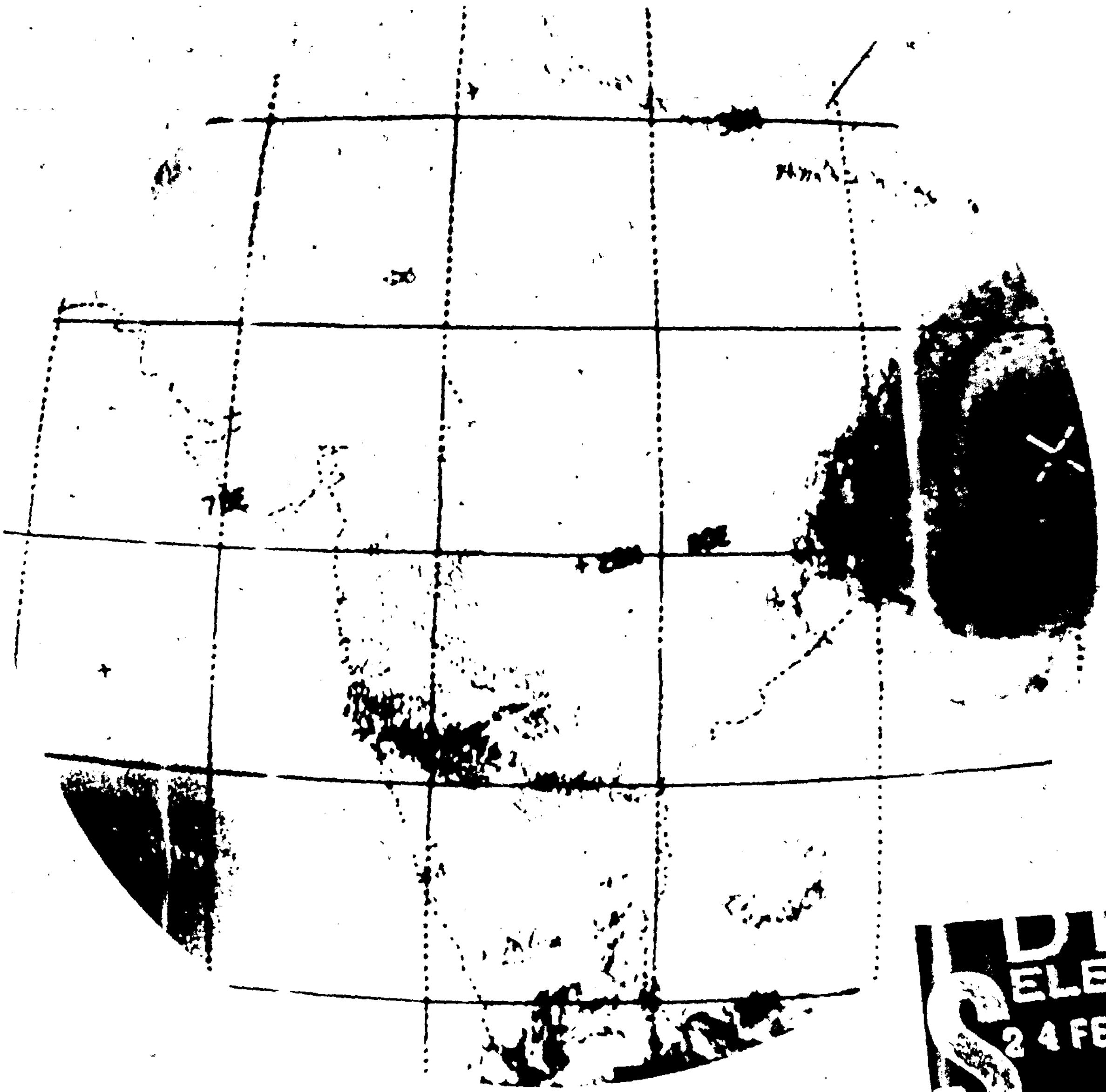
INDOOR SPATIAL MONITORING OF COMBUSTION GENERATED POLLUTANTS (TSP, CO, AND BaP) BY INDIAN COOKSTOVES

by Hemlata Menon



July 1988

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ABSTRACT

This dissertation focusses on indoor concentrations of pollutants (TSP, CO and BaP) emitted by Indian cookstoves. Experiments in a simulated village hut (SVH) determined size distribution of particulates from burning of fuelwood and cowdung, and investigated the effects of fuel, ventilation condition and sampling location on TSP, CO and BaP concentrations. 84 to 99 % of the total particulate mass in wood and dung smoke had aerodynamic diameter less than 3.2 μm, which eliminated the need for particle size discriminating sampling. These experiments finalised the field sampling protocol.

The field survey included 291 households in three central and two south Indian villages. The kitchens had either thatched or tiled roofs with a variety of volumes and open spaces on the walls. Fixed monitoring was done at roof, medium and low levels close to stove or chula (cemented to floor) and personal sampler on the cook monitored air in her breathing zone. TSP, CO and BaP were measured in 129 households in the five villages. Pollutant levels varied with sampling site, ventilation conditions and fuel quality. Mean TSP exposure to cooks was 5 mg/m^3, twenty times higher than the standard specified by regulating agencies (U.S, WHO and India) for ambient conditions. Mean CO exposure to cooks was 51 ppm, three times higher than the corresponding standard. However,

TSP and CO levels were equal to OSHA standard. Mean BaP exposures to cooks were 160 ng/m^3, equal to ambient levels found in cities in developed countries. While cook's mean exposure to TSP and CO agrees with earlier studies, her exposure to BaP is an order lower. The cook's exposure to TSP and BaP was similar to lowest indoor fixed monitoring levels but order of magnitude above outdoor concentrations. Next to the chula TSP, CO and BaP levels increased with height. TSP, CO and BaP levels in thatched huts were comparable to those measured in SVH. Tiled hut roofs allowed smoke seepage resulting in much lower concentrations than in thatched huts. TSP (roof) and CO (cook) were significantly higher in winter than during monsoon and, CO (cook) was higher in morning than evening.

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List of Abbreviations

Am: Arithmetic Mean

ANOVA: Analysis of Variance

ARI: Acute Respiratory Infection

BaP: Benzo(a)pyrene

BHEL: Bharat Heavy Electricals Ltd. (India)

CIAE: Central Institute Of Agricultural Engineering (Bhopal)

FP: Fine particulates

CO: Carbon Monoxide

GE: General Electric

Gm: Geometric Mean

GMDH: Group Method of Data Handling

HbCO: Carboxy Hemoglobin

Hi-Vol: High volume

HPLC: High Pressure Liquid Chromatography

MMD: Mass Median Diameter

NAS: National Science Academy (U.S.A)

OSHA: Occupation Safety and Health Adminstration

PAH: Poly Aromatic Hydrocarbon

POM: Polycyclic Organic Matter

QCMCI: Quartz Crystal Micro-balance Cascade Impactor

Abbreviations

RSP: Respirable Suspended Particulates

SPSSX: Statistial Package for Social Scientists

SVH: Simulated Village Hut

TERI: Tata Energy Research Institute (Pondicherry)

TSP: Total Suspended Particulates

USEPA: United States Environmental Protection Agency

WHO: World Health Organization

I. INTRODUCTION

1.1 INDOOR AIR QUALITY ISSUE

Man may have first become aware of indoor air pollution when he lit the first fires for cooking and space heating in un-ventilated caves. With improvement of the design of shelters, control of combustion products and substituting of traditional fuels by electricity and gas, most of the indoor combustion generated pollutants were minimized or vented outside making indoors more comfortable and habitable. However, it is disheartening that even today the indoor air quality in kitchens of rural homes in the developing world, where traditional fuels (wood, cowdung, crop residues etc.) are the main sources of energy for cooking, is more or less like the smoky conditions that must have occurred in unventilated caves thousands of years earlier.

The first international conference on indoor climates was organized in 1978, when it was recognized that indoor air pollution levels had increased as a result of the use of new less porous construction materials that entrapped indoor air and reduced infiltration. The 1981 second international symposium on Indoor Air Pollution, Health and Energy Conservation (Moghissi, 1982) brought scientists together from twelve developed countries to discuss public health concerns focusing on formaldehyde, radon, biological aerosols, organic vapors, combustion gases and soot. They emphasized that the U.S. Clean Air Act of 1963 focussed attention only on cleaning outdoor air and failed to address indoor air quality, inspite the fact that people spent 80-90% of their time indoors, at home, at work, or commuting. But it was also pointed out that indoor air pollution is not only a problem for the developed nations, is of great concern to third world, where cooking is done indoors with traditional fuels on stoves that do not vent outside.

The 1984 third international conference on Indoor Air Quality and Climate produced five volumes titled INDOOR AIR (Berglund, et al., 1984). Topics included recent advances in the health sciences and building design, chemical analyses of indoor air, sampling and analytical methods, indoor/outdoor relationships of the pollutants, importance of personal exposure, epidemiological studies of health disorders related to housing, sick building syndrome,etc. Recently several documents on INDOOR AIR QUALITY have been published. (WHO, 1979, 1982, 1983; Dudney & Walsh, 1981; Meyer & Hartley, 1982; U.S. National Research Council, 1981; Proceedings of Second International Symposium on Indoor Air Pollution, Health, and Energy Conservation, 1982; Spengler and Colome, 1982, Yocom, 1982; Lebowitz, 1983; Spengler & Sexton, 1983; Kirsch, 1983; Spengler & Soczek, 1984; Turiel, 1985; Meyer, 1983; Wadden and Scheff, 1983). However, all above mentioned studies addressed only the Indoor Air Quality and human exposures pertaining to the developed countries.

Research on Indoor Air Quality started only during the last few years, since previously air pollution was considered to be an outdoor phenomenon and it was assumed that buildings shelter their occupants from pollutants. Thus, air quality legislation regulated only outdoor conditions, particularly as caused by large-scale, highly visible sources, such as industry and vehicle exhausts.

Recent studies (Binder, et al.,1976; Ferris, et al.,1979; Dockery, et al.,1981; Sega, 1982; Tosteson, et al., 1982) have shown that indoor air pollution levels can often be higher than outdoors in the presence of indoor air pollutant sources. Indoor air pollutants are released by various building materials and consumer products, and combustion appliances. People and pets normally emit CO_2, moisture, odors, and microbes. Tobacco smoking can be a significant source. The soil under and around buildings emits radon gas. Table 1.1 lists the various sources of air pollution (both indoor and outdoor) and some pollutants they emit. Studies by Binder, et al., 1976, Sega, et al., 1982, Tosteson, et al. 1982, have shown that indoor levels of pollutants may be significantly higher than ambient levels measured at outdoor monitoring stations. Spengler, and Soczek, 1984 found personal exposure to indoor pollutants (carbon monoxide, (CO), Nitrogen dioxide (NO_2), formaldhyde, hydrocarbons, and suspended particulates)

Table 1.1 Typical Sources of Air Pollutants Grouped by Origin

POLLUTANTS	SOURCES
Group I. Sources predominantly outdoor:	
Sulfur oxides (gases, particles)	Fuel combustion, smelters
Ozone	Photochemical reactions in the atmosphere
Pollens	Tree and other plants
Lead	Automobiles, industrial emissions
Calcium, chlorine, silicon, cadmium	Suspension of soils or industrial emissions
Organic substances	Petrochemical solvents, natural sources, vaporization of unburned fuels
Group II. Sources both indoor and outdoor:	
Nitric oxide, nitrogen dioxide	Fuel-burning, tobacco smoke
Polycyclic hydrocarbons	Fuel-burning, tobacco smoke
Carbon monoxide	Fuel-burning, tobacco smoke
Carbon dioxide	Metabolic activity, combustion
Suspended particulate matter	Resuspension, condensation of vapours, and combustion products

Table 1.1 (Continued) Typical Sources of Air Pollutants Grouped by Origin

POLLUTANTS	SOURCES
Water vapour	Biological activity, combustion, evaporation
Organic substances	Volatilization, combustion, paint, metabolic action, pesticides, insecticides, fungicides
Spores	Fungi, molds
Group III. Sources predominantly indoor:	
Radon	Building materials (concrete, stone), water
Formaldehyde	Particle board, insulation, furnishings, tobacco smoke
Asbestos, mineral, and synthetic fibres	Fire-retardant, accoustic, thermal, or electrical insulation
Organic substances	Adhesives, cooking, cosmetics, solvents
Ammonia	Metabolic activity, cleaning products
Mercury	Fungicides in paints, spills in dental-care facilities or laboratories, thermometer breakage
Aerosols	Consumer products
Viable organisms	Infections
Allergens	House dust, animal dander

Source: WHO Publication No. 69, 1982.

better correlate to indoor source than to the levels measured in the ambient air. They found personal monitoring equipments to be useful in measuring personal exposures.

The removal rate of indoor pollutants depends mainly on the air flow in and out of the building. As a result of the energy crisis, efforts have been directed towards energy conservation. One of the most cost-effective strategies for improving energy efficiency of buildings is to reduce air flow rates. This is usually brought about by building tighter homes and using better insulating building materials. Unfortunately, in the process the removal or transportation of the indoor generated pollutants to the outside can be drastically slowed, resulting in the trapping of indoor pollutants and a number of negative impacts became apparent to the occupants.

1.2 INDOOR AIR POLLUTANTS IN THE DEVELOPING WORLD

High indoor air pollution also occur in the developing world, but not because of the reasons cited above but because of indoor combustion of traditional fuel in cookstoves without flues. Recently Aggarwal, et al., 1982, and Smith, et al.,1983 found indoor air pollutant concentrations from biomass combustion to be extremely high when compared to available ambient air quality standards and benzo(a)pyrene levels equivalent to the smoking of 20 packs of cigarettes a day. Number of important agencies viz., 1) Committee on the Epidemiology of Air Pollutants, National Research Council, Washington, 1985, 2) World Health Organization, 1985 and 3)

India's Citizen's Report, 1985 have stressed the need for further research in this area. Table (1.2) summarises studies on indoor combustion generated pollutants in the developing countries, details of which are given in Chapter Two.

There has been little research on characterization of the emissions from biomass combustion in the developing world. Almost all figures available on emissions are from wood burnt in fireplaces in the U.S., Canada and Scandinivian countries. Cooper, 1980 and Dasch, 1982 showed that CO, organic vapors and particulate matter are generated during wood combustion. Combustion of wood in stoves releases more TSP, polycyclic organic matter(POM) and other hydrocarbons, and CO, per unit of energy than combustion of oil and most coals Morris, 1982, Cooper, 1980. Recent literature on woodsmoke have been documented by Cooper, et al., 1982; De Angelis, et al., 1980; Ayer, et al.,1981; APCA, 1982; Capellen, et al., 1982. These experiments, conducted in developed countries, do not simulate combustion conditions in most cooking stoves in the developing world. Cooking in rural India, is generally performed indoors using wood, cowdung, and crop residues in a stove (usually called CHULA) consisting of just a horse-shoe shaped block of a mixture of mud, cowdung, and straw. The chula top is designed to fit the cooking pots in the house. The chula types range from a simple three stone design to relatively complicated stoves with a chimney, dampers and two or three pot holes.

Table 1.2 Studies of Indoor Combustion Generated Pollutants in Developing Countries

S.No	Site/Country	Pollutants Monitored*	Sampling Type**	Reference
1	Nigeria, Lagos	CO, NO_2, SO_2, C_6H_6	Grab Sample	Sofoluwe, 1968
2	Western, Eastern, Highlands, PNG	TSP, HCHO, CO	Simul. Pers. & Grab Sample	Cleary & Blackburn, 1968
3	Kenya	TSP, BaP, BaA, Phenols, CH_3COOH	Area	Hoffman & Wynder, 1972
4	Kenya	--do--	--do--	Clifford, 1972
5	Lufa, PNG	TSP	Area	Anderson, 1975
6	Gautemala	CO	Grab Sample	Dary, et al., 1981
7	Kumjung, Nepal	Pb, Cu, Al,Mg	Simul. Pers.	Davidson, et al., 1981
8	Ahmedabad, India	TSP, BaP, NO_2, SO_2	Area	Aggarwal, 1982
9	EWC, SVH, Hawaii	CO	Simul. Pers.	Dollar, et al., 1982
10	Gujarat, India	TSP, BaP	Exposure	Smith, et al., 1983
11	Gujarat, India	TSP, SO_2, NO_2	Area	Patel, et al., 1984
12	Calcutta, India	TSP, SO_2, NO_x, BaP	Area	Dave, 1984

Table 1.2 (Continued) Studies of Indoor Combustion Generated Pollutants in Developing Countries

S.No.	Site/Country	Pollutants Monitored	Sampling Type	Reference
13	EWC, SVH, Hawaii	TSP, CO	Simul. Pers.	Smith et al., 1984
14	Nepal	CO	Simul. Pers.	Joseph et al., 1985
15	Several villages, Nepal	TSP, RSP, crustal elements, enriched elements, SO_4, NO_3, carbon (organic & elemental) & CO	Simul. Pers.	Davidson, et al., 1986
16	Middle Hills, Nepal	TSP, CO	Simul. Pers.	Reid, 1986
17	Xuan Wei, China	TSP, BaP (PAH)	Area	Mumford, 1987
18	Bhopal & Pondicherry villages, India	TSP, BaP, CO	Simul. Pers. & Exposure	This study

* Hypothetical levels of TSP concentrations (Indoor and Outdoors) in rural villages reported by Smith et al., 1981 and Ramakrishna, 1982.

** For TSP:

Area: Air drawn above 20 lpm

Simul. Pers.: Air drawn at 1-4 lpm and device placed at some site

Exposure: Air drawn at 2-4 lpm and pump worn by the person

For CO:

Grab sample: Air collected and analysed

Simul. Pers.: Personal sampler placed at some site

Exposure: Personal sampler placed at cooks breathing zone

1.3 REASEARCH OBJECTIVES:

The objectives of this study have been formulated through a review of sampling methods and recent research discussed in section 2.6. Research was divided into two phases:

1. Simulated village hut (SVH)
2. Rural Indian kitchens (Field)

In order to prepare for field experiments in India and test instruments and gain experience, a number of experiments were run in a simulated village hut at the East-West Center of the University of Hawaii. Specifically, the objective was to identify the major factors and minimize sources of variability in ventilation, fuel and combustion chamber. The result of this work was to develop a sampling protocol for utilizing in field experiments in rural kitchens of central and southern India. This sampling protocol is described in detail in Menon, 1988.

Research questions regarding pollutant concentration and exposure, variability, and identification of factors responsible for this variability addressed in this dissertation are:

1. What is particulate size distribution of smoke from traditional fuel?
2. How does TSP and CO concentration vary with burn time?

3. What is the effect of fuel type, ventilation condition, and sampling location on TSP, CO, and BaP concentrations?
4. What is the socio-economic conditions of the villagers and their concern about fuel and smoke?
5. What is the spatial concentration distribution of TSP, CO and BaP in rural Indian kitchens?
6. How are the stationary measurements of CO, TSP and BaP related to personal exposure of CO, TSP and BaP?
7. Do measured values of cook's exposure to TSP and CO, and TSP concentration at roof differ by season, village, ventilation condition, fuel and combustion conditions?
8. What is the main and interaction effect of season, ventilation condition and sampling location on spatial concentrations of CO?
9. Can an empirical model be determined for estimating cook's exposure to TSP as a function of meteorological, ventilation, fuel and stove parameters.

2. EXPOSURE TO COMBUSTION GENERATED POLLUTANTS - LITERATURE REVIEW

2.1 BACKGROUND

One source of indoor air pollution in developing countries is combustion of traditional fuels, which is the only way that rural communities can meet their demands of fuel for cooking and space heating. In order to understand the extent of combustion-generated pollutant exposures to cooks and possible health effects from using traditional fuels, we need first to describe the pattern of traditional fuel usage.

2 2 TRADITIONAL FUEL USE IN INDIA

Hughart, 1979, points out that half of world's households cook regularly with biomass fuel and the cooking task is invariably performed by the women. Biomass fuels, which include fuelwood, crop residues, and cowdung, are used in all the rural areas of India for cooking and heating. Revelle (1976) reported that cooking dominates the energy usage in the rural sector (64%) followed by agricultural needs (22%), village industries (7%), lighting (4%) and transportation (3%) (Table 2.1). A source-wise energy consumption compiled (Table 2.2) for the rural household sector (Working Group on Energy Policy, Planning Commission, Govt. of India, New Delhi, 1979) lists firewood as the major source of fuel (68.5%) oil products (16.9%), animal dung (8.3%), coal (2.3%), electricity (0.6%)

Table 2.1 Patterns of Energy use in Rural India

Activities	Commercial energy (%)	Non-Commercial energy (%)	Energy used Kcals X 10^{14}	% of total
Domestic (cooking, house-work etc)	2% (coal)	98% (Firewood, cowdung, Agri. waste)	7.31	64.0
Agriculture	23% (Fertilizer 14%, diesel, 3% electricity, 6%)	77% (Human energy, animal energy, cow-dung manure)	2.52	22.0
Non-Agricultural work (Pottery, brick-making, etc.)	Nil	100% (Firewood, charcoal, human energy)	0.76	7.0
Lighting	100% (Kerosene 87%, Electricity 13%)	Almost nil	0.48	4.0
Transportation	Almost nil	100% (Human energy, animal energy, bicycle)	0.35	3.0

Source: Revelle, 1976

Table 2.2 Source-wise Energy Consumption in Rural Household Sector

Energy	Rural per Capita Energy Consumption			
	% share of energy forms	% share of source of supply of each form: Purchased	Collected	Home grown
Electricity	0.6	100.0	0.0	0.0
Oil Products	16.9	100.0	0.0	0.0
Coal Products	2.3	65.1	34.9	0.0
Firewood	68.5	12.7	64.2	23.1
Animal Dung	8.3	5.1	26.2	68.7
Others	3.4	8.9	61.0	30.1

Share of commercial fuels 20%

Share of non-commercial fuels 80%

Source: Report of Working Group on Energy Policy, Planning Commission, Govt. of India, 1979 and others (3.4%). Wood and cowdung constitute the primary domestic energy source for cooking (A.V.Desai, 1981). Table 2.3 gives rural per capita traditional fuel consumption (kg/year) in the different geographical zones of India. Wood and dung are the principal fuels for North-west, East & North regions whereas wood is used all over the rural parts of India. The use of dung varies from 4% in the South to 36% in the North with wood making up the rest. Table 2.3 does not list crop residues which may have been included under firewood. India has a total forest area of about 75 million hectares or 23% of the total area of the country. According to the Report of the Fuelwood Study Committee 1982, the total requirement of fuelwood is about 133 million ton per annum whereas the annual availability is at only about 49 million ton. The acute shortage of fuelwood in the rural areas is often referred to as "poor man's energy crisis" and is of great concern to the villagers. The shortage of fuelwood has resulted in increased use of agriculture residues and animal dung which otherwise would have been used to restore soil fertility and increase food production.

Table 2.3 Traditional Rural Fuel Consumption (kg/yr/capita)

ZONE*	FIREWOOD (kg/year)	COWDUNG (kg/year)	FIREWOOD (%)	COWDUNG (%)
NORTH-WEST	349.16	157.11	69.0	31.0
WEST	275.47	33.71	89.0	11.0
SOUTH	281.37	10.71	96.0	4.0
EAST	308.42	98.82	75.7	24.3
NORTH	277.72	157.60	63.8	36.2

* The zones are defined as follows: NORTH-WEST: Punjab, Rajasthan, J&K, Delhi and Himachal Pradesh. WEST: Gujarat, Maharashtra & Karnataka, SOUTH: Kerala, Tamil-Nadu, Andhra-Pradesh. EAST: Orissa, Bihar, West Bengal, Assam, Manipur & Tripura. NORTH: Uttar Pradesh & Madhya Pradesh.

Source: Desai, 1981

2.3 JUSTIFICATION FOR SELECTING TSP, CO, AND BaP FOR MONITORING .

The five combustion generated pollutants referred to as Criteria Pollutants, for which ambient emission standards have been set by different countries are :

Total Suspended Particulates (TSP)

Carbon Monoxide (CO)

Sulphur Oxides (SO_x)

Nitrogen Oxides (NO_x)

Hydrocarbons (HC)

Table 2.4 shows that for residential use of fuel wood, emission of particulates, hydrocarbons, and carbon monoxides are an order of magnitude higher than coal. The reason for these high emission rates is incomplete combustion when burning at one or two kg/hr. SO_2 and NO_2 emissions for wood are less than for coal since sulfur is almost absent in wood and low burn temperature releases negligible amounts of NO_2. Cooper (1980) identified several carcinogens, co-carcinogens and several cilia toxic and mucus-coagulating substances in wood smoke. DeKoning, et al., 1984 summarised Cooper's paper and other sources, and listed a number of known and suspected carcinogens (Table 2.5). He also listed emission factors for cilia toxic and mucous coagulating agents observed in wood smoke (Table 2.6).

Table 2.4 Comparison of Air Pollutant Emissions from Energy-Equivalent Fuels (in kilograms)

Fuel	Fuel equivalent to one million mega-joules delivered	Suspended particulate matter	Sulfur oxides	Nitrogen oxides	Hydrocarbon	Carbon monoxide
INDUSTRIAL						
Wood (70%)	80 metric tons	480	56	360	360	400
Coal (80%)	43 metric tons	2080	810	1180	6	45
Residual oil (80%)	33,000 litres	94	1310	240	4	20
Distillate oil (90%)	31,400 litres	8	1210	83	4	19
Natural gas (90%)	28,200 m^3	7	Neg.	99	2	8
RESIDENTIAL						
Wood (40%)	144 metric tons	2170	86	110	1450	18790
Coal (50%)	69 metric tons	520	1200	270	430	2380
Distillate oil (85%)	32,900 litres	11	1170	71	4	20
Natural gas (85%)	30,000 m^3	7	Neg.	38	4	10

Source: De Koning, et al., 1985

Table 2.5 Organic Substances Found in Wood Smoke Emissions

Dimethylbenzanthracene	Benzopyrenes
Benz(a)anthracene	Benzo-a-pyrene
Dibenzanthracene	Indeno(1,2,3-ed)pyrene
Dibenz(a,h)anthracene	Chrysene
Dibenz(a,c)anthracene	Dibenzopyrenes
Benzo(c)phenanthrene	Dibenzo(a,1)pyrene
Benzofluoranthenes	Dibenzo(a,h)pyrene
Benzo(b)fluoranthene	Dibenzo(a,e)pyrene
Benzo(j)fluoranthene	Dibenzocarbazoles
Methylcholanthene	Dibenzo(a,g)carbozole
3-Methylcholanthene	Dibenzo(c,g)carbazole
	Dibenzo(a,i)carbazole

Source: Cooper, 1980

Table 2.6 *Emission Factors for Cilia Toxic and Mucus Coagulating Agents Observed in Smoke and Flue Gas From Residential Wood Combustion*

Compound	Emissions (g/kg)	
	Stoves	Fireplaces
Formaldehyde	0.2	0.4
Propionaldehyde	0.2	---
Acetaldehyde	0.1	---
Isobutyldehyde	0.3	0.5
Phenol	0.1	0.002
Cresols	0.2	0.06

Source: De Koning, et al., 1984

TSP, CO and BaP were selected for monitoring because:

1. CO and TSP are designated as "criteria pollutants". BaP is well documented as a suspected carcinogen belonging to the family of polycyclic aromatic hydrocarbon (PAH).

2. Emisssions of TSP, CO and HC for residential fuelwood burning are considerably higher than those for fossil fuel (coal) burning.

3. Wood smoke literature in the developed countries has documented the emissions of CO, TSP and BaP, in case of wood heating stoves and fireplace emissions.

4. Availability of personal monitoring instruments for TSP and CO (East West Center) and permission from the Dept. of Agriculture Biochemistry to carry out, BaP analysis using HPLC (high performance liquid chromatography), the latest technology for BaP analysis.

5. Study by Aggarwal et al., 1982, and Smith et al., 1983, reported, Indian cook's TSP exposure from 4.3 to 58.6 mg/m^3 and BaP from 833 to 25,000 ng/m^3. These are very high concentration when compared to WHO recommended maximum 24-hour TSP levels of 0.2 mg/m^3.

2.4 BIOMASS GENERATED SMOKE (TSP, CO, BaP) AND HEALTH

Indoor open biomass fires can result in substantial quantities of pollutants due to incomplete combustion. Smith, 1987, has provided substantial evidence relating biomass smoke with respiratory infection and lung diseases amongst rural cooks. Table 2.7 summarizes epidemiological studies of possible health risks from the exposure to biomass smoke. Woolcock, 1967, attributed a prevalence of chronic bronchitis and cor pulmonale among the highlanders in Papua New Guinea (PNG). Sofoluwe, 1968 reported high levels of combustion generated pollutants in Nigerian homes of nearly 100 infants afflicted by bronchiolitis and bronchopneumonia. Hoffmann and Wynder, 1972; correlated indoor wood smoke to carcinoma of nasopharynx (NPC) among the highlanders of Kenya. Master, 1974 found a high prevalence of abnormal pulmonary signs in all age groups, both sexes and non-smokers of PNG. He concluded "the pathologic changes discovered suggest that air pollutants are the most important factor in the development of lung disease in New Guinea." However, Anderson, 1978, monitored respiratory abnormalities of 112 Highland school (PNG) children but was not able to find a significant correlation to woodsmoke exposures. Pandey and Ghimire, 1975 after conducting clinical examination of about 1800 heart patients in Nepal, reported high incidence of cor pulmonale and pointed at cigarette smoking and exposure to combustion related pollutants as important sources for this.

Table 2.7 (Page 1 of 3) Epidemiological Studies on Air Pollution from Biomass Combustion

Pollutant Concentration				Health Effects	Author
TSP mgm^{-3}	CO ppm	BaP ngm^{-3}	Place		
---	940	---	Lagos, Nigeria	Concentrations of CO, NO_2 (8.6 ppm, ave.) measured in the homes of 98 infants with bronchiolitis and bronchoneumonia. It was estimated that the infants were exposed to smoke from wood-fueled stoves for an average of 3 h/d.	Sofoluwe, 1968
0.6-2.0 5.0-10.0	21.3 (ave) 150.0 (peak)	---	Papua New Guinea	Wood smoke may be a factor in causation and / or maintenance of non-tubercular lung disease. Highlanders exposed to high concentrations of smoke and repeated chest infections have high incidence of chronic respiratory symptom and reduced ventilation capacity. But Anderson, in a comparative study of children exposed to wood smoke and those who were not, found no significant difference in symptoms.	Woolcock et al., 1967, 1970 Cleary & Blackburn, 1968 Anderson, 1978
0.3-7.8	---	12-291	Kenya	Positive association found between elevation and incidence of nasopharyngeal cancer, and between elevation and amount of PAH inside homes. But relationship between PAH and incidence of cancer still not clear.	Clifford, 1972 Hoffmann and Wynder, 1972

Table 2.7 (Continued, page 2 of 3) Epidemiological Studies on Air Pollution from Biomass Combustion

Pollutant Concentration				Health Effects	Author
TSP mgm^{-3}	CO ppm	BaP ngm^{-3}	Place		
---	---	---	India	Study of chronic cor pulmonale (heart disease secondary to lung disease) in Delhi between 1958-1974. Conclusion: Among women the cause of the disease was "damage to the lung from exposure to smokey cooking fuels from girlhood onwards, followed by repeated chest infections".	Padmavati and Arora, 1976
4.7-11.5	---	---	India	Women cooking with traditional fuels found to have a relatively high incidence of cough, Dyspoenea, and respiratory abnormalities.	INIOH, 1980
			Natal S.Africa	Study of acute lower respiratory tract disease found 70% of infants with wheezing, bronchitis, or pneumonia were exposed daily to smoke from cooking and/or heating fires. Only 33% of the 18 infants with no respiratory problems had such exposure. Conclusion: Wood smoke is a potent risk factor in development of severe lower respiratory tract disease in infants. Other factors normally thought to increase infant's risk such as social class, and sibling and parental symptoms may, in fact, be expressions of the same smoke-filled rooms.	Kossove, 1982

Table 2.7 (Continued, Page 3 of 3) Epidemiological Studies on Air Pollution from Biomass Combustion

Pollutant Concentration				Health Effects	Author
TSP mgm^{-3}	CO ppm	BaP ngm^{-3}	Place		
			Hill, Nepal	Crude and age-adjusted prevalence rates for chronic bronchitis significantly associated with increasing exposure to domestic smoke among female smokers and non-smokers and past smokers of both sexes. Conclusion: Domestic smoke is important contributing factor in development of chronic bronchitis in Hill region of Nepal.	Pandey, 1984
			Valley, Nepal	Study of effect of domestic smoke on respiratory function in 150 women in 30-44 age group. Lowered respiratory function noted as duration of exposure increased. Decline found to be statistically significant only among smokers.	Pandey, et al., 1984

Source: Smith, and Ramakrishna, 1986

Padmavati and Arora, 1976, reported similar problems among north Indian men and women patients based on a 15-year study. They attributed this to combustion generated air pollution in ill-ventilated kitchens. The 1980 annual report from the National Institute of Occupational Health in India reported high incidences of cough, cough with expectoration and dyspnoea among Gujarati women using traditional biomass fuel as compared to those using kerosene. Dary et al., 1981, found carboxy-haemoglobin levels above 2% in Gautamalan women cooking with biomass in poorly ventilated house. Kossove, 1982, attributed the presence of severe lower respiratory tract disease (Acute respiratory infection, ARI) in South African infants to combustion generated pollutant exposure, as it is customary for mothers to carry their infants while cooking with open fires. Pandey, et al., 1983, reported high incidence of ARI and suggested it to be an important cause of mortality and morbidity among infants less than a year old. Recently, Mumford et al., 1987, investigated the relationship between domestic fuel and lung cancer in Xuan Wei county of China, which has a high lung cancer mortality for non-smoking women. They found a link to lung cancer and domestic "smoky coal" burning but not to wood smoke or "smokeless coal".

2.4.1 TOTAL SUSPENDED PARTICULATES (TSP)

1. Mechanism

The mechanics, physics and chemistry of aerosols are described by Friedlander, 1977; Hinds, 1982; Hidy, 1984; and Spurny, 1986. Suspended particles in the atmosphere range in size from molecular clusters with diameters on the order of .001 um to dust particles of 100 µm or larger. This represents a variation of 10^5 in size and 10^{15} in mass. Generally only particles < 40 µm have sufficient atmospheric residence times or mass concentrations to be important. Very small particles grow rapidly by coagulation into the .1 to 1 µm range. TSP is normally distributed bimodally in mass around a minimum diameter of about 1 to 2 µm (Whitby, 1974). A nuclei mode may appear when the size distribution is measured very near combustion sources but is not normally evident elsewhere. The accumulation mode is between 0.1 to 0.4 µm. The coarse mode is 5 and 20 µm. Stevens, et al., 1978, noted that each mode consists of particulates from separate sources produced by independent mechanisms and composed of different materials. The accumulation mode consists of materials from combustion processes either as primary emittants or secondary products of gas to particle conversion (Dzubay and Stevens, 1975). The coarse mode contains predominantly soil products such as silica and calcium and reflects the local environment only. Smoke particles, e.g., of soot, are often very small and nearly spherical while dust particles are usually irregularly shaped, and may also aggregate.

Incomplete combustion of traditional fuels results in a mixture of particulates, gases, and vapors. Combustion generated pollutants change concentration and particle size distribution with volume and time and can go from solid to liquid and vice versa. Aerosol coagulation, one of the most important mechanisms modifying the size distribution, reduces the number-concentration and increase the mean size of the particles.

2. Health effects

The three most important characteristics of the aerosols affecting human health are particle size(size distribution), particulate concentration, and chemical composition. Undesirable health effects arise from deposition of aerosols in respiratory tracts. Ambient air concentration limits of particulates have been established such that lower levels should not cause biological damage to people exposed to them over a long period of time. OSHA (Occupation and Safety Health Adminstration) has set standards and exposure limits for different pollutants which the employers have to comply with.

The size of the particle is an important characteristic for determining it's source, and potential toxic affect (Whitby, et al., 1974). Characteristics of aerosols which could adversely affect health of exposed populations have been discussed in several documents. (Holland et al., 1979, Perera & Ahmed, 1979, Hinds, 1982, Friedlander et al., 1977 and Hidy, 1984). A knowledge of particulate size distribution is valuable in assessing the impact on health, since deposition of the particulates inside a human respiratory tract is largely size dependent. Fig.2.1 shows particle deposition in the lung as a function of size for spherical particles of a given density. For particles < 0.1 µm, diffusion produces a deposition rate inversely proportional to particle size, whereas for particles > 1 µm, gravitation produces a deposition rate which increase with size. Between 0.1 µm and 1 µm, deposition is at a minimum as these particles are too large to diffuse rapidly and too small to deposit rapidly due to gravity. Fig 2.2 shows the deposition sites as a function of particle size. For particle < 0.1 µm, deposition by diffusion increases in the lower respiratory system. For particles > 1 µm, deposition increases in the upper respiratory system. Respirable particulates (RSP) is defined as particulates of size < 2.5 µm. This size is defined by the aerodynamic diameter which is an important property characterizing filtration, respiratory deposition etc. (Hinds, 1982). The deposition sites of particulates in the human respiratory system is closely related to particle size. The physics of particle deposition in the respiratory tract is well developed (Brain, 1979; Lippmann, 1980; Heyder, 1980; Raabe, 1982; and Schreck, 1982). The Environmental Protection Agency, (EPA)

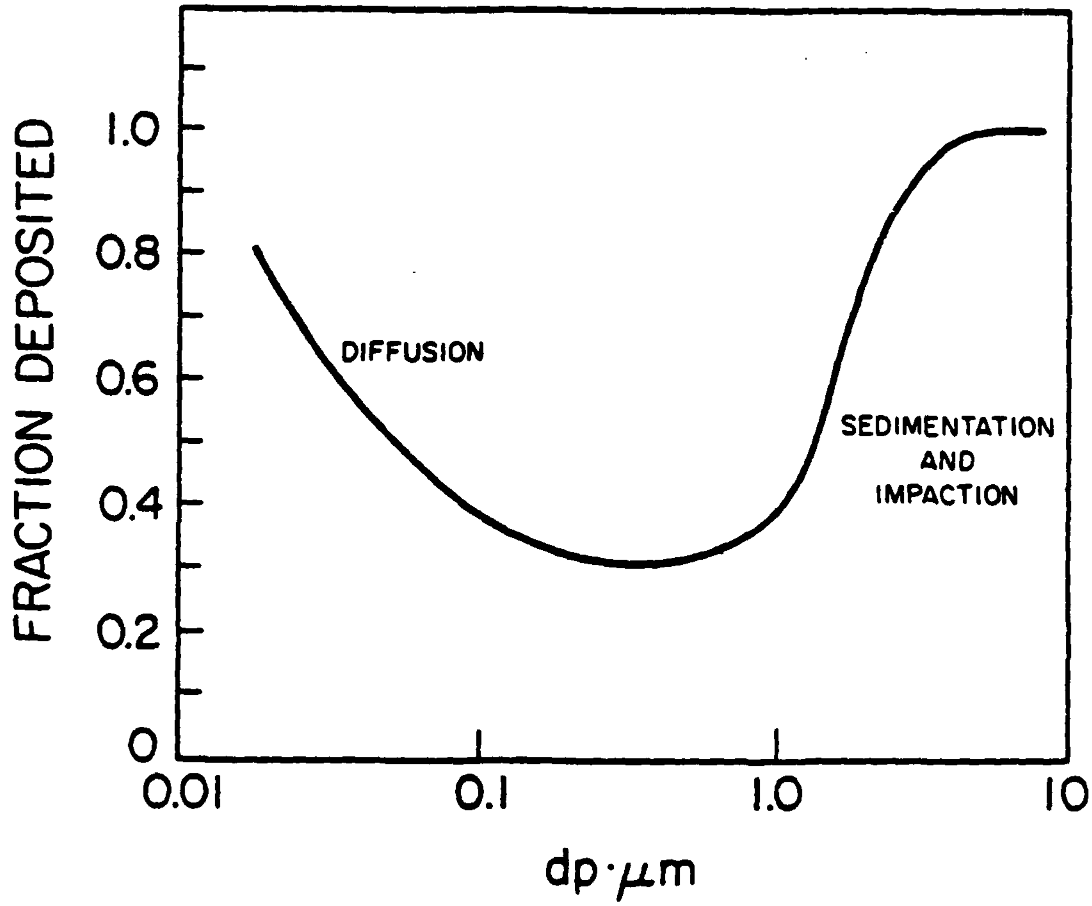

Fig. 2.1 Form of the efficiency curve for particle deposition.

Source: Friedlander, 1977

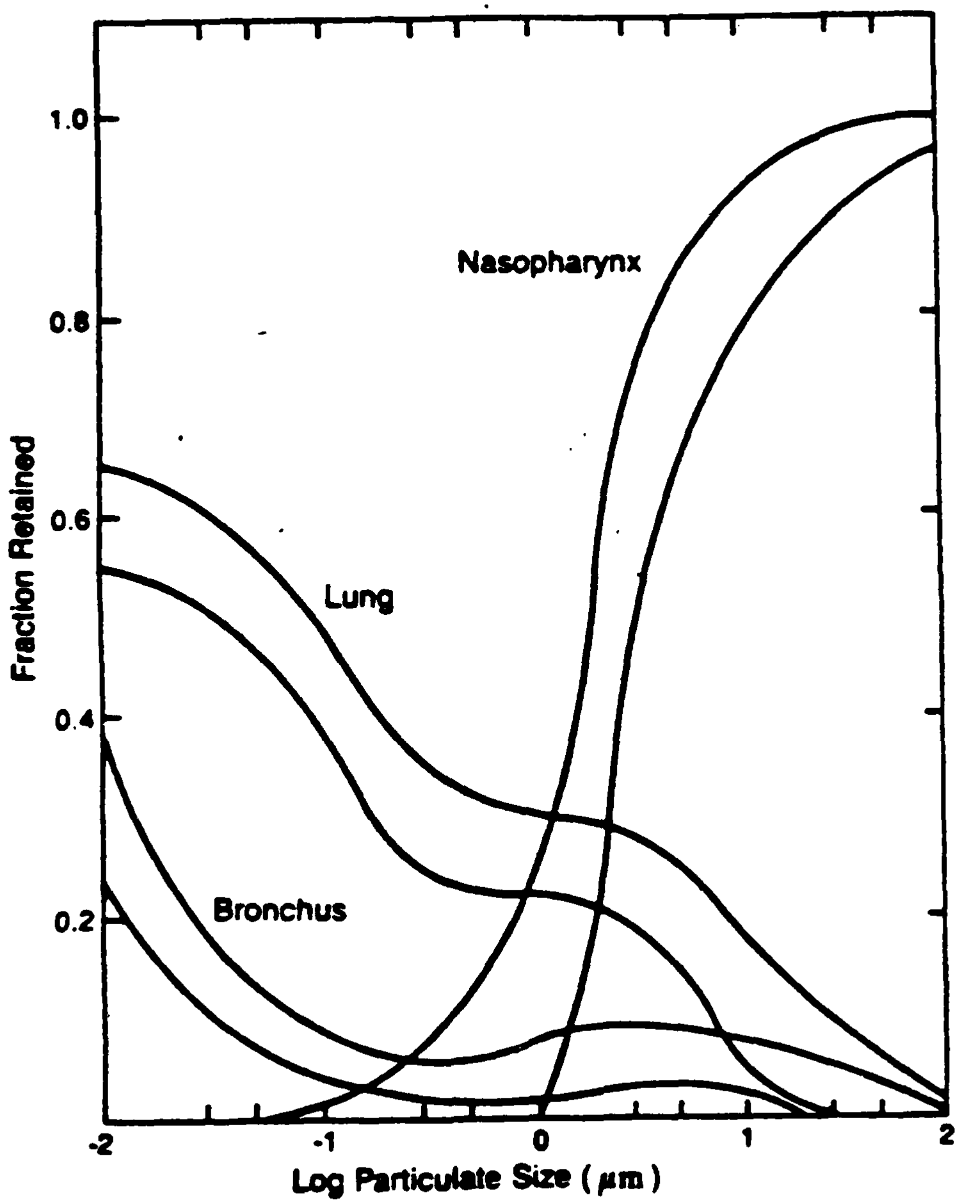

Fig. 2.2 Respiratory deposition of particulates according to size: 0.01-100 μm diameter

Source: Morrow, 1966 and USNRC, 1979

recently recognized the importance of particle size and site of deposition and converted the TSP standard to one based on particle (PM_{10}) less than 10 µm (U.S.Federal Register, 1984). Cooper, 1980, Butcher and Sorenson, 1979, DeAngelis et. al., 1980, found that the emitted particulates for fuelwood were entirely in the respirable size range (<10 µm). By convention, inhalable particulates, represent particulates sizes in the range 2-3 µm or more recently as <1 µm. Butcher and Ellenbecker, 1982 found 98.3% of the particulate emissions inhalable. Dasch, 1982, reported that woodsmoke consisted of spherical conglomeration, and ranging from 0.05 to 1 µm with a mass median diameter of 0.17 µm. Saucy et al., 1983 and Kamens, 1984, found woodsmoke particle size to be in the range of 0.1 to 0.2 µm, after aging in a teflon-walled chamber. Carrcll, 1977 reported 90% of the smoke from burning rice straw to be particulates with mass median size less than 2 µm. Hovever, Mumford, et al, 1987, reported only 6% of wood combustion-generated particles less than 1 um in diameter.

2.4.2 CARBON MONOXIDE (CO)

1. Mechanism

CO is a product of incomplete combustion with insufficient air or with the ignition and flame zone maintained at too low temperature by excess air. High moisture or organic-rich fuel will yield an excess of volatiles and a vapor/air mixture which will produce large emissions of CO, volatiles and particulates.

Poor physical arrangement of the fuels can also result in increased CO generation.

2. Health effects

CO is a colorless, odorless gas having serious debilitative health effects has been reviewed extensively by Smith, (1987). Prolonged inhalation, at high concentrations results in dizziness, physical weakness, headaches, and even ultimately death. The immediate result of CO exposure is lowering the blood's ability to transport oxygen to body tissues. This is because, hemoglobin, a constituent of the blood responsible for transporting oxygen, has an affinity for CO more than 300 times greater than that for oxygen. A rough guide of possible effects for exposures of less than a few hours proposed by Henderson and Haggard, 1943 is:

Hours x ppm < 300 (no perceptible effect)

Hours x ppm = 300-600 (just perceptible effect)

Hours x ppm = 600-900 (headache and nausea)

Arnow, 1981, reported that exposing sensitive human subjects (heart patients) to 50 ppm of CO for one hour raised COHb levels from 1.09% to 2.02%, and exercise tolerance was reduced. Stewart et al., 1970, reported no symptoms or changes in objective physiological measures when humans were exposed to levels below 100 ppm, mild sinus headaches after four hours of exposure to 200 ppm, and mild frontal headaches with nausea when exposed to 500 ppm for one hour. Goldsmith, 1970, reported that exposure to CO levels above 500 ppm results in observable physiological effects ranging from nausea, vertigo, dyspnea, cerebral misfunction to cardiovascular abnormalities.

Three important reasons why CO is a pollutant of great concern to women are (Dollar et al.,1982):

1. Women generally have less hemoglobin in reserve than men. One consequence of this difference is that women are more prone to anaemia than men. Another is that the negative impacts of CO may occur at lower doses than would be the case for men. (Weintrob, 1967)

2. During pregnancy, there is an additional demand on women's hemoglobin, further lowering their reserves. (Weintrob, 1967)

3. There is evidence from animal studies and studies of women who smoke that CO exposures can affect the unborn child. Reduced body weight at birth, for example, has been associated with such exposures. (Penny et al., 1980; Williams et al., 1977)

2.4.3 BENZO(a)PYRENE (BaP)

1. Mechanism

Polyaromatic hydrocarbons are hydrocarbons consisting of two or more benzene rings, usually referred to as Polycyclic Organic Matter (POM), Polycyclic Aromatic Hydrocarbons (PAH), or Polynuclear Aromatics (PNA). POM emission from natural sources is negligible. Principal POM emission sources include transportation, heat and power generation, burning of trash, and industrial processes. The POM species found in the atmosphere come invariably from combustion, mainly a by-product of incomplete combustion. POM can be formed in the combustion of fossil fuels or, more generally, compounds containing carbon and hydrogen. Fig 2.3 illustrates the mechanism of POM formation in the combustion processes (Badger, 1962) suggesting that polynuclear hydrocarbons are formed via hydro-carbon free radicals, which produced during pyrolysis, combine in a pyro-synthesis to the thermodynamically favored PAH. Consequently, higher yields of carcinogenic hydrocarbons and volatile phenols are emitted by the combustion of materials rich in aromatic hydrocarbons (Badger et al., 1958). Forest fires and slash burning can be expected to produce POM, but, there are no emission rates reported. Little is known about the chemical nature of POM containing particulates, or how POM is distributed with respect to size, or about their physical and chemical characteristics of POM as it ages in the atmosphere. The major portion of POM is presumed to be linked to particulates, since POM has high melting and boiling points. The very low vapor pressure of BaP (5.49×10^{-9} torr at $25^{o}C$), implys that little ambient BaP is present in the vapor phase. Commins, 1962, and Thomas, 1968, reported the presence of BaP in soot particles finding a constant amount of BaP per unit weight of soot. Demaio, 1966, reported that more than 75% of the weight of selected POM were associated with particulates less than 2.5 um in radius. NAS, 1972, reported that POM was highly reactive and degradable by photooxidation. The half-life is less than a day for the BaP degradation on the

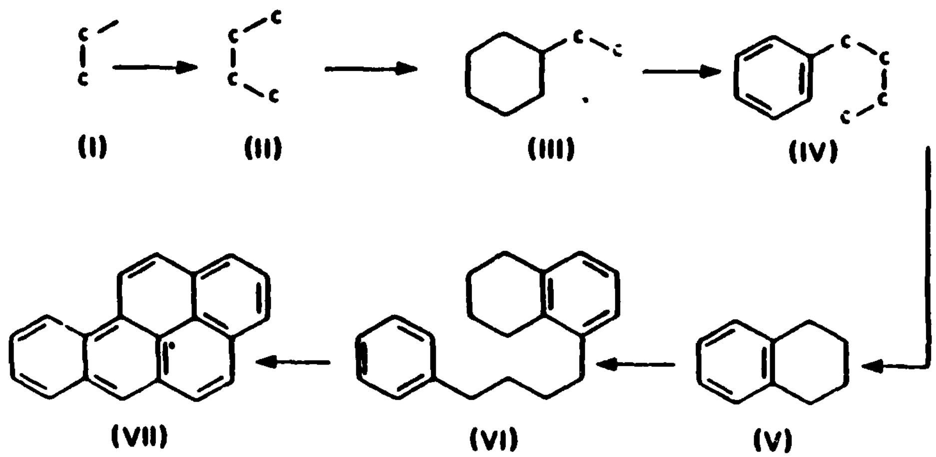

Fig. 2.3 Mechanism of Benzo(a)pyrene formation

Source: Badger, 1962

soot in the presence of sunlight (Thomas, 1968). In the absence of solar radiation, the half-life increased to several days (Falk et al., 1958). Katz, (1979) reported half-life of BaP less than couple of hours. Very little is known about the actual form of POM in the atmosphere.

Polycyclic organic matter in the atmosphere has been identified with particulate matter, especially soot. It is uncertain whether POM condenses out as discrete particles after cooling or condenses on surfaces of existing particles after formation during combustion (NAS, 1972).

BaP is used as an indicator of other POM because it is a known carcinogen, it has been studied and it is widespread (Santodonato, 1979, and Albert, 1978). Fossil fuel combustion was considered to be a major source of POM in the U.S. Hoffman, 1976, estimated the annual BaP emissions to be 900-1400 tons, mainly from coal-fired heat and power generation, followed by refuse burning, forest fires and coke production. USEPA (Super, 1985) now considers wood burning to be chief cause of POM in U.S. Most researchers have used BaP as an indicator of POM implying the presence of other components of similar structure despite the lack of proof of a relationship between benzopyrene and other compounds or the carcinogenic significance of other POM molecules. NAS, 1972, suggested BaP as an air pollution index, because it exists as solid in air, and as it is usually adsorbed on particles it can be filtered and collected. BaP concentrations in winter were

10-20 higher than summer at over 100 sampling sites in the U.S. (Sawicki, 1960). Stocks et al., 1958 and 1961, attributed PAH, benzo(a)pyrene, benzo(ghi)perylene, pyrene and flouranthene in garages and offices to improperly vented furnaces and incinerators, tobacco smoke, and leakage from the outdoors. Tobacco smoking is an important source of POM pollution e.g. Wynder et al 1968, showed in a room of size 40 m3, three smokers can produce BaP concentrations of 2 to 4 µg/m3 of the air and Galuskinova, 1964, reported BaP concentrations between 28 to 44 $\mu g/m^3$ from cigarette smoke in beer halls. Sawicki, 1960, 1962, 1965 reported in addition to benzopyrene, several other types of POM in the ambient air, viz., pyrene, anthanthrene, benz(a)anthracene, benzofluoranthenes, dibenzanthracenes, fluoranthene, and alkyl derivatives of these compounds. Hangebrauck, 1967, concluded that of the four fuels coal, oil, gas and wood, coal burnt inefficiently in hand fired furnaces produced most BaP Studies of combustion of biomass material and characterization of POM, are with the exception of cigarettes, few. Friedman, 1977, has found POM in smoke from leaf burning. Hall, 1980, and Cooper, 1980, measured emissions of various POM in smoke from wood burning. USDHEW, 1968, estimated an emission factor of 50,000 µg of BaP per million Btu from wood burning. Dasch, 1982, reported that BaP was almost exclusively associated with particulate emissions and not with gaseous emissions. Wolff et al., 1981, reported that one-third of the organic fine particulate matter in Denver aerosol could be attributed to wood smoke emissions. Muhlbaier, 1981, reports BaP emission factors of woodsmoke from fireplaces between 0.01 to 1.3 mg/kg for burn rates between 3.2 to 4.8 kg/hr. Studies by Katz, 1963; Zdrojewoski et al., 1967; Hoffmann & Wynder, 1968, and Cooke and Dennis, 1984, reported the majority of PAH in polluted air as coming from incomplete combustion of organic matter. There seems to be no published studies on PAH emission factors from burning traditional fuels in open cookstoves.

2. Health effects

BaP has been found to be carcinogenic in animals and it is suspected of being carcinogenic in man. Occupational exposures to PAH are well documented and provide sufficient evidence that lung cancer can be induced by inhalation. There are many studies (Hammond, 1958 and 1966, and Kahn, 1966) attributing human lung cancer to environmental factors, mainly cigarette smoke, which is known to contain polycyclic hydrocarbons, arsenic, nitrosamines, and polonium. Researchers indicate BaP, one of the well known carcinogen as a potential candidate for promoting lung cancer even though there are no studies linking BaP in cigeratte smoke to lung diseases. Particulate POM can be classified into two known animal carcinogens, PAH and their neutral nitrogen analogues the aza-arenes (e.g., indoles and carbazoles). Although POM represents only a very small fraction of the total amount of particulate matter associated with combustion, it is very important because of its potential hazard to humans. The degree of the hazard may be assumed to depend on the atmospheric particulate concentration. The first cited occupational disease related to the burning of fossil fuel occurred in 1775, when Percivall Pott, a doctor in London, reported a prevalence of cancer of the scrotum in chimney sweeps and attributed it to their constant exposure to soot. In no instance has exposure to a specific PAH been proved to cause tumor in man, though BaP has been demonstrated to be carcinogenic in experimental animals (Epstein, 1966, and Leiter, 1942). Falk et al., 1958, investigated "leaching" of PAH in human tissues, and suggested a possible route of degradation. Goldsmith, 1968, and Royal College of Physicians, 1970, demonstrated that BaP is irritating to the lungs of experimental animals only at high dosages, while Ishikawa, 1969, showed that the severity of diseases like emphysema are closely correlated with urban pollution levels but the role of POM cannot be ascertained from his data. Falk, 1964, gives a convincing discussion indicating BaP as a carcinogen for man but NAS, 1972, suggested caution in accepting BaP as a major carcinogen at the levels of atmospheric concentrations, based upon findings by Freeman et al., 1971, who concluded BaP from particulates collected in the ambient city air accounted for less than 1% of carcinogenic activity of the air.

Moller, 1980 and Daisy, 1986, showed air particulate extracts to exhibit mutagenic activity using the Salmonella test. BaP's role as a mutagen suspected by Tomingas, 1977, and Carnow, 1973 was disproved by Lofroth, 1978, Chrisp, 1978, Jager, 1978 and Pitts, 1978 who showed nitroaromatic compounds to be mutagenic. Ramdahl, 1982 demonstrated the presence of nitrocompounds and oxygenated polycyclic compounds in emissions from biomass combustion. Dasch 1982, Ramdahl et al., 1982, and Alfheim, 1984, showed low direct-acting mutagenic activity of the particulate extracts from wood smoke. Kamens et al., 1984 reported a substantial increase in direct mutagenic activity of wood smoke when reacted with NO_2 and O_3 in the dark. He, 1985 reported that the PAH fraction of particulates accounted for only a small fraction of the total mutagenic activity in both the reacted and unreacted wood smoke. Above references focus on the PAH in the particulate matter only. Recently Kleindienst, 1986, demonstrated that both the gas and the particulate phase components of wood combustion show little direct-acting mutagenic activity, but when mixed with NO_x, their activity increased significantly.

2.5 REVIEW OF STUDIES RELATED TO INDOOR MONITORING OF COMBUSTION GENERATED POLLUTANTS EMITTED FROM COOKING STOVES USING TRADITIONAL FUELS.

The studies mentioned in Table 1.2 are reviewed to familiarize the reader with reported methods, sampling protocols, and specific indoor biomass combustion generated pollutant levels, in the few of existing studies. They have been classified as area or personal, depending on their sampling protocol. Smith (1983), demonstrated the need for personal monitoring when cook's exposure to combustion-generated pollutants needs investigation. Some researchers used Hi-Volume sampler to collect TSP samples, whereas, others used personal samplers fixed at some site. None of the studies reported simultaneous sampling for measurement of TSP, CO and BaP. This study carried out area and personal monitoring for TSP, CO and BaP.

Sofoluwe, 1968, investigated pollution from cooking fires in the homes of 98 infants suffering from bronchiolitis and bronchopneumonia in Lagos, Nigeria. CO levels (Table 2.8) ranged from 100-3000 ppm, with average value of 940 ppm, NO_2 from 0.5-50 ppm with average value of 8.6 ppm, SO_2 from 5-100 ppm with average value of 37.8 ppm and Benzene (C_6H_6)ranging from 25-200 ppm with average value of 85.6 ppm. Maximum value of CO appears questionable. Average duration of exposure of

Table 2.8 Concentration of Toxic Gases in Smoke in Houses in Lagos, Nigeria

Gases	Total No. Tested	Positive Number	%	Negative Number	%	Range of Conc. (ppm)	Mean Conc. (ppm)*
Carbon monoxide	46	46	100	---	---	100-3000	940.2
Nitrogen Dioxide	44	22	50	22	50.0	0.5-50	8.6
Sulfur Dioxide	46	43	93.5	3	6.5	5-100	37.8
Aromatic Hydrocarbons(as benzene)	46	33	71.7	13	28.3	25-200	85.6

Source: Sofoluwe, 1968 * Zero values excluded in calculations of mean concentrations the children to the smoke was estimated at 3.2 hrs per day ranging from 1.3 to 9 hrs per day. Infants that were exposed to smoke while carried by their mothers on the backs or laps while cooking over open fuelwood fires. There was prevalence of open shed community kitchen, where as many as 8 mothers cooked simultaneously. 65 of the mothers used fuelwood, 39 kerosene, 7 coal, and 10 gas. The method and sampling protocol were not reported explicitly except that samples were taken at convenient times during cooking.

Cleary and Blackburn, 1968, reported high night time values of smoke, formaldehyde and CO concentrations from open wood fires used for indoor space heating at breathing height of people sleeping inside thatched roof huts in Pompomere, in the Eastern highlands of Papua New Guinea, 7,200 ft above sea level and at Baiyer River, in the Western highlands between 4000 to 5,200 ft. above sea level. A high prevalence of chronic non-tuberculous lung disease among the natives of the Eastern highland was attributed to high indoor concentration of smoke from open fires burning continuously during the night time. The roofs of the huts in the Eastern highland were lower than those of the Western highlanders. Another difference was that Western highlanders slept on the floor, while Eastern highlanders slept on bamboo shelves about one and half feet above the ground level, resulting in a difference in concentrations. TSP grab samples were collected three to five times during the night. Six huts in the Western and 3 in the

Eastern highlands were monitored. Average concentrations at Pompomere for TSP was 843 $\mu g/m^3$ (Range 0-4.8 mg/m^3), HCHO 1.23ppm (Range 0.3-3.8 ppm) and CO 30.5 ppm (Range 10-150 ppm). At Baiyer river they were 359 $\mu g/m^3$ (Range 0-1.25 mg/m^3), 0.67 ppm(Range 0.1-1.9 ppm) and 11.3 ppm (0-60 ppm). A boundary between a more dense upper smoke layer and a lower layer with comparatively less smoke (3 to 4 ft. above ground level) was noted. Smoke density was determined optically.

Higher levels of the pollutants in Pompomere were attributed to

1. Lower roofs
2. Samples collected at higher level (18" above the floor)

Hoffman and Wynder, 1972, and Clifford, 1972, measured TSP, BaP, BaA phenols, and acetic acid in 8 Kenyan huts at different altitudes, Table 2.9. The air volume sampled was 93,446 liters and 105,050 liters. The sampling instrumentation, duration, flow rate, location of the sampling port with respect to the source, or the method used for the chemical analysis of PAH were not reported but they probably monitored continuously for a few days at 10 to 20 liters per minute, the usual rates for HI-Volume samplers. Huts of the mountain tribes had smaller volume and wood fires burned more continuously as compared to huts of coastal tribes. The difference in hut size and fuel usage pattern was attributed to an increased prevalence of nasopharynx cancer among the natives

Table 2.9 Chemical Analytical Data: Situations Analyzed During Cooking in Huts

Geographic Location	Ethnic Group	Tribe & Hut No.	Sample Size@	TPM# mgm^{-3}	TOM* mgm^{-3}	BaP ngm^{-3}	BaP/TSP $\mu g/g$
Mountain	Bantu	Nyeri 2	A	7.8	6.8	166	21
Mountain	Bantu	Nyeri 3	A	2.7	2.6	85	31
Coast	Bantu	Wadigo 1	A	1.5	0.8	24	16
Coast+	Bantu	Wadigo 1	B	0.3	0.3	0	0
Mountain	Nilo-Hamitic	Nandi 1	B	4.1	2.8	291	71
Mountain	Nilo-Hamitic	Nandi 2	B	5.6	3.9	140	25
Central-Plateau	Nilo-Hamitic	Samburu	A	2.6	1.0	37	14

@ Total Sample Size A=3,300 ft^3 = 93.5 m^3, B=3,710 ft^3 = 105 m^3

TPM = Total Particulate Matter Collected, *TOM = Total organic matter extracted

+ Sample collected in the bedroom adjacent to kitchen

Source: Hoffmann and Wynder, 1972

in the mountains. TSP ranged from 1.5 to 7.8 mg/m^3, BaP from 0 to 291 ng/m^3, BaA 16 to 515 ng/m^3, phenols 0.78 to 1.19 $\mu g/m^3$ and acetic acid 5.05 to 8.82 ug/m^3.

Anderson, 1978, used a portable air pump and filters, to conduct indoor sampling in six Papua New Guinea houses with volumes ranging from 40 to 80 m^3. TSP levels ranged from 0.8mg/m^3 to 11.2 mg/m^3 in early evening, when samples were taken at sitting or squatting levels. Late evening samples in sleeping area were mostly below 1mg/m^3. Concentrations in the sleeping area between 6.00pm and 4.00am ranged from 0.57 to 1.98 mg/m^3.

Dary et al., 1981, studied ill-ventilated houses in two Guatemalan communities at different altitudes. 200 randomly selected houses were classified according to wall materials, number and size of doors and windows, presence of chimney and good or bad kitchen ventilation. In the lower altitude village, 71% of the houses had good ventilation, whereas in the higher elevation only 30% had it. Gas chromatography was used to analyze CO in the grab samples taken one meter from the fire and at a height of 1 meter above the floor. The time of sampling was not mentioned. Higher CO levels (30-50 ppm) were found in poorly ventilated kitchens in both the villages. Ventilation significantly reduced CO at the time of maximum cooking. Blood samples for 208 women taken during the period of maximum smokiness showed higher levels of HbCO for women living in poorly ventilated houses in both the villages. Grut et al., 1970, and Wright et al., 1975, mention several countries that have set 32-40 ppm as the safe levels of one-hour exposure to CO. Stewart, 1970 found HbCO levels above two percent to be associated with an increased incidence of cardiac disease. Dary suggests that HbCO levels between 1.5 to 2.5 percent which can, cause respiratory and eye diseases in the children could be due to CO exposure for infants were constantly carried on their mother's back.

Aggarwal et al., 1982, monitored TSP and BaP in 16 urban kitchens in Ahmedabad,in Western India, where biomass is used for cooking (Table 2.10). Mean TSP (mg/m^3) exposure of the cooks using wood was 7.2, cattle dung 16.0, cattle dung plus wood 21.2, and coal 26.1 mg/m^3. Corresponding values for BaP were 1300, 8200, 9300, and 4200 ng/m^3. In addition to concentration they reported, the ratio of BaP to TSP and demonstrated it's usefulness in identifying the sources. The mean BaP to TSP ratio for wood and dung smoke ranged from 200 to 600 μg/gm. TSP and BaP concentrations reported are possibly the highest ever recorded in any part of the world. They used a HI-Volume sampler 1.5 m above the floor for 15 minutes during the morning and evening cooking period and the flow rate was 0.8 m^3/min. It seems possible that the sampler flow induced air currents dislodging soot deposited on the roof and resuspended loosely packed fly-ash, dust and soot from the walls and floor. The thermal draft carrying the soot and fly-ash directly from the fire might also have been directed

Table 2.10 Average BaP Concentration Near Breathing Zones of Domestic Housewives Using Different Local Cooking Fuels

Type of fuel	No. of houses surveyed	BaP (ng/m^3)	TSP ($\mu g/m^3$)	BaP/TSP ($\mu g/gm$)
Wood	5	1,270 (963-1,683)	7,203 (4,711-11,460)	188 (147-219)
Cattle Dung	4	8,248 (4,171-13,580)	15,966 (9,590-20,036)	560 (208-743)
Cattle dung + Wood	7	9,317 (833-25,653)	21,165 (9,968-58,577)	534 (71-1,668)
Coal	3	4,207 (488-10,820)	26,147 (4,119-48,174)	273 (224-321)

Source: Aggarwal et al., 1982

towards the sampler. Combustion conditions and emissions might also have been affected by the forced sampler air flow. It seems therefore questionable what they monitored should be interpreted cook's personal exposure. Ventilation conditions and building material of the kitchens were not mentioned nor was a precision value for the BaP analysis.

In the simulated village hut on the East West Center grounds, Dollar et al., 1982 measured CO using a sequential sampler in line with an Ecolyzer model. They found increasing levels of CO with heights, similar to Cleary and Blackburn (1968).

Smith et al., 1983, monitored exposures of women cooks to TSP and BaP in 36 households in four west Indian villages during the morning and evening cooking periods. Personal samplers were worn by the cooks during the complete cooking duration, or to a maximum of 45 minutes. The samplers drew 1.7 to 3 liters of air per minute through a closed-face mode filter cassette holding a pre-weighed 37mm glass fiber filter. The filter cassette was hooked to the cook's collar and so drawing the air in the breathing zone. BaP was determined using an Aminco Bowman Spectrophoto-flourometer with an excitation/emission wave length of 405 nm. A mean TSP concentration of 7 mg/m^3, a mean BaP concentration of 4000 ng/m^3 were found and a mean BaP to TSP ratio of 900 $\mu g/gm$ (Table 2.11). Of the 36 houses sampled 13 were classified as pucca (constructed of durable materials,such as brick and

Table 2.11 Summary of Household Data and Measured Concentrations

	Mean	Range	Std. dev.	Number in sample
Family				
Size				
Kuccha	6.4	3-15	2.7	23
Pucca	6.2	2-9	2.0	13
Income (rupees)				
Kuccha	4050 ($435)	600-15000	2940	23
Pucca	10820 ($1160)	3000-21500	5600	13
Age(years)				
Of cook	33	13-57	10	36
Began cooking	13	10-16	1.6	36
Cooking				
Fuel use (kg)				
Per day	6.5	2.5-11	1.9	36
Per hour	1.9	0.5-4.3	0.8	65
Size of kitchen (m^3)	42	8-100	19	36
Time (h)				
Cooking	2.8	1.5-5	0.9	36
Other use of chula	1.7	0.5-3.5	0.8	36
Indoor Conc.				
TSP (mgm^{-3})	6.9	1.1-56.6	7.5	65
BaP (ngm^{-3})	3900	62-19284	3600	65
BaP/TSP (μgg^{-1})	860	10-8439	1200	65
Ambient Conc.				
Height of measurement(m)	2.5	1.5-3.5	0.7	5
Time of day	6.30 pm	5.50-7.00pm		5
TSP (mgm^{-3})	1.5	0.5-2.5	0.8	5
BaP (ngm^{-3})	230	107-410	110	5
BaP/TSP (μgg^{-1})	190	70-560	170	5

Source: Smith, et al., 1983

cement) and 23 as kucha (constructed of thatch and mud) houses. A cross-section of different house types were sampled with various kitchen types and stove types. The socio-economic conditions, family size, cook's age and number of years of cooking, and amount of fuel used were noted as was the ventilation and kitchen volumes. Annual doses of TSP and BaP was estimated for a variety of exposure conditions and they reported cooks receiving a larger dose of pollutants than the residents of the dirtiest urban environments.

Dave, 1984, found SO_2 levels between 882 and 1390 $\mu g/m^3$, NOx from 43.8 to 47.4 $\mu g/m^3$, TSP from 78.5 to 157 $\mu g/m^3$ and BaP from 14 to 23 ng/m^3 in Calcutta kitchens and huts where the cooks used bituminous coal.

Patel et al., 1984, monitored SO_2, NO_2 and TSP in 125 households in Gujarat, India using traditional and modern fuels. Coal was included in the category of traditional fuels. Besides air quality test, Pulmonary functional tests (PFT) of housewives, 160 that cooked with traditional fuel and 89 that used modern fuel, were carried out. Cooks using traditional fuels were at greater risk to develop pulmonary disorders as their PFT values were significantly lower. Excluding coal might have changed this conclusion as it is well documented as a dirty fuel. Table 2.12 shows that the highest level of SO_2 in the air occured for cooks using coal, with a mean of 1682 mg/m3 while fuelwood/cowdung and modern fuel users experienced considerably lower values, 156-253 μg/m3. The highest levels

Table 2.12 Levels of Air Pollutants Observed and Types of Fuels used at Cooking Places

Types of Fuels	Number of Samples (n)	Levels of air pollutants (mean±s.d)		
		SO_2 (μg/m^3)	NO_2 (μg/m^3)	SPM (mg/m^3)
Dry animal dung	32	234±247	138±310	18.3±19.4
Wood	22	156±166	312±412	15.8±18.3
Wood and dry animal dung	22	253±229	321±451	18.4±15.1
Wood charcoal	10	83±39	75±39	5.5±5.4
Coal	14	1682±2096	166±161	24.9±21.2
Modern fuels	25	201±266	422±375	0.9±1.4

Source: Patel, et al., 1984

of NO_2 (mean 422 $\mu g/m3$) were associated with modern fuels. TSP levels were largest (mean 24.9 mg/m3) for coal but comparable to wood/cowdung (15.8-18.4 mg/m3). Indoor use of a Hi-Volume sampler might have as with Aggarwal, 1982 study, resulted in unrealistically high readings.

Smith et al., 1984 reported preliminary results of TSP in SVH using QCMCI. Detailed results are presented in this dissertation.

Davidson et al., 1986, sampled indoor and outdoor air in several villages in Nepal, where biomass fuels was used for cooking and space heating. Indoor levels of TSP ranged from 3 to 42 mg/m^3 and respirable particulates from 1 to 14 mg/m^3. Outdoor TSP had a mean of 0.3 mg/m^3. Sampling lasted for 1 to 2 hrs at a rate of 2 liters/min. Simulating the cook's exposure indoor TSP was collected on Teflon filters (37mm) 0.7m above the floor and 1m from the stove. Reid, et al., 1986 measured personal exposures to TSP for 60 cooks in Middle Hills in Nepal and conducted stationary monitoring of CO inside kitchens with regular or improved stoves with flue. Both TSP and CO exposures were significantly reduced for improved stoves from mean TSP and CO levels of 2.6 mg/m3 and 240 ppm for ordinary chulas to 1.1 mg/m3 and 67 ppm for improved chulas.

Mumford et al., 1987 associated indoor air quality in Xuan Wei County of China with highest lung cancer mortality in the counties attributing it to indoor burning of "smoky" coal as opposed to wood or "smokeless" coal. Higher concentrations of submicron particles containing mutagenic organics were found in smoky coal emission than in that from wood or smokeless coal. Hi-vol samplers with size selective inlet measured mean TSP levels of 20 mg/m3 for households burning smoky coal/wood while in smokeless coal households it was 2 mg/m^3. Organic dissolved particulates were analyzed for PAH using GC/MS and tests for assessing mutagenicity of organic extracts and fractions were carried out.

III. RESULTS AND DISCUSSION

3.1 RESULTS OF THE EXPERIMENTS PERFORMED IN SVH

The results of experiments performed in SVH from fall 1982 to spring 1983 are discussed in the following paragraphs.

The objectives were:

1. Determine particle size distribution in wood and dung smoke
2. Determine particle size variation with burn time
3. Determine variation of TSP and CO concentration with burn time
4. Determine the effect of fuel type, ventilation condition, and sampling location on TSP, CO, and BaP concentrations
5. Summary of results and recommendations for field experiments.

All material/method (listed below) used in SVH / Ag.Biochemistry / Animal Sciences laboratory are discussed in Appendix (A.1 to A.9), Menon (1988).

1. Fire lighting
2. Filter weighing
3. Filter cassette preparation
4. Pump flowmeter calibration
5. Fuel-supporting measurements (Ash, Moisture and Calorific value)
6. Ambient measurement for TSP
7. Particle-size of combustion generated particulates
8. Spatial TSP and CO measurements in SVH
9. Chemical analysis for BaP

3.1.1 PARTICLE SIZE DISTRIBUTION OF WOOD AND DUNG SMOKE

Appendix A.7 (Menon,1988) presents method, data and statistics for ten SVH experiments where smoke samples were collected by a 10-size stage Quartz Crystal Mass Cascade Impactor. The ten experiments were grouped into five categories (Table 3.1) according to fuel type, ventilation condition and sampling location.

Table 3.2 presents a summary of the data listing for each category the range (in brackets) and average particle size (Am & Gm) for TSP concentration.

Representative TSP concentrations are plotted in two ways as functions of particle size:

1) <u>Cumulative mass (%) of TSP versus particle size on log probability paper</u>. Such plots are commonly used since if the particulate concentration is log-normally distributed, as is often found, the distribution will be straight line. Representative data for beginning, middle and end of a burn for wood and dung smoke is plotted in Fig 3.1. As can be seen these data are poorly described by a straight line and thus not log-normally distributed. This conclusion holds for all the data in Appendix A.7 (Menon, 1988).

2) <u>Mass per impactor stage divided by the log of the size interval of the stage (dM/dlogD) versus the log of the size interval of the stage (dlogD)</u>. These plots, known as generalised histograms, dM/d(log dp) plots or Lundgren plots,

Table 3.1 Fuel, Ventilation and Burn Parameter in Simulated Village Hut for the Quartz Crystal Mass Cascade Impactor Experiments

S.NO	Fuel	Burn Period (min)	Burn Rate (kg/hr)	Ventilation* Type	Sampling** Height	Category***
1	Wood	65	0.8	1	H	One
2	Wood	59	1.7	1	H	One
3	Wood	65	0.7	1	H	One
4	Wood	60	1.1	1	H	One
5	Wood	60	1.0	2	H	Three
6	Wood	63	1.0	2	L	Four
7	Dung	72	0.9	1	L	Five
8	Dung	7	0.8	1	H	Two
9	Dung	58	0.9	1	H	Two
10	Wood	62	2.1	1	H	One

*1: Only door open
2: Door and window open

**H: 1.6 m above floor
L: 0.6 m above floor

***One: Fuel: wood, Ventilation:1, Sampling site: H
Two: Fuel: dung, Ventilation:1, Sampling site: H
Three: Fuel: wood, Ventilation:2, Sampling site: H
Four: Fuel: wood, Ventilation:2, Sampling site: L
Five: Fuel: dung, Ventilation:1, Sampling site: L

Table 3.2

Average and Range[@] of TSP (mg/m^3) and Size (Am and Gm)* of Combustion Generated Particulates for Different Experimental Setup During the Quartz Crystal Mass Cascade Impactor Experiments in the Simulated Village Hut

Experimental** Category	Background TSP Conc. (mg/m^3)	TSP Conc. (mg/m^3)	% Fine TSP***	Am (µm)	Gm (µm)
I	0.07 (.04-.12)	3.28 (.2-10.5)	91 (86-97)	0.93 (.16-6.88)	0.18 (.08-1.36)
II	0.14 (.05-.24)	17.7 (3.1-41.6)	93 (89-97)	0.88 (.23-3.72)	0.20 (.11-.42)
III	0.10	2.5 (0.4-4.3)	99	0.60 (.14-1.20)	0.16 (.09-.33)
IV	0.05	1.1 (0.3-3.0)	84	0.91 (.44-2.90)	0.19 (.13-.31)
V	0.09	2.6 (1.8-3.8)	95	0.41 (.20-0.70)	0.14 (.11-.20)

@ Range values in brackets
* Am: Arithmetic mean & Gm: Geometric mean

**I: Fuelwood, only door open & sampler 1.6 m above floor
II: Cowdung, only door open & sampler 1.6 m above floor
III: Fuelwood, door & window open, & sampler 1.6 m above floor
IV: Fuelwood, door & window open, & sampler 0.6 m above floor
V: Cowdung, only door open, & sampler 0.6 m above floor

***Percent of total mass in stages 5-10 (< 3.2 µm in size)

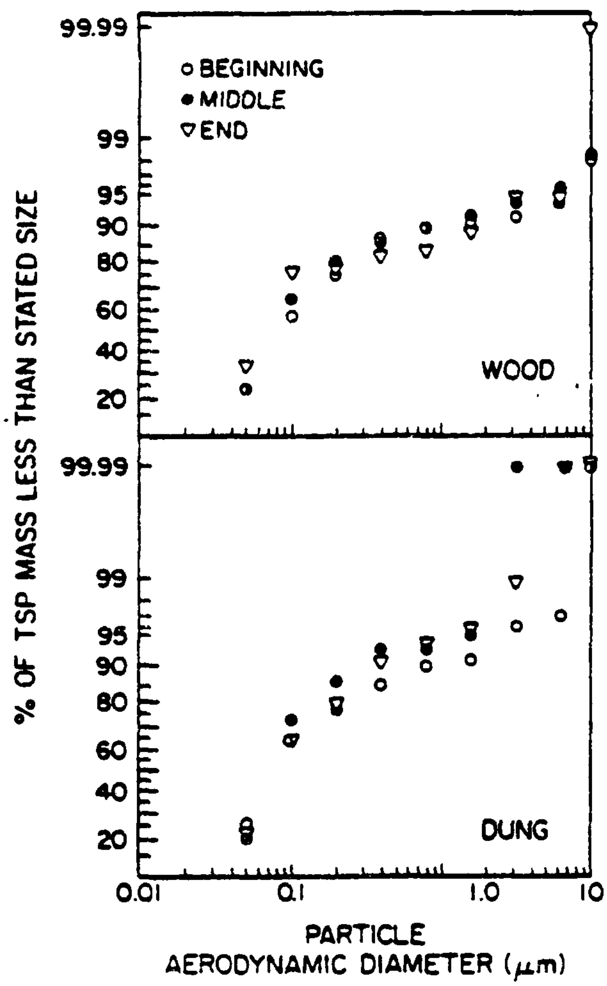

Fig. 3.1 Typical log probability plot of particle aerosol size for wood and dung smoke. (Simulated village hut, November, 1982)

Sampler: Quartz Crystal Micro-balance Cascade Impactor

have been used by several researchers viz., Miguel and Friedlander, 1978, Van Vaeck, 1978, Raabe, 1982 and Knutson and Lioy, 1983. Unlike statistical histograms, which have size classes of equal width, the generalised histogram have size classes which are not necessarily of equal width. The area, and not height, of the histogram is proportional to the mass of the TSP in the size range. Examples of such plots for dung and wood smoke are given in Fig 3.2 which show that both wood and dung smoke distributions are unimodal, have similar shapes and peak in the same size range (0.1 to 0.2 µm) despite almost order of magnitude different in concentration. The average geometric mean particulate size for all ten experiments was 0.17 um, for both wood and dung smoke (Table 3.1). This result is similar to Dasch's (1982) of 0.17 µm MMD for wood smoke sampled from fireplaces. Similar results have been reported by Carroll, 1977, Butcher, 1982, and Saucy, 1983, who have analyzed for wood/biomass smoke particle sizes.

Conclusions:

1. The cumulative mass of dung and wood smoke are not log-normal distributed.
2. The average geometric mean for dung and wood smoke particle size is 0.17 µm.

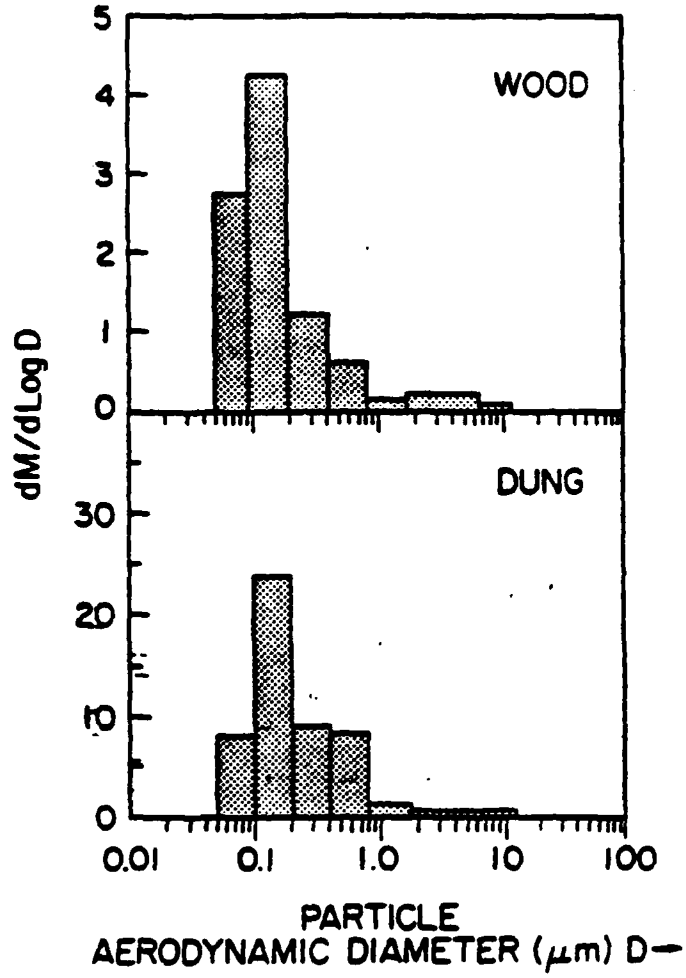

Fig. 3.2 Typical generalized histogram plot of aerosol particle size for wood and dung smoke. (Simulated village hut, November, 1982)

Sampler: Quartz Crystal Micro-balance Cascade Impactor

3. Dung and wood smoke have unimodal size distributions similar in shape and both peak between 0.1 to 0.2 µm though total mass is an order of magnitude larger for dung smoke.

3.1.2 VARIATION OF PARTICLE SIZE WITH BURN TIME

Data from Appendix A.7 (Menon,1988) were plotted in two ways to illustrate the variation of particle size with burn time.

1. Mean size versus time. Fig 3.3 shows typical plots of mean wood and dung smoke particle size versus burn time. The variation in mean particle size is large ranging from 0.16 to 1.7 um for wood and from 0.23 to 3.72 µm for dung. The fluctuations may be due to varying combustion intensity in the uncontrolled open fires.

2. Percentage mass less than 3.2 µm versus time. Fig 3.4 shows typical plots of these wood and dung smoke percentage (stages 5-10 of the QCMCI) versus time during the burn. Between 84 and 99 percent of the total particulate mass in wood and dung smoke fell in this range . This limit, which corresponds to particles of 2 g/cm3 with aerodynamic diameters .05-3.2 µm (50% cutoffs), is roughly equivalent the upper limit of "fine particulates", FP of 2.5 µm. FP are of particular concern because of the relatively high fraction that can penetrate deep into the lung. Thus, it is not necessary to

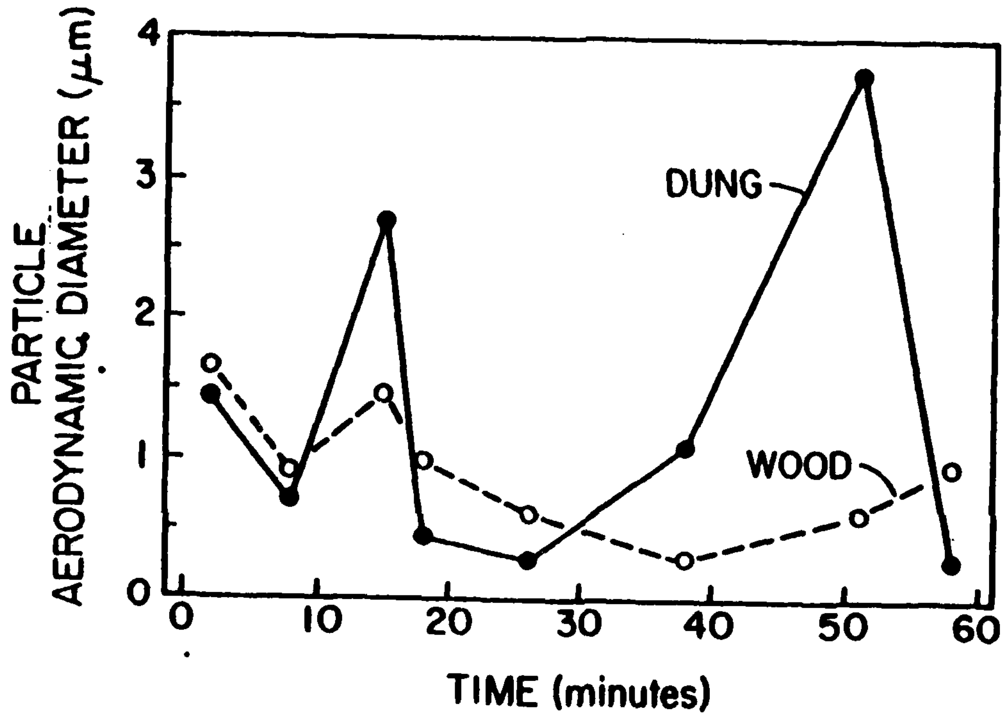

Fig. 3.3 Typical variation of particle size (arithmetic mean) with burn time for wood and dung smoke.

Sampler: Quartz Crystal Micro-balance Cascade Impactor (Simulated village hut, November, 1982)

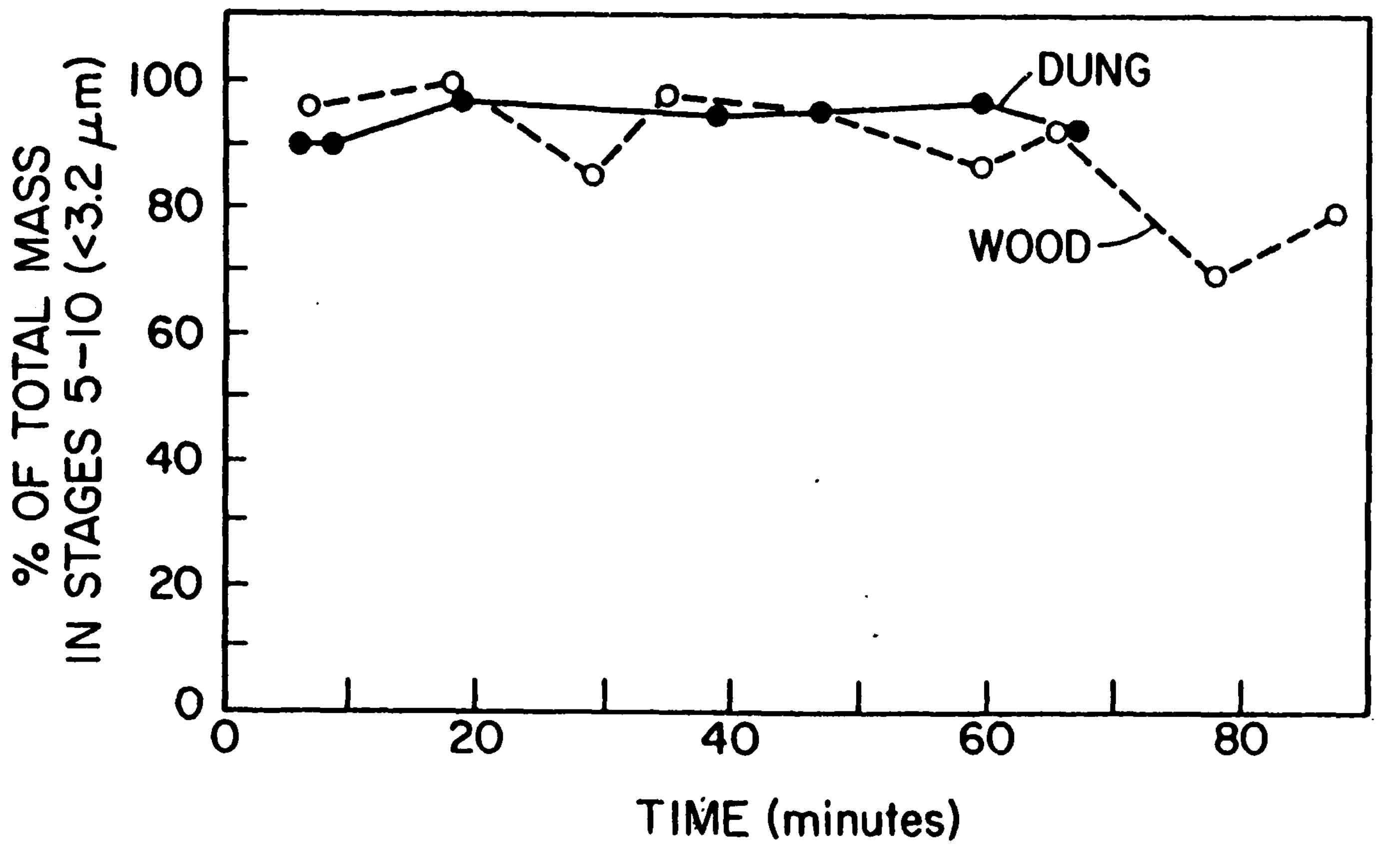

Fig. 3.4 Respirable fraction of combustion generated particulates sampled during typical cooking period in simulated village hut. (November, 1982)

Sampler: Quartz Crystal Micro-balance Cascade Impactor

segregate smoke particles on the basis of size as they are essentially all in the respirable range and therefore miniature cyclones, which have been extensively used in conjunction with personal sampling, are superflous.

Dasch (1982) also found that majority of particulate mass (83-90%) in wood smoke to be smaller than 0.5 µm. However, recently Mumford et al (1987) reported that 94% of wood combustion generated particulate sizes to range between 1 and 30 um. This discrepancy in particle size distributions may be due to the long period of integrated sampling necessatited by Mumford using personal sampler which might have resulted in agglomeration of the particulates and size increase.

Conclusions :

1. Particulate mean size for wood and dung smoke fluctuate substantially during the cooking period.
2. 84 to 99 percent of the total particulate mass in wood and dung smoke was in size range 0.05 to 3.2 µm during the burn cycle. This eliminates the need for particle size discriminating sampling.

3.1.3 VARIATION OF TSP AND CO CONCENTRATION WITH BURN TIME

Data from Appendix (Menon,1988) (for TSP and CO) were analyzed to give mass variations as a function of time.

<u>TSP versus burn time</u>: Table 3.2 shows a large inter experiment range of TSP concentrations for all experimental setups. Fig 3.5 shows typical variations of TSP concentration with time for wood and dung smoke. In this case TSP concentration for dung smoke ranged between 3 to 42 mg/m3, while that for wood smoke ranged between 0.3 to 3.4 mg/m3. Though much smaller on an absolute scale, the wood smoke range is about the same as that for dung smoke when normalized by the mean concentration.

<u>CO versus burn time</u>: CO levels were read on a GE CO personal monitor every six seconds after the fire was lit at one of five low level and four high level sites. Sites 7 and 8 were too close to the fire to be monitored. A burn cycle lasted 15 minutes. Table 3.3 presents the mean and range of CO levels (1-min average) for fuel wood and cowdung smoke at the sampling site used during each of the 22 experiments. Fig 3.6 shows a typical plot with a much larger absolute variation of CO concentration (dung smoke) with burn time at a high level site as compared to a low level site. When normalized by the means the ranges are though about the same. This was found to be true for all sites and for wood smoke as well. In almost

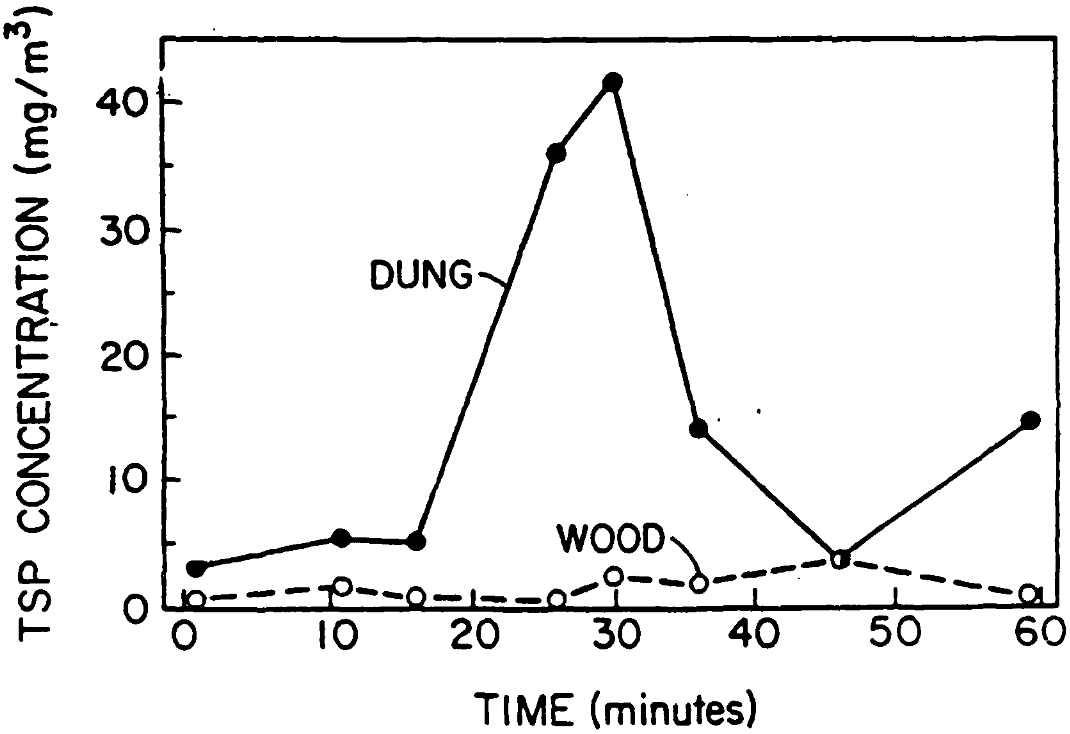

Fig. 3.5 Typical TSP concentration (mg/m^3) with burn time (min) for dung and wood smoke. Sampling probe* located at 1.6 m above floor and TSP sampled under limited ventilation condition (only door open). (Simulated village hut, November, 1982)

*Sampler: Quartz Crystal Micro-balance Cascade Impactor

Table 3.3

Average CO Concentration (ppm) Monitored at Nine Points in the Simulated Village Hut for Burn Period Lasting 15 Minutes Using Fuel Wood and Cowdung

Site*	FUELWOOD				COWDUNG			
	V1**		V2***		V1		V2	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
1L	21	5-46	---	---	16	3-25	---	---
3L	21	11-51	11	7-18	16	8-28	8	4-13
5L	23	11-52	---	---	15	5-28	---	---
9L	20	13-45	---	---	17	3-33	---	---
11L	12	3-25	---	---	17	7-33	---	---
2H	120	39-253	---	---	113	30-190	---	---
4H	146	43-294	27	15-55	106	43-198	46	24-82
6H	136	42-265			121	44-157		
10H	148	41-291			110	17-208		

*Sampling grid: Fig. 3.7A, L and H stand for low and high level
V1**: Only door open, V2***: door and window open

Sampler: General electric carbon monoxide detector (Model 15ECS3)

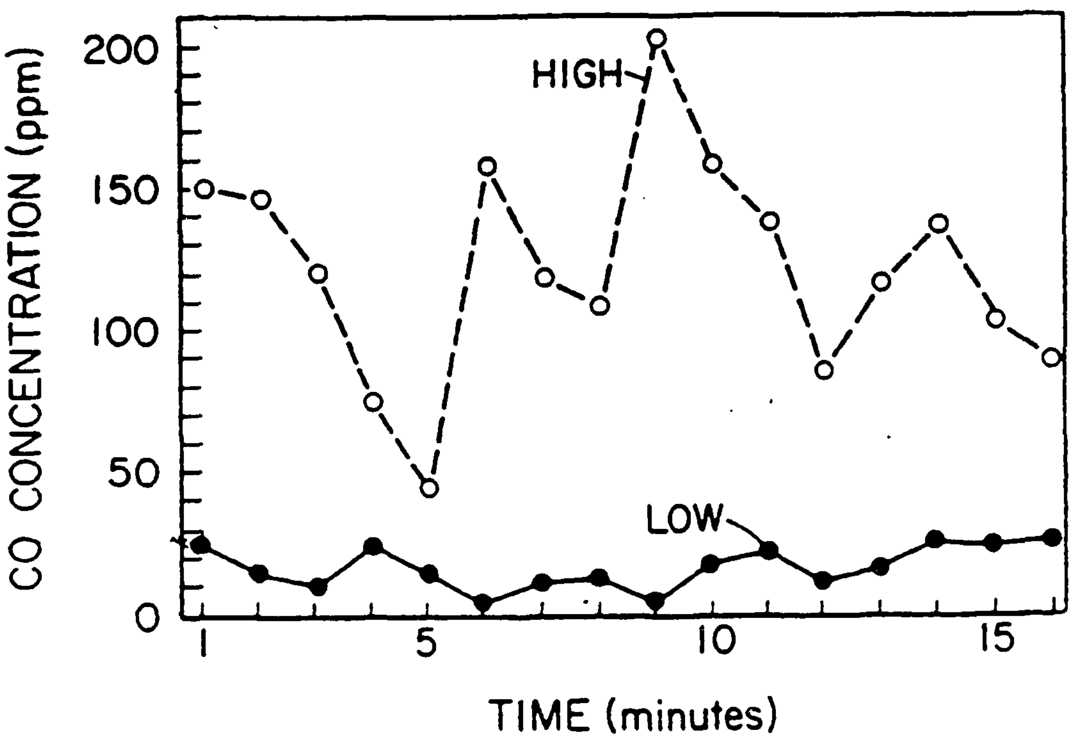

Fig. 3.6 Typical variation of CO concentration (ppm) in dung smoke with burn time (min) for a high and low level site*. Sampling done under limited ventilation condition (only door open)

*High site: 4
Low site: 3
Sampling grid Fig. 3.7a

Sampler: General Electric CO portable monitor (Simulated village hut, Nov.-Dec., 1982) all cases concentrations peak 7 to 10 mins after the fire was lit. This probably coincides with the time of the mid burn fuel feeding.

Conclusion :

1. TSP and CO concentrations for both wood and dung smoke vary considerably with time during the burn. The range of fluctuation is proportional to the mean value.

3.1.4 EFFECT OF FUEL, VENTILATION AND SAMPLING LOCATION ON TSP, CO, BaP CONCENTRATION AND RATIO OF BaP TO TSP

The following paragraphs discuss the results of experiments conducted to investigate the effect of fuel, ventilation and sampling location on :

A. TSP concentration

B. CO concentration

C. BaP concentration

D. Ratio of BaP to TSP

A. TSP CONCENTRATIONS:

Appendix (Menon, 1988) presents method and lists data for all 18 experiments conducted using a sequential sampler to determine TSP levels at eleven indoor sites (Fig 3.7A). These data are summarized in Fig 3.7B to 3.7E which show average TSP concentration (mg/m3) for wood and dung smoke at the sites for two ventilation conditions. Site 11 simulates a squatting woman close to the chula.

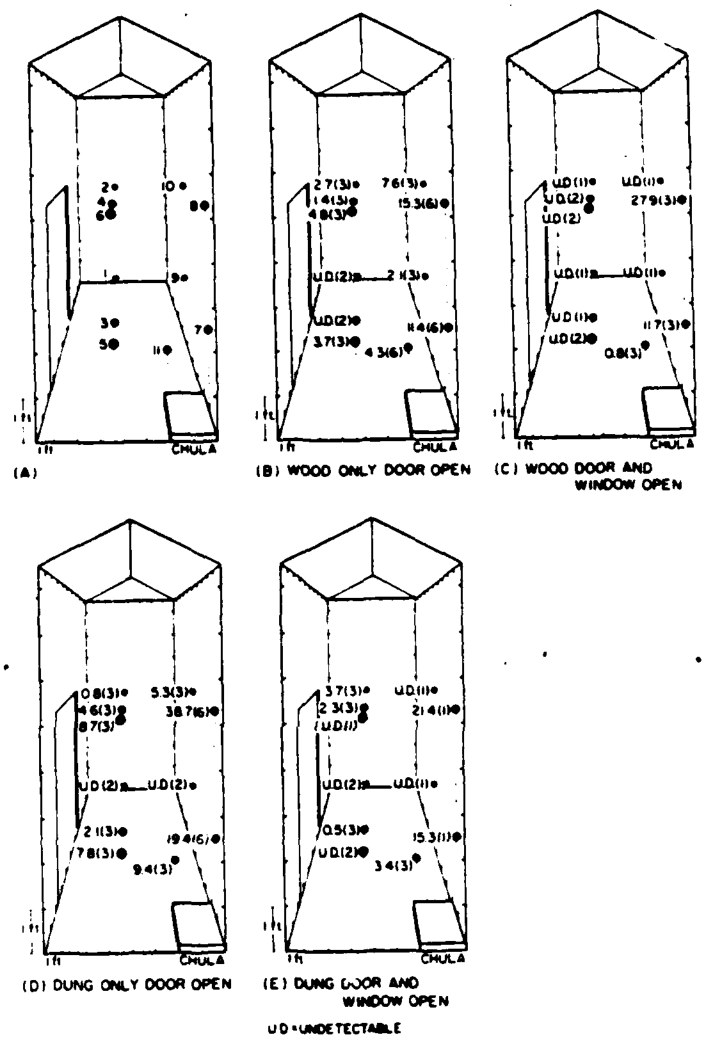

Fig. 3.7 Mean TSP concentration (mg/m^3) measured at 11 sites using a sequential sampler. Sampling done for wood and dung smoke under limited (only door open) and better (door and window open) ventilation condition. (Simulated village hut, Oct-Dec., 1982)

Note: Values in the bracket denote the number of times that site was sampled.

The vertical scale doubled for clarity

Effect of fuel type : With only door open woodsmoke (Fig 3.7B) had TSP levels about half that for cowdung smoke (Fig 3.7D) at most of the sites. This ratio is the same for door and window open (Fig 3.7C-wood and Fig 3.7E-dung) as well. The highest level monitored was 42.3 mg/m^3 at site 8, i.e directly above the chula, with the dung burning and limited ventilation. As a comparision the Hawaii Air Quality Standards limits the highest 24 hour mean TSP concentration to 0.15 mg/m3.

Fig 3.5 in which concentrations are plotted versus time shows that higher smoke concentration prevailed for dung than for wood throughout the burn cycle.

Effect of ventilation condition: With better ventilation i.e door and window open (Fig 3.7C), all the sites except 7, 8 and 11 had undetectable particulate level for wood smoke, while with only door open (Fig 3.7B) most sites had detectable levels. The two sites above the chula had though higher concentrations with better ventilation probably because the air stream was created which moved the smoke past the point out through the window before much dispersion could take place. The concentration are reduced by roughly 50% for dung smoke as well with improved ventilation. This shows the importance of an open window above chula in reducing indoor smoke concentrations. TSP levels were always below detection limit at site 1, just opposite door at low level.

Fig 3.8a shows that TSP concentrations for wood smoke for better ventilation condition (door and window open) remained about half of that during limited ventilation condition throughout the burn cycle.

Effect of sampling location: Mean TSP concentrations are higher at higher levels than at lower levels. Concentration closer to chula are higher than at sites away from the chula for limited ventilation condition (Fig 3.7).

Fig 3.8b shows that TSP concentrations stay about twice as high at high level than at low level for better ventilation condition (door and window open) throughout the burn cycle.

Conclusions :

1. TSP concentrations range from below detection limit (< 0.5 mg/m3) to 38.7 mg/m3 at the different indoor sites.
2. TSP concentration were higher at high level sites than at low level sites.
3. The presence of an open window above chula resulted in significant lower levels of TSP at most of the sites.
4. TSP levels were about twice as high for dung smoke than for wood smoke.
5. The effect of fuel type, ventilation condition and sampling location did not vary throughout the burn.

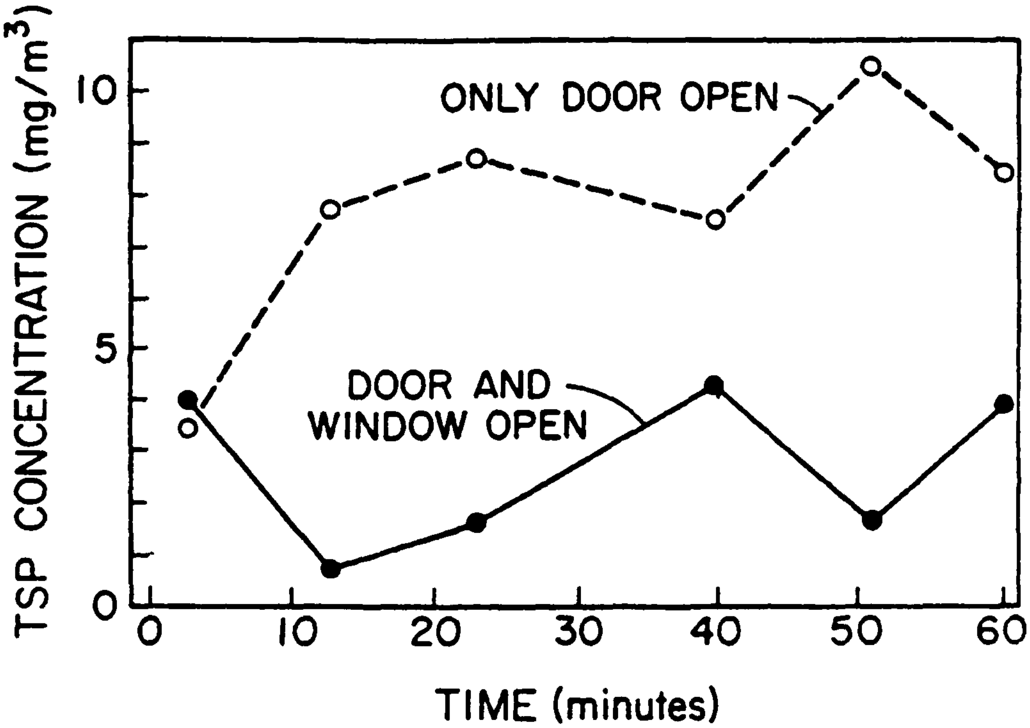

Fig. 3.8a Variation of TSP concentration (mg/m^3) for wood smoke with burn time (min) showing the effect of ventilation. Sampling probe* located at 1.6 m above floor.

*Sampler: Quartz Crystal Micro-balance Cascade Impactor (Simulated village hut, November, 1982)

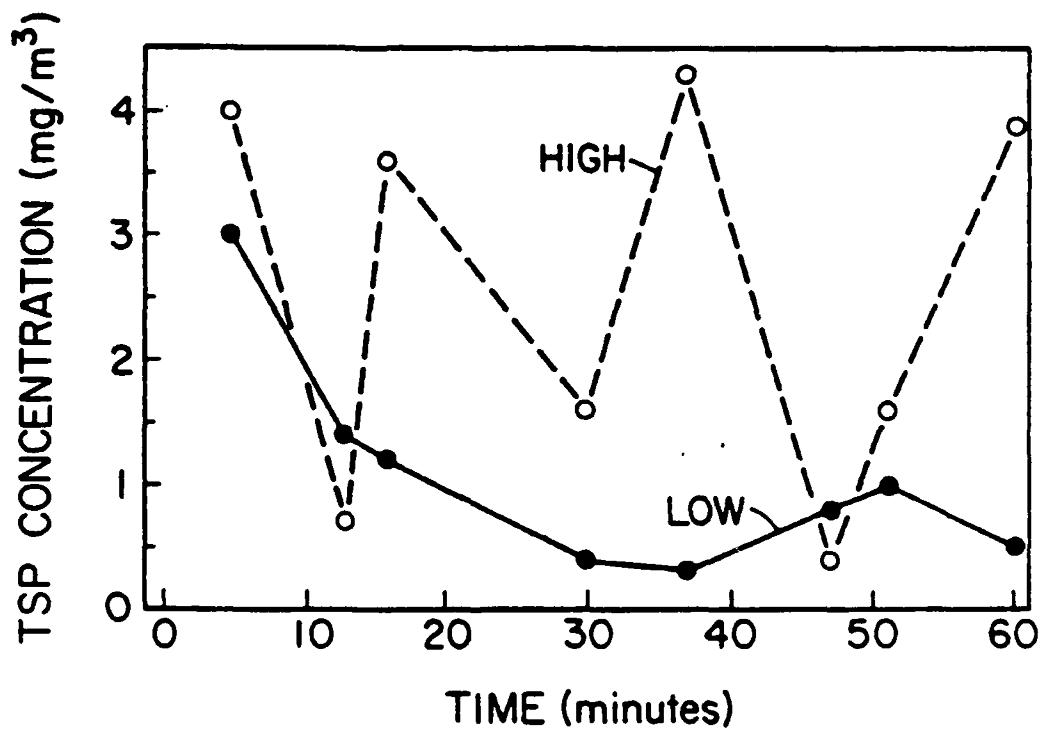

Fig. 3.8b Variation of TSP concentration (mg/m^3) for wood smoke with burn time (min) showing the effect of sampling location.

Sampler: Quartz Crystal Micro-balance Cascade Impactor (Simulated village hut, November, 1982)

B. CO CONCENTRATIONS:

Appendix (Menon, 1988) gives CO data from GE monitor for 22 experiments which were analyzed to illustrate:

Effect of fuel type: Table 3.3 shows no marked difference between wood and dung smoke for all sites. Fig 3.9 shows CO concentration for wood and dung smoke similar through the burn cycle.

Effect of ventilation condition: Table 3.3 shows CO levels are about 2 to 4 times lower for better ventilation condition (door and window open) than for limited ventilation condition (only door open). The ratio is maintained throughout the burn cycle (Fig 3.10).

Effect of sampling location: Table 3.3 shows CO levels in wood and dung smoke about 100 ppm at high level sites and about 20 ppm at all low sites. The CO concentrations for the low level sites do not vary substantially during the burn (Fig 3.6).

Further, CO data (Appendix A.8.4, Menon 1988) were investigated using statistical technique (Split-plot Analysis) to determine significant effect of fuel type, ventilation condition, sampling location and their interactions. Table 3.4 summarizes and presents sum of squares, degrees of freedom, mean squares, F ratios and probabilities associated with each F ratio. We note that sampling height specified by the level (high, medium or low) is significant at alpha=.01.

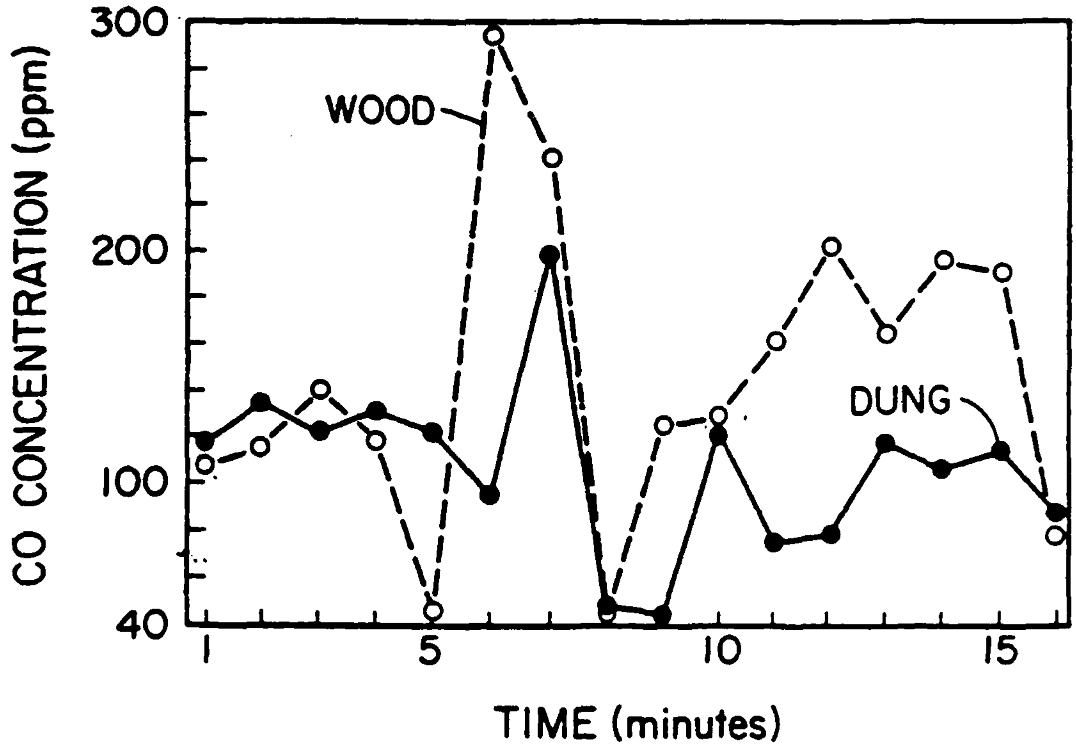

Fig. 3.9 Typical variation of CO concentration (ppm) in wood and dung smoke with burn time (min) for a high sampling site*. Sampling done under limited ventilation condition (only door open)

*Site 4: Sampling grid Fig. 3.7a

*Site 4: Sampling grid Fig. 3.7a

Sampler: General Electric CO portable monitor
(Simulated village hut, Nov.-Dec., 1982)

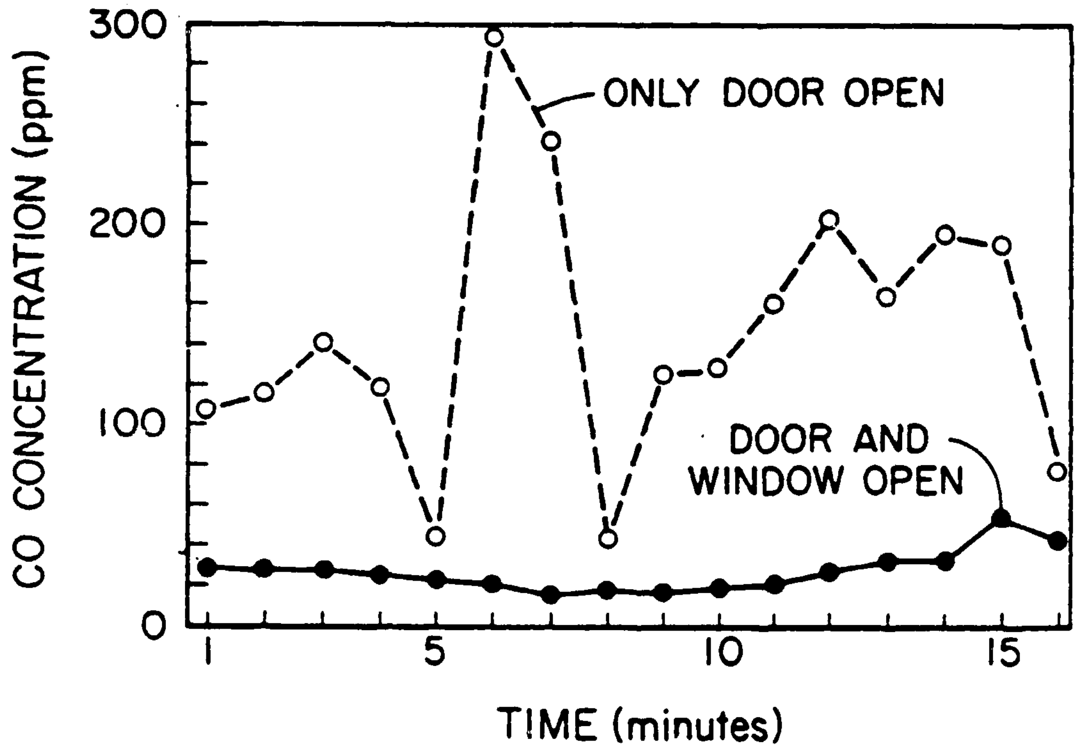

Fig. 3.10 Effect of ventilation on reducing CO concentration (ppm) at high sampling site.* General Electric personal sampler used to monitor CO levels in wood smoke.

*Site 4: Sampling grid Fig. 3.7a

Sampler: General Electric portable monitor
(Simulated village hut, Nov.-Dec., 1982)

Table 3.4

Test of Variance of CO by Fuel Type, Ventilation Condition, Sampling Height and Location in Simulated Village Hut

Whole Plot Analysis	DF	Mean Sq.	F
Fuel Type	1	1016.11	0.04
Ventilation	1	408452.16	16.80
Level	2	1079902.23	44.30**
FLTYP X VENT	1	7181.27	0.3
FLTYP X LEVEL	2	1892.65	0.1
VENT X LEVEL	2	182814.94	7.5
Whole Plot Error			
FLTYP X VENT X LEVEL	2	24369.8	
Sub Plot Analysis			
SITE	8	226.2	0.02
SITE X FLTYP	8	661.7	0.53
SITE X VENT	8	146.7	0.12
SITE X LEVEL	16	792.7	0.64
SITE X FLTYP X VENT	8	566.4	0.46
SITE X FLTYP X LEVEL	16	207.1	0.17
SITE X VENT X LEVEL	16	282.4	0.23
SUB-PLOT ERROR	1528	1238.6	

** Effect significant at .01 level

Conclusions:

1. CO concentrations for dung and wood smoke ranged from 12 to 148 ppm with a mean of 18 ppm for low levels and 120 ppm for high levels. No marked difference exists between fuel type.
2. Better ventilation conditions reduced CO levels about 2 to 4 times.
3. Mean CO concentrations for limited ventilation condition are about 100 ppm at high level sites and about 20 ppm at low sites for both fuels. Effect of sampling height is statistically significant at .01 level.
4. Effect of fuel, ventilation condition and sampling location hold true throughout the burn.

C. <u>BaP CONCENTRATIONS</u>:

TSP sampled filters used with personal samplers (Gilian samplers) were chemically analyzed for BaP using HPLC. Table 3.5 gives the average BaP concentrations for different fuel, ventilation condition and sampling location. The result were confirmed by a few TSP samples analyzed by HPLC at Lawerence Berkley Laboratory (Table 3.6).

Effect of fuel type: No marked difference exists between fuel type. In contrast, Aggarwal et al., 1982, found BaP concentrations to be seven times higher for dung smoke.

Effect of ventilation condition: Roof BaP values are as high as 1800 ng/m3 for limited ventilation (only door open) for both wood and dung smoke. These concentrations are almost twice of those for better ventilation condition (door and window open).

Effect of sampling location: BaP concentration at roof level are about six times higher than at low levels for both dung and wood for limited ventilation but only about twice as high for better ventilation condition. BaP concentrations at low levels are comparable in all cases, ranging from 250 to 430 ng/m3, whereas roof BaP were thousands of ng/m3.

D. RATIO OF BaP TO TSP:

Table 3.5 and 3.6 gives mean ratio of BaP to TSP for different fuel, ventilation condition and sampling location.

Effect of fuel type: Ratio of BaP to TSP for wood smoke higher (about twice) than that for dung smoke. This may be explained due to presence of higher percentage of inorganics in dung. In contrast, Aggarwal, (1982) reported higher (thrice) mean ratio for dung smoke.

Effect of ventilation condition: No marked difference exists between ventilation condition.

Effect of sampling location: Table 3.5 indicates no marked difference between sampling location.

Table 3.5

Spatial Indoor BaP Concentrations# (ng/m^3) and ratio of BaP to TSP ($\mu g/g$) in the Simulated village Hut by Fuel Type, Ventilation Condition, and Sample Height

Sampling Height@	Fuel: Wood				Fuel: Cowdung			
	V1*		V2**		V1		V2	
	BaP	BaP/TSP	BaP	BaP/TSP	BaP	BaP/TSP	BaP	BaP/TSP
Roof	1757	55	867	118	1786	62	879	58
Medium	500	158	870	132	1128	61	231	28
Low	257	125	426	124	300	52	427	19

Sample size: 2

@ Roof Height: 7.5 ft. above floor
Medium Height: 5.6 ft. above floor
Low Height: 2.3 ft. above floor

V1*: Only door open
V2**: Door and window open

Table 3.6[1]

Integrated Levels of TSP, CO, BaP and Ratio of BaP to TSP During a Typical Cooking Period in Simulated Village Hut.(November, 1982)

Experimental Category*	RSP@ Conc. (mg/m^3)	CO Conc. (ppm)	BaP# Conc. (ng/m^3)	BaP/RSP (µg/g)
I	8.9	32	4884	549
II	27.0	48	5066	223
III	5.7	19	2170	381
IV	4.2	11	323	77
V	7.4	11	659	89

*I: Wood, only door open and sampling site 1.6m above floor
II: Dung, only door open and sampling site 1.6m above floor
III: Wood, door & window open, sampling site 1.6m above floor
IV: Wood, door & window open, sampling site 0.6m above floor
V: Dung, only door open, sampling site 0.6m above floor

@ Particulates collected on teflon filter using cyclone fitted sampler (Prototype sampler-Lawrence Berkely Laboratory)

BaP analysis done at Lawrence Berkley Laboratory using High Performance Liquid Chromatography

[1] I thank Mr. Mike Apte for operating the QCMCI and providing us with RSP and BaP results analyzed at Lawrence Berkeley Lab.

Background levels of TSP, CO and BaP in SVH: Background levels of TSP and BaP were measured on several occasions inside the SVH, for about 24 hours with no fire using the Hi-volume sampler. Appendix.A.6 presents method for using Hi-volume sampler. TSP levels ranged from 43 to 215 $\mu g/m^3$ with mean value of 94. Some of TSP background filters were analyzed for BaP. Surprisingly BaP levels ranged between 65 to 150 ng/m^3, with no fire, possibly a result of drawing settled soot from walls / roof / floor, by the Hi-volume sampler. Background levels of CO inside SVH were always less than 1 ppm.

Moisture, ash and calorfic value of fuel: Wood and cowdung samples were analyzed for moisture and ash content for several of the experiments. Appendix.A.5 (Menon,1988) presents method used for determining moisture,ash and calorific value of fuel. The moisture of fuelwood (leucaena) and cowdung ranged from 10 to 25% on dry wt. basis. The ash content for wood was considerably lower than for cowdung, ranging between 1 to 6% for wood and between 12 and 16% for cowdung. The mean calorific value determined for leucaena wood was 4200 cal/gm (range 4000 to 4580 cal/gm) and for cowdung was 2800 cal/gm (range 2020 to 3500 cal/gm).

Conclusions:

1. BaP concentrations for wood and dung smoke are about same but ratio of BaP to TSP higher(twice) for wood smoke. This result is contrary to Aggarwal, et al., (1982) study.
2. Only roof BaP concentrations reduced as a result of increasing ventilation.
3. Roof BaP concentrations were in the order of thousand ng/m3 whereas at low levels they were in hundreds.
4. BaP concentrations were well correlated to TSP concentration.

3.1.5 SUMMARY AND RECOMMENDATIONS FOR FIELD EXPERIMENTS

The main results of experiments in SVH are:

1. Particulate size, TSP and CO concentrations for both wood and dung smoke vary considerably during burn.
2. Particulate size for both wood and dung smoke were in the respirable range(<3.2 µm).
3. TSP, CO and BaP concentrations depend strongly on sampling location and ventilation condition. TSP concentrations for dung were substantially higher. TSP,

CO and BaP levels were greatly reduced with window open and when the sampling location was at low levels. Ratio of BaP to TSP higher for wood smoke at all sampling locations and both ventilation conditions.

4. TSP, and CO concentrations were extremely high when compared to existing U.S Ambient Air Quality Standards.

Partly as a result of the high levels of TSP, CO and BaP obtained in SVH and research conducted by Agarwal (1982) Smith et al (1983) it was deemed necessary to carry out field experiments to see if the very hazardous respiratory environment found in the SVH exists in rural Indian huts.

It was however not feasible to take QCMCI, sequential or Hi-Vol sampler to the rural huts in India because continuous supply of electricity is not available in rural huts, extremely difficult to transport bulky equipments, and it was considered important to monitor the exposure of cooks.

Five battery operated and light weight TSP (Gilian HFS 113) and one CO (Ecolyzer 210) samplers were procured. The instruments were tested in the SVH in order to gain working experience and develop a sampling protocol for rural kitchens and to compare results with previously used samplers.

Eight experiments were therefore conducted collecting simultaneous data for TSP and CO concentrations at different locations and investigate effect of fuel type and ventilation.

Appendix.A.8.2 & A.8.4 (Menon,1988) lists the data obtained for TSP and CO concentrations. The results obtained are similar to results discussed in earlier section. Hence feasible sampling design (using personal samplers) for monitoring TSP and CO concentrations in rural huts was:

1. <u>For TSP</u>: Sampling cook's exposure along with space at roof, medium and low levels at a distance of about two feet from the chula (Fig 3.11).
2. <u>For CO</u>: Sampling nine sites in front of chula at three different levels along with cook's exposure (Fig 3.12).

As the micro-meteorological variables such as indoor-outdoor temperature, wind, relative humidity may interact with fuel quality and combustion conditions it was decided to also measure these during the tests in India. Several research results exist relating fuel quality, burn rate and emission of combustion generated pollutants. Exposure of cooks to indoor pollutants should be highest during monsoon months, because of poor fuel quality, ventilation conditions and unfavorable meteorological conditions. While during the winter months indoor pollutant levels should be lower because of better fuel quality, ventilation conditions and general weather conditions. Hence climatological conditions may significantly effect pollutant levels.

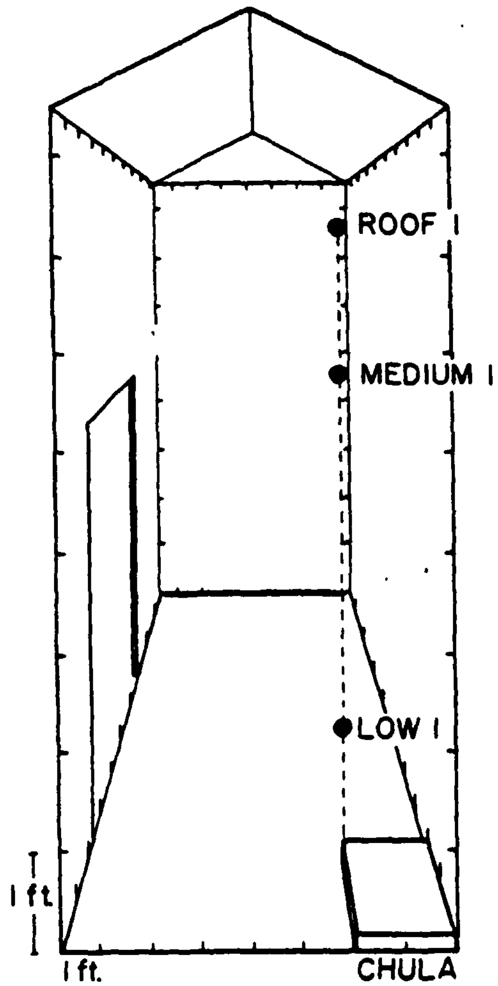

Fig.3.11 Sampling sites for measurement of TSP concentration (mg/m^3) in the rural kitchens using personal samplers.

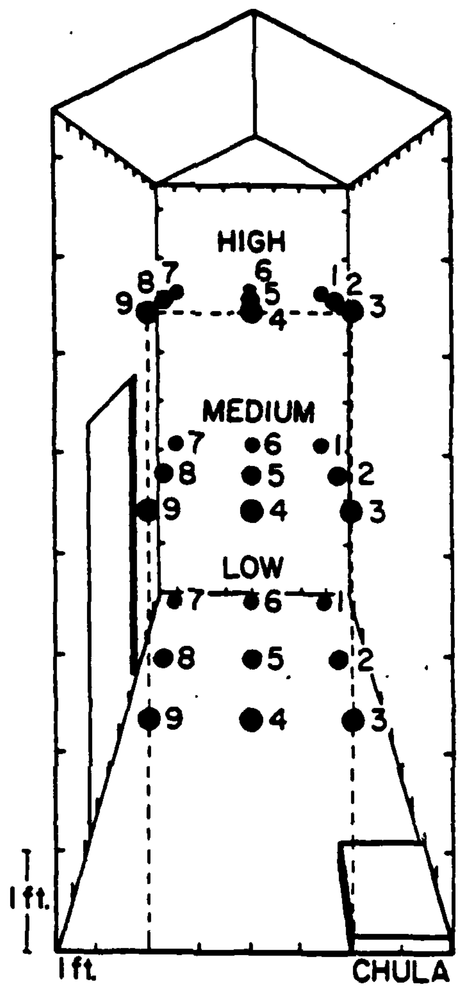

Fig. 3.12 Sampling sites for measurement of CO concentration (ppm) in the rural kitchens using personal sampler.

The field sampling protocol was designed from finding of the effect of fuel type, ventilation condition and sampling location on pollutant concentration in SVH and consideration of climatological conditions discussed in previous paragraph. To evaluate statistically, it was necessary to carry out indoor sampling in atleast 100 rural huts because of the large variability in ventilation conditions, fuel quality, combustor conditions and weather conditions.

3.2 FIELD EXPERIMENTS (INDIA)

The following paragraphs present the results of experiments performed in Indian rural huts from July, 1983 to February, 1984. The objectives were:

1. Determine socio-economic (housing) conditions of the selected rural population and their concern about fuel and smoke.
2. Determine cook's exposure to TSP, CO and BaP and their concentrations at roof, medium and low level within short distance of chula.

3. Determine whether cook's exposure to TSP and CO, and TSP concentration at roof were significantly different for:

    a. Village
    b. Season
    c. Time of day
    d. Kitchen type
    e. Roof type
    f. Door location
    g. Fuel type
    h. Food type

4. Determine the effect and interaction of climate, ventilation and sampling location on spatial concentrations of CO.

5. Model for estimating cook's exposure to TSP as a function of meteorological, ventilation, fuel and stove parameters.

3.2.1 SOCIO-ECONOMIC CHARACTERISTICS, FUEL USE AND PERCEPTION OF PROBLEMS RELATED TO SMOKE

Field experiments were carried out in five villages of India, two in the south and three in the central region. The main criteria for the selection of villages were organizational support, usage of wood and dung as principal cooking fuels, distinct months of rainfall and winter conditions, no language problem, and proximity to a city-- as the air sampling pumps required daily electrical charging.

The three villages selected in central India were adopted by Bharat Heavy Electricals Ltd. (author's parent organization) and the Central Institute of Agricultural Engineering (CIAE) under the India's late Prime-Minister Indira Gandhi's 20-point program for rural development. The Tata Energy Research Institute (TERI) had extension services connected with an improved fuel-efficient stove program in the two villages in south India. Organizational support facilitated logistics/transportation and introduction to the village population greatly helped in gaining the villager's trust and cooperation.

Characteristics of villages selected in central India

The villages Padaria and Adampur, located in Madhya Pradesh some 30 km west of Bhopal, were adopted by BHEL in an effort to change the poverty and backwardness of the village. Islamnagar, situated some 15 km north of Bhopal, was adopted by the CIAE as part of their village extension program. About 100 families live in each of Adampur and Padaria while about 250 families live in Islamnagar. The main occupation in the villages is agricultural-related. The monsoon dominates the weather during late June to September while winter lasts from November to February.

Most households have one single room with a verandah. The stove is usually placed in a corner of the room and cemented to the floor with mud. Some householders have a portable stove and its position can change. The single room is used for: dining and sleeping as well as entertaining guests. Most households gather dead wood in the form of branches and twigs from the nearby forests. Hardly anybody purchases fuel. The villagers use a mixture of types of wood and it was very difficult to identify particular species[1]. Fuelwood was often used in conjunction with dung. Only for a few specific dish was cooking done with dung alone. The chief food roti (bread made from whole wheat) and dal (lentils), sometimes supplemented by vegetables. Most households cook twice a day (morning and evening). While cooking roti, the cook has to be near the fire all the time, unlike rice when the cook only has to attend the stove occasionally.

Characteristics of villages selected in south India

The Ariyur and Perambia villages, are located about 40 km southwest Pondicherry in southeast India. The monsoon period is October/November and the region does not experience a cold winter. Most villagers in Perambia are landless agricultural laborers living in thatched huts, whereas Ariyur has a strata of economic conditions. Fuel is both bought and gathered. Most southern cooks use logs of Casurina, and coconut husks and fronds for fuel. Use of cowdung is minimal. Most stoves have two ports. The main food is rice, dal and vegetables. Cooking

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[1] Appendix B.2 lists the local and scientific names for different wood species. Mr.R. Singh's help in identifying the wood species and Dr.S.D.M Tiwari's (retired Principal Chief Conservator of forests, Govt.of Madhya Pradesh, India) help in providing us with scientific names is greatly appreciated.

is usually done once a day, during the early afternoon or evening, though sometimes it is done three times a day as opposed to the central Indian villages where two meals are prepared each day.

Appendix(B.1, Menon, 1988) presents the questionnaire, (similar to that used in Smith, et al., 1983), used to collect information from a large number of households in the villages about their socio-economic conditions, physical characteristics of their houses, kitchens and stoves, cooking patterns perception of smoke and it's impact on health. The questionnaire was invariably answered by the head of the family - usually men -, only the section on smoke perception and cooking practices was answered by one or more women. Appendix (B.2, Menon,1988) presents graph of the results of the 67 questions. Table 3.7 summarizes the result. A total of 291 arbitrarily selected households were interviewed. The number of households in the central Indian villages Adampur, Islamnagar, and Padaria were 46, 73, 96 respectively, whereas in the south Indian villages Ariyur and Perambia they were 38 each.

Five socio-economic variables were family size, smoking habits, income, occupation of the head of the family, and house ownership. Most households(71%) had six or fewer members, 10% had ten or more members, the largest one had 22. There were no smokers in 45% of the households, one in 44% and more than two in the remaining 11%. The smokers were all men who said they

Table 3.7 (Page 1 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

1. Village and Household Identification

V001	House Number	1 to 291
V002	Sampled Houses by Village	Adampur: 46 Islamnagar: 73 Padaria: 96 Ariyur: 38 Perambia: 38

2. Socio-Economic Characteristics

		Mean	Median	std.dev.	Max	Min
V003	Family Size	7.0	6.0	3.1	22.0	1.0
V004	Smokers Number	1.0	1.0	0.9	8.0	0.0
V005	Income(Rs)	4898.0	3000.0	6249.0	50,000.0	0.0
V006	Occupation	Farmer: 97 Laborer: 82 Stone cutter/ Brick kiln Worker: 18				
V007	House Ownership	Owned: 279 Rented: 11 Other: 1				

Table 3.7 (Continued page 2 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

3. House and Kitchen Physical Characteristics

V008	House Structure	Detached: 161 1/2 of structure: 30 Unit of row: 100
V009	House Age (years)	Mean: 26 Median: 19 Std.Dev.: 25
V010	House Type	Pucca: 17 Tiled: 201 Jhuggi: 72

		Mean	Median	std.dev	Max	Min
V011	House Area(m^2)	60.4	37.0	88.9	930.0	3.3
V012	Number of rooms	2.0	2.0	1.5	16.0	1.0
V013	Kitchen Area(m^2)	16.0	11.7	13.2	97.5	1.5
V014	Kitchen Roof Ht(m)	2.0	2.1	0.9	9.9	0.9
V015	Kitchen Volume(m^3)	36.3	25.5	42.3	361.0	2.3

V016	Kitchen Type	Tiled: 185 Pucca: 12 Thatch: 94
V017	Kitchen Site	Attached: 91 Separate: 78 Verandah: 17 No other room: 105
V018	Kitchen Use	Cooking: 57 Cooking and eating: 68 Cking+Eating+Sleeping: 166
V019	Kitchen Wall Material	Thatch: 28 Mud/Brick: 246 Metal: 1 Concrete: 16
V020	Kitchen Roof Material	Thatch: 96 Concrete/Metal: 18 Tiles: 177
V021	Kitchen Floor Material	Mud: 268 Concrete: 20 Brick: 3
V022	Open Space In Wall	Nil: 191 <25% :79 <50% :5 >75% :1 & Not Applicable:14
V023	Doors in Kitchen	Mean: 1, Median: 1 Max:7, Min:1

Table 3.7 (Continued page 3 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

4. Stove and Cooking Characteristics

V024	Other Cooking Sites	Yes: 104, NO: 187
V025	Other Cooking Sites-Specify	Open/Verandah: 74 Other room: 24 Same room: 5 Not Applicable: 187
V026	Period for Cooking at Other Site	Summer: 49 Winter: 19 Monsoon: 3 Guests/Celebration: 20 Child birth: 5 Not Applicable: 188 All Season: 7
V027	Cooks for (number)	Mean: 7, Median: 6 std.dev: 3 Max: 25, Min: 1
V028	Cooking Time	Morning: 2 Noon: 2 Evening: 42 Morn. & Noon: 1 Morn. & Even: 198 Noon & Even: 8 Morn, Noon, Even: 38
V029	Guests per week	Mean: 1, Median: 1 Max: 9, Min: 0
V030	Food Type	Rice & Curry: 68 Roti & Curry: 95 Rice & Roti: 128
V031	Number of Cooks	Mean: 1, Median: 1 Max: 4, Min: 1
V032	Cook's Age	Mean & Median:30 std.dev:11
V033	Years of Cooking	Mean:19,Median:17 std.dev:11
V034	Total Cooking Hours Per Day	Mean:6,Median:3,std.dev:17 Max:8, Min:3

Table 3.7 (Continued page 4 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

V035	Other People in Kitchen while Cooking	Yes: 155, No: 135
V036	Present in Season	Winter: 59, Mon, Win & Summer: 94 Not Applicable: 136
V037	Cook Near Fire-Duration	Always: 132 Most of the Time: 24 Half of the Time: 78 Less: 57
V038	Fire for other Purposes-Duration	Zero hour: 108 Half hour: 157 > One hour: 26
V054	Stove Type	One mouth: 188 Two mouth (attached): 29 Two mouth (connected): 27 Other: 47
V055	Stove Replacement	Yearly: 117 Once in Two Years: 18 Birth of Child: 3 Broken: 108 Never: 45
V057	Ventilation Change In Monsoon	Yes: 45 No: 217 Don't Know: 29
V058	Ventilation Change In Winter	Yes: 62 No: 183 Don't know: 46
V059	Kerosene Lamp While Cooking	Yes: 232, NO: 59

Table 3.7 (Continued page 5 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

5. Fuel Characteristics

V039	Fuel Type	Wood: 46 Dung: 4 Wood & Dung: 209 Wood & Crop Residue: 32
V040	Qty. of Fuel per Day (kg)	Mean:14,Median:6,std.dev:25 Max: 20, Min: 0.5
V041	Cost of Fuel per Ten kg (Rs)	Mean:28,Median:3, std.dev:43
V042	Fuel Storage	Kitchen roof: 49 Separate Room: 31 Verandah: 40 Animal Shed/ out Shed: 29 Open: 98 None: 40
V043	Fuel Change in Last Five Years	Yes: 21, No: 270
V044	Fuel Gathering-Summer hours	Mean:8, Median:4, std.dev:19 Max: 24, Min: 0
V045	Fuel Gathering-Monsoon Hours	Mean:6, Median:0, std.dev:19 Max:12, Min: 0
V046	Fuel Gathering-Winter Hours	Mean:8,Median:4,std.dev:19 Max: 15, Min: 0
V047	Fuel Gathered by	Men: 137, Women: 19 Children: 2 Men & Women: 44 Men, Women & Children: 14 Women & Children: 4 Not Applicable: 71

Table 3.7 (Continued page 6 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

V048	Ease in Collection	Impossible: 57 Difficult: 118 Satisfactory: 7 Easy: 64 Not Applicable: 45				
V049	Wood From	Compound: 55 Jungle: 169 Buy from shop/others: 67				
		Mean	Median	std.dev	Max.	Min.
V050	Fuel Cost / Head	8.2	7.0	5.9	40.0	2.0
V051	Fuel Cost / Cycle	15.5	12.0	15.8	85.0	2.0
V052	Fuel Cost / Cart	69.0	57.0	65.0	600.0	4.0
V053	Type of Wood Used*	Satkut: 176 Beshram: 5 Casurina: 18 Portia: 3 Mixture of Casurina Portia and Sugar Cane: 24 Don't Know: 30				

* Appendix lists local and scientific names

Table 3.7 (Continued page 7 of 7) Summary Statistics: Socio-Economic, Fuel and Smoke Perception Survey

6. Villager's Perception About Fuel and Smoke

V064	Smoky Fuelood species	Gurgan: 69 Crop residue: 33 Other: 111 Don't know: 41
V065	Less Smoky Species	Sagun: 64 Dry wood: 37 Other: 85 Don't know: 49
V066	Effort to get less Smoky Fuel	Yes: 93, No: 156 Yes but not available: 42

7. Cook's Attitude Towards Smoke

V060	Smoke Bother	Yes: 243, No: 35 Don't know: 13
V061	Smoke Dislike	Very Much: 224 Little: 44 None: 23
V062	Perceived Health Problem	Yes: 166 No: 85
V063	Problem of	Lungs: 59 Eyes: 109 Lungs and Eyes: 56 Don't know & N.A: 67
V067	Desire to Get Rid Of Smoke	Yes: 195 No: 49 Don't Know: 47
V068	Desire Fuelwood Delivery (at cost) or Smokeless Chula (at no cost)	Fuelwood Delivery: 291 Smokeless Chula: 0

did not smoke in the kitchen. Most family heads were farmers (33%) followed by agricultural laborers(28%), and 18% employees of companies or the Government. There existed a wide range of income among the sampled population. 2% of family had no income at all and 2% had incomes of more than RS.24,000 p.a. The mean annual income was Rs.4900, and the median Rs.3000. 96% of the households owned their house.

Sixteen variables describe the house and the kitchen e.g., house structure and area, kitchen volume, location and sources of ventilation. The houses were either detached(55%), part of a row(34%) or half of a unit(11%). The age of the houses, ranged from 1 to 135 years with a mean age of 26 and a median of 19. Twelve percent of the houses were built in the last 5 years and there appeared to be no differences between their construction materials or structures and those of the older houses. The floor area of the houses ranged from 3.3 to 930 m2 with a mean of 60 and median 37. The number of the rooms ranged from 1 to 16 with a mean and median of 2. Most houses had tiled roofs(69%) followed by roofs of thatch(25%) and the remaining 6% of the houses were constructed of cement or concrete. This is similar to census data 1971 of Madhya Pradesh, which reported tiles, slate and shingle to be predominant (70 to 80 %) of roof material of the rural houses. 36% of the houses had one room, one corner of which served as a kitchen, 31%, had their kitchen attached to another room and 26%, had a separate room which was used solely for cooking purposes and 6% did their cooking in one corner of the verandah. A majority of the householders(57%) used the kitchen area for cooking, eating, and sleeping, 20% used it for cooking only and the remaining 23% used it for both cooking and eating. Most kitchen walls were made of mud and brick(85%), 10% were of thatch, and 5% of concrete. All houses had mud floors. Roof material was an important variable for smoke seepage. In thatched kitchens the researchers while questioning were forced to sit on the floor because of intolerable levels of smoke. Tiles on the roofs were laid on wooden rafters at a slight angle, thereby leaving spaces for ventilation which prevented the buildup of smoke indoors. A total of 177 houses, (61%), had tiled kitchen roofs, and 96, (33%) had thatched roofs. Kitchen areas ranged from 1.5 to 97.5 sq.m, with a mean of 15.5. Kitchen roof height was usually about 2 m with a maximum of 9.1 and minimum of 0.9 m. Kitchen volume ranged from 2.3 to 360 m3 with a mean of 36 and median of 25. A majority of kitchens (66%) had no opening in the walls, 27% had less than a 25% opening in the walls. Most kitchens(81%) had only one door, 12% had 2 doors and the rest (7%) had 3 doors or more. When asked if they changed the ventilation conditions (spacing of tiles on roof) during monsoon or winter, most (63 to 75 %) answered no. As the stove was usually in a dark place most of the cooks(80%) use a small kerosene lamp near to the stove.

Twenty one stove and cooking variables provide information about cooking sites, seasonal patterns of cooking periods, cooking time and duration of nearness to the fire, food type, cook's age and the number of years that she has performed the chore, presence of other people in the kitchen etc. When questioned if they sometimes cooked elsewhere, 36% answered yes. 75% cooked outdoors or in the verandah much of the summer and when relatives or friends visited. 68 percent of the cooks performed their cooking chores during the morning and evening, 14% during the evening and the remaining 18% at other times. Most cooks prepared meals for about 6 persons, but in some households they cooked for as many as 25 persons. 84% percent of the households had one or more guest per week. 64% percent of the households had only one cook, 30% had 2 cooks, either the wife or the daughters-in-law of the head of the family or in some houses by a mother and her young daughters and the remaining 6% had more than two cooks. The cook's age ranged from 11 to 70 with both a mean and median of 30 years. The number of years the cooks had been cooking with traditional fuels ranged from 3 to 60 years with a mean of 19. 44 % prepared both rice and roti, 33% only roti and dal, and the rest rice and curry. Roti and dal is the predominant food in central India whereas rice and curry is the staple food of the south. Cooking of roti requires the cook to be close to the fire throughout the cooking cycle whereas rice cooking requires only occassional presence of the cook. Asked for the number of hours of cooking per day, 3% had no idea and the rest mentioned between 0.5 to 8 with a mean of 6 and median 2.5 hours. While cooking most (70%) stayed close to the fire. When asked whether other members of the family were present during cooking, a little more than 50% answered yes. Sixty percent said that other members were present where they cooked throughout the year, whereas the rest specified that the others were with them only during winter season, usually to warm themselves in front of the cooking fires. When asked for how long they used their fires for tasks other than cooking, about 37% answered never, 54%, for less than half an hour per day, and the rest (9%) for more than 1 hour. 65% used a single port stove, and the rest mostly in south, used a two port stove. 37% replaced the stoves only when broken, 28% did so annually and the rest (35%) had never replaced a stove or had replaced it once in two years. The cost of replacement of the stoves, was estimated at Rs.1.

Fifteen fuel variables provide information about fuel type, cost, storage, seasonal patterns of fuel gathering, by whom and where the fuel was gathered, and level of difficulties experienced in finding fuel. A great majority (93%) had always used the same type of fuel and never changed to any other energy source. 34% stored their fuel in the open, the others stored it on the rafters below the kitchen roof, in a separate room, verandah, or outside shed. 0.5 to 20 kg (median 6) of fuel was used daily. 72% used both wood and cowdung in combination, 16% used wood alone and the remaining 12% used wood and crop residue. In the majority of the households(47%), the fuelwood was procured only by male members, in 21% of the households women members assisted in fuel gathering. During summer as much as 24 hours per day was spent in procuring fuel whereas during winter and monsoon periods 15 and 12 hours respectively were used. During the monsoon 50% did not go for fuel gathering at all relying on stored summer fuel. 41% had great difficulty in getting the fuel, 20% thought fuel gathering was relatively easy and the rest 20% found it to be an almost impossible chore. 58% went to a nearby forest to collect dead branches for firewood, 18% chopped trees on their own land and the rest bought wood. 69% used whatever type of fuel was gathered generally a mixture of seven different species(satkut). 27% had no idea about the cost of fuelwood, the rest estimated from 0 to Rs.2/kg. Fuel is usually sold by headload, bicycle load or cart load. 60 to 70% had no knowledge about the cost of fuel per head, cycle or cart.

Three variables pertaining to the villagers' knowledge about smokiness as related to fuel type and their effort to procure less smoky species of fuelwood. The cooks characterised a number of fuelwood types as smoky, amongst which Gurgan was most commonly mentioned in the north and crop residue in the south. When asked if they knew less smoky fuel, 22% in central region suggested Sagun while in the south many mentioned Casurina. 54% did not try to get less smoky fuel, 32% did so successfully, and the rest usually failed to get less smoky fuel.

Five variables give information about the cook's perception of the smoke, perceived health related problems and desire to get rid of smoke. Most cooks(84%) said that smoke bothered them very much. 57% indicated one related health problem, mainly eye trouble, and 20% attributed both eye and lung problems to smoke. 67% wanted to get rid of smoke but when given a choice between a cost free smokeless chula and fuelwood delivery at nominal cost, all opted for the latter, suggesting fuel procurement as the priority need.

SUMMARY

1. Most of the rural population were farmers and laborers and their income varied considerably.
2. All kitchen had mud floors and most had stone/brick with mud walls. Kitchens with thatch roof had untolerable smoke levels when compared to those with tiled roof. Most kitchens had tiled roofs with a variety of kitchen volume and open space on the walls. Not a single kitchen had a hood/chimney/open space above the chula. Kitchen site was usually dark.

3. Cooking was mainly performed indoors on one port stove. Cooks in central India spend most of the cooking time close to the stoves. Stoves, food type and cooking pattern were similar within each geographic region.

4. Most rural cooks in central India use mixed species of fuelwood in conjunction with cowdung and gathered fuelwood from neighboring forest. They did not know cost of fuelwood.

5. Villagers knew about less smoky fuel, however most did not make an effort to procure it.

6. Cooks were bothered by smoke and wanted to get rid of smoke, however, fuel procurement was their chief concern.

3.2.2 COOK'S EXPOSURE TO TSP, CO AND BaP AND THEIR SPATIAL CONCENTRATIONS

Experiments were carried out during the monsoon and winter months of 1983 to determine spatial distribution and the cook's exposures to TSP, CO and BaP in the rural kitchens during typical cooking period. The households selected met the following criteria:

1. Cooking performed indoors(rooms with only a door or rooms with a door and some openings in the walls as well).
2. Cooking done on single u-shaped chula.
3. Fuel using wood and cowdung.
4. Willingness to take part in the study.

Appendix (Menon,1988) presents the field sampling protocol and summary graphs for each of the variables measured for the 129 households in the three central Indian villages and two south Indian villages. The number of kitchens sampled in the central Indian villages Adampur, Islamnagar, and Padaria were 23, 42, 54 respectively whereas in the south Indian villages Ariyur and Perambia were 4 and 6. Table 3.8 summarises meteorological (six variables), ventilation (nine variables), fuel (thirteen variables), stove (four) and pollutant (seventeen) characteristics.

Table 3.8 (Page 1 of 6) Summary Statistics: Field Experiments in Rural Kitchens of India

1. Village and Household Identification

V001	House Number	1 to 129				
V002	Village	Adampur: 23 Islamnagar: 42 Padaria: 54 Ariyur: 4 Perambia: 6				
V005	Region	Central India: 119 South India: 10				

2. Meteorological Indicators

V006	Time of Day	Morning: 60 Evening: 69				
V012	Climate	Monsoon: 76 Winter: 53				
		Mean	Median	std.dev	Max.	Min.
V015	Indoor Temperature (deg. C)	27	29	5.7	39	14
V016	Outdoor Temperature (deg. C)	24	26	5.5	32	11
V017	Indoor rel. humidity	67	69	18.0	100	30
V018	Outdoor rel. humidity	78	84	19.4	100	10

Table 3.8 (Continued page 2 of 6) Summary Statistics: Field Experiments in Rural Kitchens of India

3. Ventilation Indicators

V013	Kitchen Type	Only Door: 91 Door + open space: 38				
V014	Roof Type	Tiled: 100 Pucca: 6 Thatch: 23				
		Mean	Median	std. dev	Max.	Min.
V019	Volume I (m^3)*	27	23	18.1	98	4
V020	Volume II (m^3)**	7	6	5.0	32	0
V021	Wall Height (m)	2	2	0.5	4	1
V022	Slant Height (m)	1	1	0.4	2	0
V023	Total Volume (m^3)	35	29	22.0	116	6
V024	Area of Walls (m^2)	30	27	13.2	72	8
V025	Wall Open Area (m^2)	2	1	1.0	7	1
V026	Open Area Index	7	6	4.0	24	2
V027	Door w.r.t chula	Back wall: 24 Side wall: 31 Front wall: 50 Far side: 24				

* Cubical volume within four walls
** Roof volume within slanted roofs

Table 3.8 (Continued page 3 of 6) Summary Statistics: Field Experiments in Rural Kitchens of India

4. Fuel Indicators

V009 Fuel Type: Wood: 36; Cowdung: 1; Wood + Cowdung: 90; Wood + Crop Res.: 2

		Mean	Median	std.dev	Max.	Min.
V028	Qty. of Wood (kg)	2	2	0.8	4	0
V029	Qty. of Cowdung (kg)	1	1	0.7	5	0
V030	Burn Time (hr)	1	1	0.3	2	0
V031	Burn Rate (kg/hr)	2	2	0.7	6	1
V032	Moisture wood (%)	13	12	4.2	35	7
V033	Moisture dung (%)	11	10	2.3	17	7
V034	Ash wood (%)	3	2	1.9	11	0.3
V035	Ash dung (%)	20	19	6.6	37	7
V036	Wood length (cm)	74	72	28.9	200	15
V037	Wood Thickness (cm)	5	4	2.5	13	1
V038	Diam. dung (cm)	24	24	4.5	33	12
V039	Thickness dung	3	3	1.3	8	1

5. Stove Indicators

		Mean	Median	std.dev	Max.	Min.
V040	Stove volume(m^3)	0.01	0.01	0.02	0.25	0.004
V041	Stove height (cm)	20	20	4.1	42	11

V010 Food cooked: Rice: 12, Roti: 108; Rice + Roti: 9

V011 Cooked for (number): Mean: 6, Median: 5, std.dev:2; Max: 20, Min: 2

Table 3.8 (Continued page 4 of 6) Summary Statistics: Field Experiments in Rural Kitchens of India

6. Pollutant Levels Measured

A. Total Suspended Particulates (TSP mg/m^3)

	Location	n	Mean	Median	std.dev	Max.	Min.
V042	Roof	129	21	13	17.8	74	2
V043	Medium[a]	-do-	8	6	7.8	44	1
V044	Low[b]	-do-	4	3	3.4	21	1
V045	Cook	-do-	5	4	2.6	13	1
*	Outdoor	13	0.1	0.1	0.2	0.3	0.1

Ambient Air Quality Standards[#]

WHO (Daily mean)	India (8 hr. mean)	U.S.A Public (Daily mean)	U.S.A Occupation (8 hr. mean)
0.1-0.15	0.20	0.25	5.00

[a] Site 5.6 ft above floor (at 2 ft. from chula)
[b] Site 2.3 ft above floor (at 2 ft from chula)
* During winter in central Indian villages
# Source: Smith, 1987

Table 3.8 (Continued page 5 of 6) Summary Statistics: Field Experiments in Rural kitchens of India

B. Carbon Monoxide (CO ppm)

	Location	n	Mean	Median	std.dev	Max.	Min.
V046	Cook[c]	129	51	45	35	179	5
V047	High[d]	84	28	28	19	117	6
V048	Medium[e]	84	22	18	15	71	2
V049	Low[f]	84	18	12	15	84	2
V050	Door (Top)	81	10	7	11	52	0
V051	Door (Middle)	82	9	5	9	47	0
V052	Door (Low)	82	7	5	6	31	0
V053	Outdoor	82	4	4	2	11	0

Ambient Air Quality Standards[#]

WHO (one hr mean)	WHO (maximum allowed at any time)	India (8 hr mean)	U.S.A Public (1 hr mean)	U.S.A Occup. (8hr. mean)
33	100	2	33[@]	42

c Average of 3 to 5 sites around chula (1 ft above)
d Site 6.4 ft above floor (Average of 6 to 9 points, Fig. 3.12)
e Site 5.0 ft above floor (----------------do-----------------)
f Site 2.3 ft above floor (----------------do-----------------)
@ not to exceed more than once
# Source: Smith, 1987

Table 3.8 (Continued page 6 of 6) Summary Statistics: Field Experiments in Rural Kitchens of India

C. Benzo(a)pyrene (BaP ng/m^3)

Location	n	Mean	Median	std.dev	Max.	Min.
Roof	70	2053	699	2875	11,736	97
Medium	58	219	53	435	2,917	0
Cook	76	164	124	138	565	0
Outdoor	12*	4	3	5	7	3

D. Ratio of BaP to TSP (μg/g)

Location	n	Mean	std.dev	Max.	Min.
Roof	70	120	97	483	12
Medium	58	67	102	507	0
Cook	76	39	36	122	0
Outdoor	12	50	44	100	19

* During winter in central Indian villages

METEOROLOGICAL VARIABLES The six meteorological variables were time of day, season, indoor temperature, outdoor temperature, indoor relative humidity and outdoor relative humidity. 76 households were monitored during the monsoon and the remaining 53 during the winter season. The number of experiments performed during the morning and evening were 60 and 69 respectively. The mean indoor temperature was 27 C and the maximum 39 C whereas for outdoor the maximum recorded was 32 C. The relative humidity was similar indoors and outdoors.

VENTILATION VARIABLES The nine kitchen ventilation variables were kitchen type, roof type, volume, wall height, roof slant height, wall area, open area in the walls and the position of door with respect to chula. 70% had only door and the remaining 30% had some form of opening in the walls. 92% of the kitchen had tiled roofs, and the rest 8% had thatched roofs. The kitchen volume was the sum of the cubical space between the four walls and the triangular space beneath the slanted roofs. The volume varied greatly ranging from 6 to 116 m3 with a mean and median of 35 and 29 respectively. A large range of wall heights and total wall area were recorded, the means were 2 m and 30 m2 respectively. The open area in the walls, was defined as the ratio of the open wall area to the total wall area ranged from 2 to 24 % with mean of 7. 40% had door in the wall facing the chula (Fig.3.13), 24% had it in side wall, and rest 36% had equally door on the back wall and the far side wall.

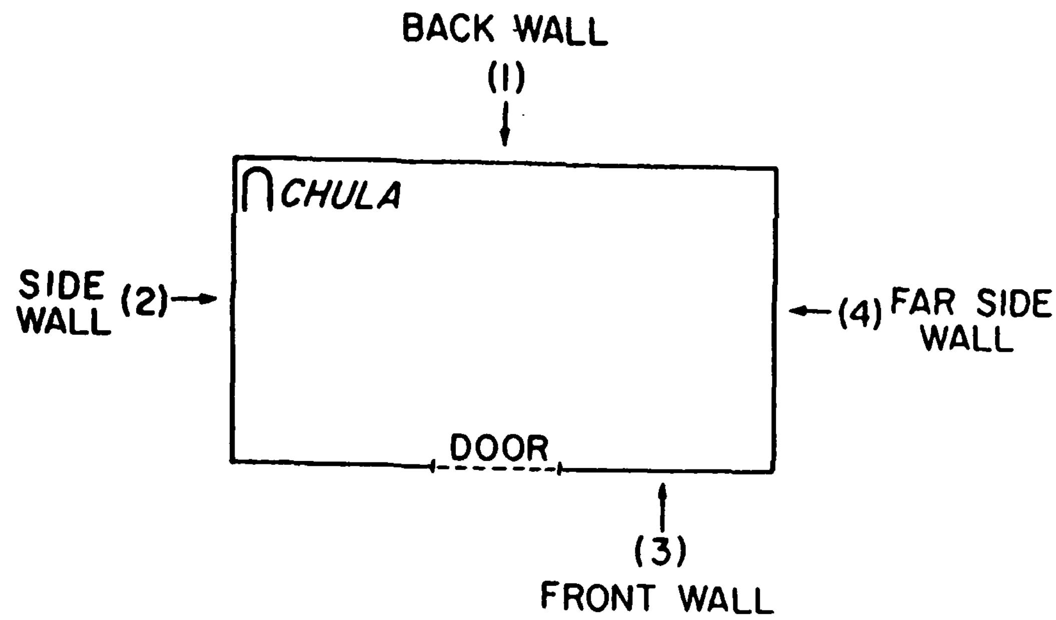

Fig. 3.13 Designation of wall with respect to chula

FUEL VARIABLES The thirteen fuel variables were quantity of wood and dung, total burn time sampled, fuel burn rate, moisture of wood and dung, ash of wood and dung, wood length and thickness, and dung length and thickness. 70% of cooks used wood and dung together generally in a ratio of about 3 to 1, 28% used wood alone and the rest 3% used wood and crop residue only. The fuel burn rate ranged between 1 to 6 kg per hour with mean of 2. This large variation in burn rate may be due to cook's differences in managing the fire burn. The cook's age varied from 12 to 65 years. Burn rate for experiments performed in SVH ranged between 1 to 3 kg per hour. The average moisture content of both fuelwood and dung was about 12%, whereas the mean ash content of the fuelwood (3%) was considerably lower than that of dung (20%). Similar values were obtained in SVH except for a larger ash content in dung used in the rural kitchens which may be related to the fact that village cows graze on meadows in rural India whereas Hawaiian cows are fed in stalls.

STOVE VARIABLES The four stove variables were stove volume, height, type of food cooked, and the number of people for whom cooked. The stove size varied greatly ranging from .004 to .3 m3. 84% prepared roti, 9% rice and the rest 7% both. The food was cooked for an average number of 6 members and in some houses as much as 20 members.

POLLUTION VARIABLE-TSP Table 3.8 shows statistic for the levels of TSP measured at cook's breathing site, at three indoor sites (about 2 feet from chula) and outdoors[1]. The indoor sampling was performed for the whole period of cooking or a maximum of two hours. Ambient standard level set by the U.S, WHO and India for TSP is presented for reference.

The mean indoor TSP concentrations (mg/m3) at roof, medium, low level and cook's breathing zone were 21, 8, 4 and 5. Ambient (outdoor)[2] TSP levels with mean of 0.1 mg/m^3 is comparable to values reported for rural Bombay (Rao, et al., 1980) and rural Nepal (Davidson, 1986) but an order less than reported by Smith et al., 1983. The least level of TSP sampled indoors is an order higher than recommended by the ambient air quality regulating agencies and equal to occupational standard set by OSHA for nuisance dust (inert). Even though cooking can be considered as occupation, using occupational standard (set for young, healthy working group) does not seem appropriate in this circumstances as cooking may be performed by very young (11 year olds), sick and very elderly women. The cook's

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[1] Sampling performed only during winter in the three villages in central India using Hi-vol sampler borrowed from National Environmental Engineering Research Institute, Nagpur, India. Help rendered by Dr.A.L.Aggarwal and Dr.B.B.Sunderesan is greatly appreciated.

[2] Sampling done during evening to early morning for two consecutive days at 3-5 sites in the three villages (Padaria, Islamnagar and Adampur). Sampling during day time could not be performed due to frequent power shortage.

exposure to TSP was similar to the indoor concentration at lower level than levels measured outdoors. This finding is similar to other indoor air pollution studies carried out in the U.S and European countries for e.g., Binder, et al., 1976, Sega, et al., 1982, Tosteson, et al., 1982, and Spengler & Soczek, 1984, where they have reported that when the polluting source is indoors, personal exposures are better correlated to concentrations monitored indoors than outdoor level. The range of values for indoor TSP was large with maximum of 74 mg/m3. The average ratio of TSP concentrations at roof level to that at low level and at the cook were both about 10, similar to SVH results. These ratios for tiled kitchens varied from 1 to 50, whereas, for thatched huts it ranged from 1 to 10. Thus the smoke density in thatched huts was more uniform than in tiled kitchens where air gaps between the slanted tiles allowed bouyant smoke to escape preventing smoke build up in the kitchen. Table 3.9 presents a comparision[1] between TSP concentrations in SVH and in field. With both door and window open the SVH simulated the tiled roof huts rather well while with only door open the SVH was closer to a thatched hut.

Fig 3.14 presents cook's exposure to TSP concentrations in different rural ares of the developing world obtained by several authors viz., Cleary and Blackburn, 1968, Hoffman and Wynder, 1972, Anderson, 1975 Aggarwal, 1982, Smith, 1983,

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[1] Results comparing SVH to field data is not conclusive due to small sample size of SVH experiments

Table 3.9 Mean* TSP, CO and BaP in the Field and in the Simulated Village Hut

Location	Field	Tiled Roof	Thatched Roof	Simulated Village Hut V1*	Simulated Village Hut V2**
A. TSP Conc. (mg/m^3)					
Roof	21 (129)	20 (100)	27 (23)	35 (4)	17 (4)
Medium[a]	8 (129)	6 (100)	16 (23)	28 (4)	8 (4)
Low[b]	4 (129)	3 (100)	8 (23)	3 (3)	4 (3)
Cook	5 (129)	4 (100)	6 (23)	7 (9)	2 (6)
B. CO Conc. (Average of 6 to 9 points, see Fig.3.12) (ppm)					
High[c]	28 (84)	23 (67)	49 (17)	150 (4)	56 (4)
Medium[d]	22 (84)	18 (67)	38 (17)	68 (4)	28 (4)
Low[e]	18 (84)	16 (67)	29 (17)	14 (4)	20 (4)
Cook[f]	51 (129)	53 (100)	43 (23)	15 (2)	-- --

*Sample Size within brackets
V1* : Only door open, V2** : Door and window open

a Site 5.6 ft above floor (at 2 ft. from chula, see Fig. 3.11)
b Site 2.3 ft above floor (-------------do------------------)
c Site 6.4 ft above floor (Average of 6 to 9 points, Fig.3.12)
d Site 5 ft above floor (-----------------do----------------)
e Site 2.3 ft above floor (---------------do----------------)
f Average of 3 to 5 sites around chula (1 ft above)

Table 3.9 (Continued) Mean* TSP, CO and BaP in the Field and in the Simulated Village Hut

Location	Field	Tiled Roof	Thatched Roof	Simulated Village Hut V1*	Simulated Village Hut V2**
C. BaP Conc. (ng/m^3)					
Roof	2053 (70)	--	--	1172 (2)	873 (2)
Medium	219 (58)	--	--	814 (2)	551 (2)
Cook	164 (76)	--	--	279 (2)	427 (2)
D. Ratio BaP to TSP (μg/g)					
Roof	120 (70)	--	--	58 (2)	88 (2)
Medium	67 (58)	--	--	109 (2)	80 (2)
Cook	39 (76)	--	--	88 (2)	71 (2)

*Sample Size within brackets
V1* : Only door open, V2** : Door and window open

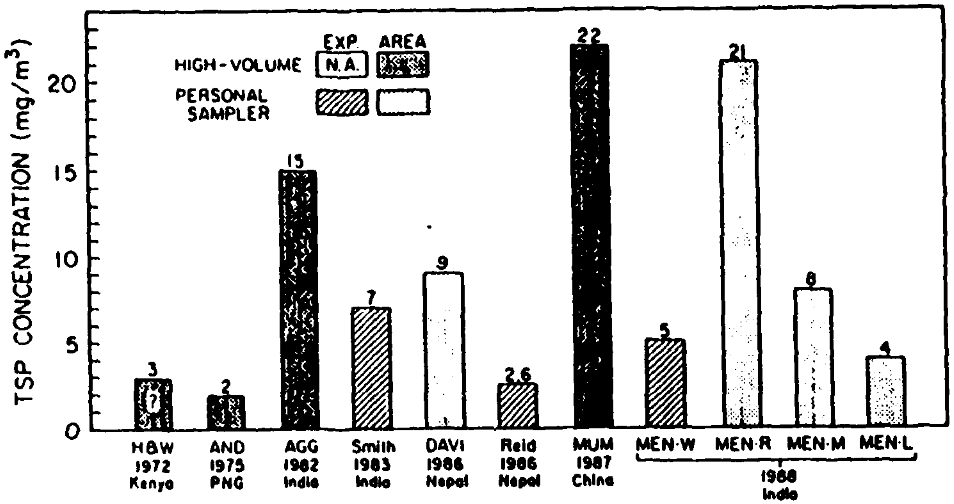

Fig. 3.14 Indoor mean TSP concentration (mg/m^3) reported by several authors. Area sampling means sampler fixed at some point, whereas, exposure means sampler worn by cook.

Davidson, 1985, Reid, 1986 and Mumford, 1987. All these studies, except for Smith, 1983 and Reid, 1986 reported levels sampled at one stationary point in the kitchen and called this the cook's exposure. This study, adopted Smith's 1983 methodology and sampled using personal samplers attached to the cooks in addition to stationary sampling at three sites close to chula. Fig 3.14 shows results to be comparable for studies where personal sampler was used. The higher values reported by Aggarwal and Mumford may be attributed to the use of Hi-volume sampler. The high pump flow rate of which might have refloated lightly deposited soot from walls/roof/floor and dust particulates on mud floors. Further, Aggarwal's result could have introduced error in using less sensitive analytical balance (10-4 gm) as compared to ours (10-5 gm).

POLLUTION LEVEL- CO The mean indoor CO concentrations (ppm) at high, medium, low level and cook's breathing zone were 28, 22, 18 and 51 whereas mean outdoor level was 4 (Table 3.8). The cook's exposure was calculated as the average of CO levels recorded at 5 points at one foot above the chula. The mean CO at high , medium and low levels was calculated as the average of CO levels recorded at several (6 to 9) sites. The levels of CO monitored at the door at three different heights - high, medium, and low level were 10, 9 and 7 respectively. Outdoor CO concentrations ranged between 0 and 11 ppm with mean of 4. Cook's exposure to CO was higher than at any of the stationary sites. (CO was not measured at roof space, which would be definitely higher). Table 3.8 shows increasing indoor CO levels with height both at the door and close to the chula. Table 3.9 shows similar result measured at SVH (High, medium and low levels). CO levels measured for a simulated cook in the SVH was considerably lower with mean of 15 ppm as compared to cook's mean exposure of 51 ppm. This difference is because in the field the CO was monitored around the stove and not exactly at women's breathing zone. The well defined stratified smoke is evident in the SVH and field CO data.

Fig 3.15 presents cook's exposure to CO concentrations as measured by several authors: Sofoluwe, 1968, Cleary and Blackburn, 1968, Dary et al., 1981, Davidson, 1986, Joseph, 1986, Reid, 1986. My results are comparable to Cleary and Blackburn's, Dary's, and Davidson's. The high level sampled by Reid may be due to the placement of sampler on shelf in the wall back of chula where smoke dispersal might be minimum. The exceptionally high levels monitored by Sofoluwe and Joseph may be inaccurate because of low resolution in their methods. Joseph used a monitor with a lowest measurable concentration of 100 ppm, whereas CO monitor used in this study could detect as low as 1 ppm.

POLLUTION LEVELS-BaP The mean indoor BaP concentrations (ng/m3) at roof, medium, and cook's breathing zone were 2053, 219, and 164 and outdoor level was 4 (Table 3.8). BaP analysis was carried out on a limited number of and arbitrarily selected filters. Table 3.8 shows large range of values for each of

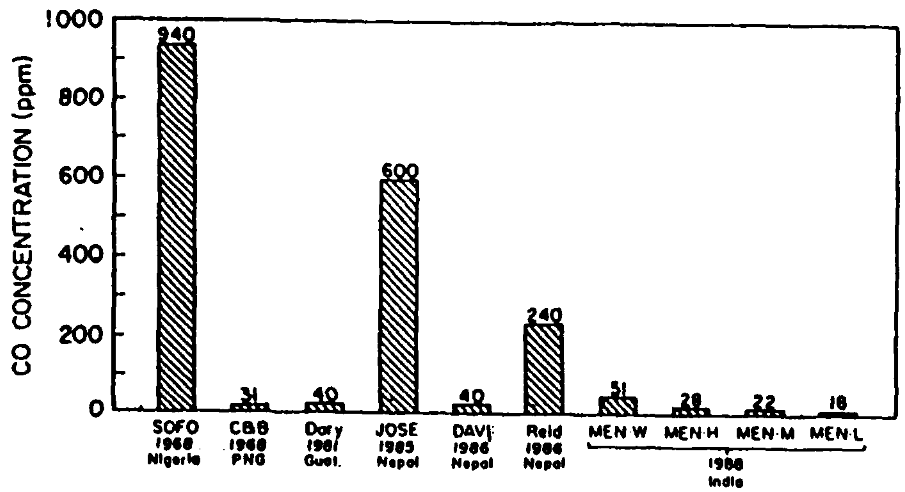

Fig. 3.15 Indoor mean CO concentration (ppm) reported by several authors. All area monitoring.

indoor BaP levels. Table 3.9 shows that roof BaP levels were similar for SVH and field but at the mid level BaP concentrations were considerably smaller in field.

Fig 3.16 presents cook's exposure to BaP concentrations measured by; Hoffmann & Wynder, 1972, Aggarwal, 1982, Smith, 1983, Mumford, 1987. All authors except Smith sampled at stationary site and called it as cook's exposure. My results for cook's exposure are comparable to Hoffmann and Wynder's. The exceptionally high levels reported by Aggarwal and Mumford may be questionable for reasons cited in earlier paragraph relating to use of a Hi-volume sampler (page 124). The levels of BaP found by Smith, et al., 1983 (mean 4000 ng/m3) seem unrealistically high as compared to my mean results of 164. Smith et al., reported levels >500 ng/m3 of BaP in 95% of the sampled filter whereas in this study only 3% were above this level. Smith et al., reported levels for the cook between 62 to 19,300 ng/m3 whereas my BaP results for the cook ranged between 0 and 565. The highest level of BaP for roof was 11,800 which was closer to highest value reported by Smith et al., for cook's exposure. This large difference[1] in BaP result between Smith et al., and my study was suggested to be due to the storage period (6 to 12 months) of my TSP samples before analysed. Hence ten filters exposed to smoke in the breathing zones of cook's in rural kitchens of Nepal were analysed for

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[1] Literature (Rudling, et al., 1982)shows wide variation in PAH emission rates (fireplace) under slight changes in combustion conditions

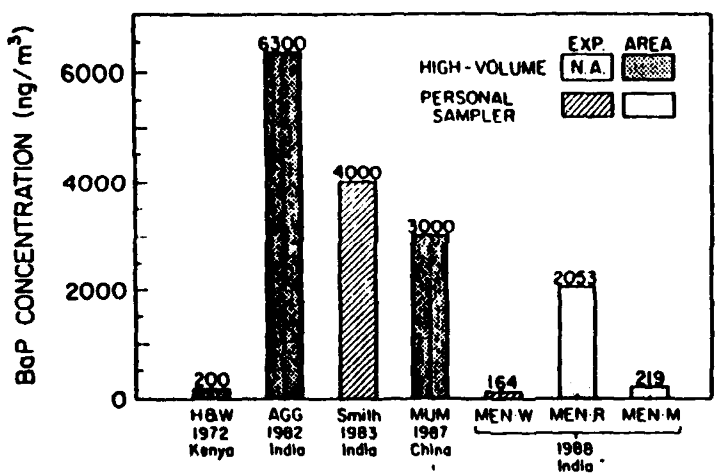


Fig. 3.16 Indoor mean BaP concentration (ng/m^3) reported by several authors.

BaP within three months of sampling for TSP. Table 3.10 shows BaP concentrations obtained and the ratio of BaP to TSP. The concentration ranged from 0 to 1056 ng/m3 with mean of 400 similar to my results. Ambient BaP levels with mean of 4 ng/m3 is comparable to values reported by Rao, 1980 for rural Bombay site. However, it disagrees by almost two orders with the ambient levels reported by Smith,83.

RATIO OF BAP TO TSP The indoor mean ratio of BaP to TSP for roof, medium and cook is 120, 67 and 39 μg/g (Table 3.8). The lower ratio for the cooks may indicate that the filters collected ash/dust blown from the stove and mud floors. Alternatively, the higher ratios for the roof might be due to collection of refloated soot deposited on the roof. Table 3.9 does not show similar result for SVH data, which might be expected as there were negligible soot deposits on the steel roof.

Table 3.11 presents the ratio of BaP to TSP obtained by several authors. We note the mean ratio obtained in this study agrees with other studies (Hoffmann and Wynder, 1972, Dasch, 1982, and He, 1986) except that of Aggarwal, et al.,1982 and Smith et al., 1983. The exceptionally high value obtained by Smith, et al., 1983 is difficult to explain, especially considering the identical sampling protocol (use of personal samplers) and similar combustion conditions (mean burn rate of 2.0 kg/h).

Table 3.10 Cook's Exposure to BaP Concentration in Rural Kitchens of Nepal*

Filter Code	BaP Concentration (ng/m^3)	Ratio BaP/TSP (µg/g)
HO41	1056	111
HO42	0	0
HO43	0	0
HO44	760	83
HO64	622	160
HO65	187	160
HO66	553	62
HO67	233	27
HO68	373	36
HO49#	3510	718

* Filter samples collected by Holly F.Reid.
\# HO49 was used as backup filter for several filters, explaining for it's large difference in BaP concentration

Table 3.11 Mean Ratio of BaP to TSP (µg/g) for Biomass Smoke Reported by Several Authors

S.NO.	n	Mean (µg/g)	Range (µg/g)	Sampling Type	Country	Author
1	7	30	0-71	Area	Kenya	Hoffmann & Wynder,1972
2	9	52	3-141	Emission	USA	Dasch, 1982*
3	19	500	(71-1600)	Area(Indoor)	India	Aggarwal et al.,1982
	--	15	(11-19)	Outdoor		
4	65	800	(10-8000)	Personal	India	Smith, et al., 1983
	5	190	(70-500)	Outdoor		
5	9	71	(0-160)	Personal	Nepal	Reid et al., 1986**
6	62	150	(-----)	Area	China	He, 1986
	12	10		Outdoor		
7	4	73	(55-118)	Roof Area	SVH	This study
8	4	95	(28-158)	Mid level	SVH	----do-----
9	4	80	(19-125)	Low level	SVH	----do-----
10	6	384	(223-549)	Mid level	SVH@	----do-----
11	2	83	(77-89)	Low level	SVH@	----do-----
12	76	39	(0-122)	Personal	India	----do-----
13	70	120	(12-483)	Roof area	-------do---------	
14	58	67	(0-507)	Mid-level	------do---------	
15	12	50	(19-100)	Outdoor	------do---------	

* Fireplace emission

** TSP Filter samples collected by Holly. F.Reid. Filters analysed for BaP by author.

@ Samples taken by Mr.Mike Apte during QCMCI experiments (November, 1982) in simulated village hut and analysed for BaP at Lawrence Berkeley Laboratory.

Conclusions:

1. Ventilation condition varied greatly between kitchens as indicated by an order of magnitude difference in kitchen volume and percentage of open area in the walls. Wall heights differed by 3 m and roof slant height by 2 m. Inspite of a very similar fuel comparision, the burn rate of the fuel used varied from 1 to 6 kg/hr. This may be due to large variations in fuel quality as moisture varied by a factor of 4 and ash content by a factor of 8. Additionally stove size varied by a factor of 30. The cook's experience of maintaining the fire varied considerably with the cook's ages ranging from 8 to 65 years. Under these different ventilation, fuel, stove condition and cook's experience it is reasonable to infer that indoor pollutant levels varied greatly as a result of complex interacting factors.
2. Mean TSP exposure to cooks was 5 mg/m3, twenty times higher than standard specified by regulating agencies (U.S, WHO, and India) for ambient conditions. However, it was equal to the 8-hour time weighted

average standard for occupational condition (OSHA standard for inert nuisance dust). In thatched huts, 66% of the cook's were exposed to TSP above the OSHA standard while in tiled huts it was only 28%. The percentage for twice OSHA standard were 16 and 4 for thatched and tiled roofs respectively. Mean CO exposure to cooks was 51 ppm, three times higher than standard but equal to OSHA's 8-hour time weighted average standard. In thatched huts 25% of the cook's were exposed to CO higher than OSHA standard while for tiled huts it was 48% . Mean BaP exposures to cooks were 160 ng/m3 equal to ambient levels found in urban cities in developed countries. No standard exists for BaP as any amount ingested is harmful as it is suspected to be a carcinogen. The mean ratio of BaP to TSP for the cooks was 39 µg/g. The average cook's exposure to TSP and CO agree with earlier studies in the literature. The mean cook's exposure to BaP is twenty times lower than that reported by Aggarwal et al., (1982) and Smith et al., (1983). Smith and Aggarwal reported levels >500 ng/m3 of BaP in 95% of the sampled filter, whereas in this study only 3% were above this level. The higher (20 times) value for the ratio of BaP to TSP obtained by Smith et al., 1983 is difficult to explain considering similar sampling protocol and combustion conditions.

3. TSP, CO and BaP levels are different at different locations in the room with the cook's exposure similar to low indoor levels and an order of magnitude higher than ambient(outdoor) concentrations. Close to chula TSP, CO, BaP concentration and ratio of BaP to TSP increased with height. Mean TSP and BaP concentrations at roof level were five and ten times higher than those experienced by the cook's whereas cook's exposure to CO was twice than at standing height. In thatched huts, TSP at standing height was almost all times greater than cook's exposure while for tiled huts it was so only in half the cases. In case of thatched huts, 45% of CO at standing height was greater than cook's exposure while for tiled huts it was only

18%. These results indicate the uniform stratification in thatched huts in comparision to tiled huts and also indicate existence of varying ventilation conditions.

4. TSP, CO and BaP levels in thatched huts were comparable to those measured by me in SVH.

3.2.3 SIGNIFICANT DIFFERENCES OF COOK'S EXPOSURE TO TSP AND CO AND LEVELS OF TSP AT ROOF

Analysis of variance (ANOVA) was one of the statistical methods used to determine whether cook's exposure to TSP and CO, and TSP concentration at roof were significantly different for:

a. Village
b. Season*
c. Time of day*
d. Kitchen type*
e. Roof type
f. Door location
g. Fuel type
h. Food type

When only two groups are present, the ANOVA reduces to the two-sample t-test and this method was used for variables having two groups (indicated by asterisk) the ANOVA for the rest. The t-Test procedure tests both the equality of means and variances of the two groups. If the variances are significantly different, the separate t-Test procedure is used to test equality of means, otherwise the pooled t-Test procedure. Table 3.12a shows t-Test result obtained for variables marked in asterisk above.

The mean roof TSP levels was significantly ($p < .01$) lower during monsoon (15 mg/m3) than during winter (30 mg/m3). This seems reasonable, as during the winter season the chula was usually used for space heating in early morning and late evening. Thus smoke from space heating was sampled along with smoke from cooking.

Mean CO exposure to the cook during monsoon (47 ppm) was significantly ($p < .05$) lower than during the winter season (58 ppm). This can be explained by the fact that during the monsoon, the cooks generally used dry wood stored and saved during winter and summer months which burns more complete. This is contrary to earlier stated (section 3.1.5, page 99) hypothesis, that the poor fuel quality during monsoon months would result in high exposures to cooks, during the monsoon months.

Mean CO exposure of the cook was significantly ($p < .01$) higher during the morning (60 ppm) than during the evening (44 ppm). This is probably a result of the chula being moist and colder(chula not in use for about 12 hours) before the morning fire is lit, whereas in the evening cooking period it's opposite is true. Smith et al., (1983) and Reid et al., (1986) reported higher evening concentrations of TSP and CO but attributed these to local ground level atmospheric inversions.

TAble 3.12a T-test of Pollutants by Season, Sampling Time and Kitchen Type

Variable	Group	n	TSP (Roof) mg/m³ Mean	T	TSP (Cook) mg/m³ Mean	T	CO (Cook) ppm Mean	T
Season (V012)	Monsoon	76	15	4.5**	4.6	1.0	47	1.7*
	Winter	53	30		4.2		58	
Time of Day (V006)	A.M	60	20	0.9	4.7	1.1	60	2.8**
	P.M	69	22		4.2		44	
Kitchen Type (V013)	Door	91	30	0.8	4.5	0.3	50	0.5
	Door + Open Area	38	19		4.3		54	

* Difference significant at .05 level
** Difference significant at .01 level

It seems more reasonable that the bouyancy of the smoke would be a dominant factor in pollutant dispersion near the chula during cooking periods rather than an outdoor inversion.

The ANOVA procedures enables one to carry out a posteriori contrast, to determine the significantly different means. Two of the many procedures is the SNK (Student-Newman-Keuls) and Scheffe (Scheffe's test). The Table 3.12b summarizes the results obtained for the remaining variables listed in previous paragraph.

The significant difference ($p < .05$) between the mean level of CO that a cook is exposed to in the village Adampur (36 ppm) and that at Islamnagar (65 ppm) is an effect of experimental setup, since all the experiments in Islamnagar were carried out in the morning period whereas all the experiments in Adampur were carried out in the evening period due to transportation constraint. As already found by the T-test the CO exposure to the cooks were significantly higher in the morning than in the evening.

Mean TSP (roof) concentrations were significantly ($p < .05$) higher (22 mg/m3) when roti is cooked as opposed to when rice is cooked (11 mg/m3). It is possible that the higher moisture content during rice cooking might have led to greater deposition of particulates on the walls.

The mean cook exposure to TSP was significantly ($p < .01$) higher (6 mg/m3) in kitchens with thatched roofs when compared to those in tiled roof (4 mg/m3). Intolerable smoke levels

Table 3.12b Test# of Variance of Pollutants by Village, Roof Type, Door Position, Fuel and Food Type

Variable	Group	n	TSP (Roof) mg/m3 Mean	TSP (Roof) Pair Sig. Diff.	TSP (Cook) mg/m3 Mean	TSP (Cook) Pair Sig. Diff.	CO (Cook) ppm Mean	CO (Cook) Pair Sig. Diff.
Village (V002)	1.Adampur	23	26	NONE	4	NONE	36	(1,2)*
	2.Islamnagar	42	22		5		65	
	3.Padaria	54	20		5		49	
	4.Ariyur	4	13		3		61	
	5.Perambia	6	12		2		27	
Roof Type (V014)	Tiled(1)	100	20	NONE	4	(1,3)**	53	NONE
	Pucca(2)	6	17		4		37	
	Thatch(3)	23	27		6		49	
Door w.r.t Chula (V027)	Back(1)	24	20	NONE	5	(3,4)*	45	NONE
	Side(2)	31	23		5		41	
	Front(3)	50	21		4		55	
	Far Side (4)	24	19		6		63	

\# One-way program in SPSSX (Statistical Package for Social Scientists, Nie, 1980)

* Difference significant at .05 level
** Difference significant at .01 level

Table 3.12b (Continued) Test# of Variance of Pollutants by Village, Roof Type, Door Position, Fuel and Food Type

Variable	Group	n	TSP (Roof) mg/m^3 Mean	TSP (Roof) Pair Sig. Diff.	TSP (Cook) mg/m^3 Mean	TSP (Cook) Pair Sig. Diff.	CO (Cook) ppm Mean	CO (Cook) Pair Sig. Diff.
Fuel Type (V009)	Wood(1)	36	20	NONE	5	NONE	47	NONE
	Dung(2)	1	16		9		51	
	Wood and Dung(3)	90	22		4		54	
	Crop Residue(4)	2	11		3		30	
Food Type (V010)	Rice(1)	12	11	(1,2)*	3	NONE	46	NONE
	Roti(2)	108	22		5		51	
	Rice and Roti (3)	9	23		5		65	

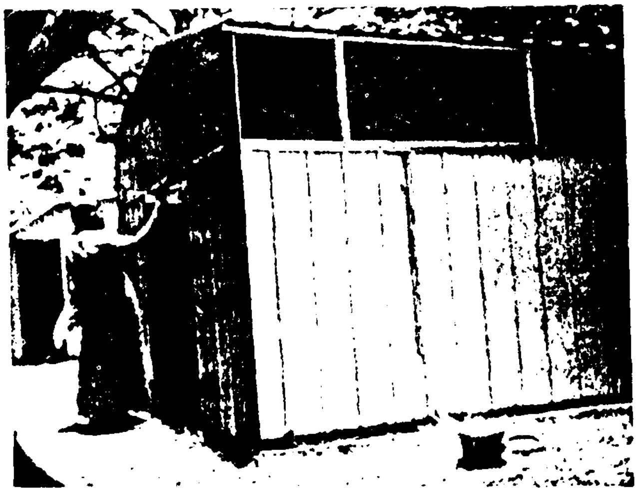
* Difference significant at .05 level

inside thatched huts clearly demonstrated the need to include roof type as one of the ventilation indicators. On entering a thatched hut the researchers immediately got tears and squatted on the floor to interview the cooks, whereas in tiled kitchens, the air quality was tolerable and in some cases quite comfortable while standing. The environment within SVH and thatched hut were comparable. Fig 3.17 shows the different roof types.

The cook's mean TSP exposure (4 mg/m3) was significantly ($p < .05$) lower for the kitchens with the door in the front than for those (6 mg/m3) with door on the far side (Fig 3.13).

Summary of significant differences in TSP (roof), cook's exposure to TSP and CO:

1. CO higher for cooks in village Adampur than cooks in Islamnagar, due to experimental setup.
2. TSP (roof) and CO (cook) are higher in winter than in monsoon.
3. CO (cook) higher in morning than evening.
4. No difference between kitchens with only door and kitchens with door and open space.
5. TSP (cook) higher for kitchens with thatched roofs than for tiled roofs.
6. TSP (cook) lower for kitchens with door in front wall than kitchens with door in side wall.



SIMULATED VILLAGE HUT
HONOLULU, HAWAII

THATCHED ROOF HUT
PADARIA VILLAGE,
BHOPAL, INDIA

TILED ROOF HUT
PADARIA VILLAGE,
BHOPAL, INDIA

Fig. 3.17

7. No difference between fuel type.
8. TSP (roof) higher for roti when compared to rice.

3.2.4 MAIN EFFECT AND INTERACTIONS OF CLIMATE, VENTILATION AND SAMPLING LOCATION ON CO

Indoor spatial CO data were obtained by repeatedly measuring CO at 6 to 9 sites at three levels (high, medium and low, Fig 3.12) in all the huts sampled in the 5 villages. These data were used to statistically determine which of the factors season, roof type, sampling site, sampling height, and interaction amongst these, had significant effect on CO concentration. The statistical procedure for this was the k-way ANOVA. The reasons for selecting season, roof type, sampling height and site as variables were:

1. The experiments were conducted in two seasons, monsoon and winter. CO(cook) and TSP(roof) were found to be significantly higher during the later season.
2. Roof type was found to be an important ventilation factor in determining pollutant levels inside village huts.
3. Sampling height and site was found to affect pollution concentration both in the field and SVH experiments.

SPSSX ANOVA procedure was used to determine the effect and interaction of climate, ventilation, sampling level and site. Table 3.13a presents the result of this investigation. The effects of roof type, sampling height, site and 2-way interaction effect of level with roof type and site were found to be significant. On finding the effect of season not significant, kitchen volume was included as additional factor of ventilation condition and the computation was performed this time for monsoon and winter separately. As the volume of the kitchens varied greatly, it was categorised into three classes:

1. Low volume (low-thru 22 m3)
2. Medium volume (22 thru 40 m3)
3. High volume (above 40 m3)

During both season (Table 3.13 b and c) the main effects of roof type, sampling height level and site were found to be significant. During the monsoon the 2-way interaction of roof type with site had significant effect on CO, while during the winter interaction with volume dominated.

Conclusion:

1. Roof type, sampling height and site significantly affected CO concentrations.
2. During the monsoon 2-way interaction of roof type with site had a significant effect on CO, while during the winter interaction with volume dominated.

Table 3.13a

Test of Variance of CO by Roof Type, Season, Sampling Height and Location in Indian Huts Using Split-Plot Analysis

Whole Plot Analysis	DF	Mean Sq.	F
Roof Type	1	106536.1	73.7**
Season	1	854.8	0.6
Level	2	77267.9	53.4**
Level X Roof Type	2	9293.1	6.4**
Level X Season	2	2378.1	1.6
Roof Type X Season	1	34.4	0.0
Whole Plot Error			
RFTYP X SEAS X Level	2	1446.2	
Sub-Plot Analysis			
Site	8	67437.9	103.5*
Site X RFTYP	8	1089.4	1.7*
Site X Season	8	409.8	0.6
Site X Level	16	1344.7	2.1*
Site X RFTYP X Season	8	608.9	0.9
Site X RFTYP X Level	16	358.2	0.6
Site X Season X Level	16	414.2	0.6
Sub-Plot Error	3076	651.4	

* Significant at .05 level
** Significant at .01 level

Table 3.13b

Test of Variance of CO During Monsoon by Roof Type, Kitchen Volume, Sampling Height and Location in Indian Huts Using Split-Plot Analysis

Whole Plot Analysis	DF	Mean Sq.	F
Roof Type	1	52510.9	20.0*
Volume	2	9276.3	3.5
Level	2	62083.2	23.6**
Level X Roof Type	2	7674.6	2.9
Level X Volume	4	669.6	0.3
Volume X Roof Type	2	962.4	0.4
Whole Plot Error			
RFTYP X VOL X Level	4	2626.4	
Sub-Plot Analysis			
Site	8	38727.9	61.2**
Site X RFTYP	8	2001.1	3.2*
Site X Volume	16	1030.9	1.6
Site X Level	16	1281.9	2.0
Site X RFTYP X Volume	16	744.7	1.2
Site X RFTYP X Level	16	366.1	0.6
Site X Volume X Level	32	378.9	0.6
Sub-Plot Error	1769	632.4	

* Significant at .05 level
** Significant at .01 level

Table 3.13c

Test of Variance of CO During Winter by Roof Type, Kitchen Volume, Sampling Height and Location in Indian Huts Using Split-Plot Analysis

Whole Plot Analysis	DF	Mean Sq.	F
Roof Type	1	39129.8	22.9**
Volume	2	5921.6	3.5
Level	2	19115.5	11.2*
Level X RFTYP	2	2886.6	1.7
Level X Volume	4	161.2	0.1
Volume X RFTYP	2	13833.1	8.1*
Whole Plot Error			
RFTYP X VOL X Level	4	1701.4	
Sub-Plot Analysis			
Site	8	29550.6	46.8**
Site X RFTYP	8	126.9	0.2
Site X Vol	16	1065.9	1.7
Site X Level	16	506.8	0.8
Site X RFTYP X VOL	16	938.4	1.5
Site X RFTYP X Level	16	253.9	0.4
Site X Vol X Level	32	241.7	0.4
Sub-Plot Error	1139	630.9	

* Significant at .05 level
** Significant at .01 level

3. For CO measured in SVH, we found only sampling height had a significant effect (Table 3.4). This may be due to uniformity in fuel type and ventilation conditions.

3.2.5 STATISTICAL MODEL FOR ESTIMATING COOK'S EXPOSURE TO TSP

Three techniques were employed to develop a statistical model for estimating cook's exposure to TSP in terms of meteorological, ventilation, fuel and stove parameters:

A. Multiple linear regression

B. Path Analysis

C. Group Method of Data Handling (Ivakhnenko polynomial)(GMDH)

A. A multiple linear regression model between cook's exposure to TSP and several indicators of the independent variables (meteorological, ventilation, fuel and stove) variables was developed using step-wise regression procedure. The best 3-variable model explained only 27% of the variance in cook's exposure to TSP. The statistical relationship was in terms of three variables (roof type, fuel type and volume of the roof space) as listed in Table 3.14.

Table 3.14 Multiple Regression* Model Between Cook's TSP Exposure and Best 3 Variables

Maximum R-square Improvement for dependent variable (cook's exposure to TSP)

R Square = 0.27 C(P) = -5.18

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	211.3	70.4	14.2	0.0001
ERROR	115	572.4	4.9		
TOTAL	118	783.7			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-5.6				
FUEL TYPE	1.1	0.43	31.8	6.4	0.0129
ROOF TYPE	1.0	0.18	59.9	32.1	0.0001
VOL.(ROOF AREA)	0.1	0.04	23.5	4.7	0.0319

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND

* Using step-wise regression procedure, SAS

B. Path Analysis

A path model was hypothesized (Fig 3.18) showing the direct and indirect relationships between meteorological, ventilation, fuel, stove and cook's exposure to TSP. The meteorological variable is employed as the source factor affecting the ventilation, fuel quality, combustor conditions and the pollutant concentration. Ventilation is shown affecting fuel quality and combustor conditions. Fuel variable is viewed as a function of the direct affect of both meteorological and ventilation parameters. Finally the pollutant concentration is viewed as a function of the direct affects of fuel and stove and of the affects, both direct and indirect of ventilation and meteorological factors.

LISREL (Joreskog and Sorbom, 1979) is one of the most common method of path analysis known and is available at U.H. Computing center. However, the use of LISREL in small sample situations (< 1000) is not appropriate, therefore, the procedure developed by Rao et al., (1980) at the Population Genetics Laboratory of University of Hawaii was used to evaluate the proposed model. The mathematical formulation and it's salient features are discussed in Gunashekharan (1985).

The best indicators of meteorological, ventilation, stove and fuel were obtained from the correlation matrix between cook's exposure to TSP and the different indicators for each of the independent parameters. Indoor relative humidity (In.R.H),

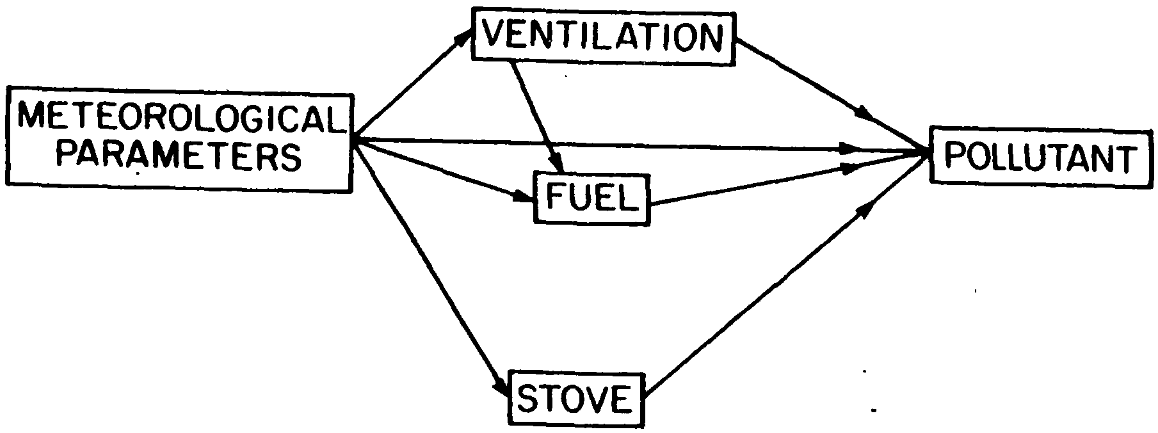


Fig. 3.18 Proposed structural model showing direct and indirect relationships between meteorological, ventilation, fuel, stove and pollutant.

roof type, fuel type and stove wall height were the best indicators for meteorological, ventilation, stove and fuel parameters respectively Fig 3.15 (a to d). The input for the path analysis procedure is the correlation matrix (Table 3.16) between these variables and cook's exposure to TSP. The result of the path analysis is illustrated in Fig (3.19). The model fits quite well (p =.60), but the linear association between individual variables is weak. The only significant association is between roof type and cook's exposure to TSP.

C. Group Method of Data Handling (Ivakhnenko polynomial)

Because of the weak linear relationship between the meteorological, ventilation, fuel, and stove variables with cook's TSP exposure, an interactive statistical approach for identifying an optimally complex model, which may have greater explanatory power (GMDH, Farlow, 1984) was employed. A complex statistical model (Ivakhnenko polynomial) explaining 70% of the variance in cook's TSP exposure was obtained in terms of the variables roof type, position of door with respect to chula and their interactions. The functional form was:

$$\text{Cook's TSP exposure} = 8.2 + 6.1(\text{Roof type}) - 9.2\,(\text{door w.r.t chula}) - 1.0\,(\text{Roof type})^2 + 2.1\,(\text{door w.r.t chula})^2 - 0.3\,(\text{Roof type X door w.r.t chula})$$

Conclusion:

1. The relationships are not linear.
2. GMDH method better than path analysis.

Table 3.15a Correlation Matrix of Cook's TSP Exposure and Climate Indicators

	TIME	SEASON	INDOOR TEMP.	OUTDOOR TEMP.	INDOOR R.H.	OUTDOOR R.H.	COOK'S EXP TSP
TIME	1.00	0.03	-0.23	-0.23	0.26	0.05	0.079
SEASON		1.00	0.81	0.79	0.62	0.45	0.145
INDOOR TEMP.			1.00	0.94	0.37	0.36	0.141
OUTDOOR TEMP.				1.00	0.40	0.35	0.152
INDOOR R.H.					1.00	0.04	0.154
OUTDOOR R.H.						1.00	0.072
COOK'S EXP TSP							1.00

Table 3.15b Correlation Matrix of Cook's TSP Exposure and Stove Indicators

	FOOD COOKED	NUMBER (PEOPLE)	STOVE VOL.	STOVE WALL HT.	COOK'S EXP TSP
FOOD COOKED	1.00	-0.09	-0.04	-0.03	0.01
NUMBER (PEOPLE)		1.00	0.27	0.11	0.09
STOVE VOLUME			1.00	0.55	-0.03
STOVE WALL HT.				1.00	0.14
COOK'S EXP TSP					1.00

Table 3.15c Correlation Matrix of Cook's TSP Exposure and Ventilation Indicators

	KCHTYP	RFTYP	Cubical Volume	Roof Volume	Wall Height	Slant Roof Height
KCHTYP	1.00	0.11	-0.35	-0.13	-0.29	0.04
RFTYP		1.00	-0.11	0.01	-0.29	-0.01
Cubical Volume			1.00	0.68	0.44	-0.03
Roof Volume				1.00	0.19	0.48
Wall Height					1.00	0.18
Slant Roof Height						1.00

Table 3.15c (Continued) Correlation Matrix of Cook's TSP Exposure and Ventilation Indicators

	Total Kitchen Volume	Open Area Index	Door w.r.t Chula	Cook's Exposure TSP
KCHTYP	-0.33	-0.41	-0.04	0.00
RFTYP	-0.10	0.13	0.10	0.45
Cubical Volume	0.86	-0.12	0.14	0.06
Roof Volume	0.55	-0.14	0.03	0.16
Wall Height	0.41	0.20	0.17	-0.12
Slant Roof Height	-0.05	0.15	-0.01	0.05

Table 3.15c (Continued) Correlation Matrix of Cook's TSP Exposure and Ventilation Indicators

	Total Kitchen Volume	Open Area Index	Door w.r.t Chula	Cook's Exposure TSP
Total Kitchen Volume	1.00	-0.18	0.04	0.01
Open Area Index		1.00	-0.17	-0.01
Door w.r.t Chula			1.00	0.23
Cook's Exposure TSP				1.00

Table 3.15d Correlation Matrix of Cook's TSP Exposure and Fuel Indicators

	FLTYP	Wood Qty.	Dung Qty.	Total Burn Time	Burn Rate	Moisture Wood
FLTYP	1.00	-0.04	-0.17	-0.09	-0.09	-0.03
Wood Qty.		1.00	-0.22	0.32	0.58	0.10
Dung Qty.			1.00	0.33	0.28	0.06
Total Burn Time				1.00	-0.19	0.08
Burn Rate					1.00	0.04
Moisture Wood						1.00

Table 3.15d (Continued) Correlation Matrix of Cook's TSP Exposure and Fuel Indicators

	Moist Dung	Ash Wood	Ash Dung	Wood Length	Wood Thick	Dung Diam.	Dung Thick	Cook's Expos. TSP
FLTYP	-0.44	-0.11	-0.39	-0.24	-0.09	-0.44	-0.42	0.19
Wood Qty.	-0.28	0.16	-0.33	0.08	0.18	-0.23	-0.17	0.00
Dung Qty.	0.54	0.05	0.45	0.09	0.11	0.48	0.36	-0.09
Total burn Time	0.14	0.05	0.04	0.22	0.03	0.15	0.18	-0.14
Burn Rate	0.02	0.15	0.02	-0.04	0.22	0.04	-0.05	0.02
Moisture Wood	0.07	-0.07	-0.11	0.14	0.09	-0.07	-0.05	-0.06

Table 3.15d (Continued) Correlation Matrix of Cook's TSP Exposure and Fuel Indicators

	Moisture Dung	Ash Wood	Ash Dung	Wood Length	Wood Thick	Dung Diam.	Dung Thick	Cook's Expos. TSP
Moisture Dung	1.00	0.01	0.72	0.03	-0.06	0.83	0.75	-0.08
Ash wood		1.00	-0.03	0.10	-0.09	0.13	0.12	-0.10
Ash Dung			1.00	0.06	-0.04	0.77	0.62	-0.07
Wood Length				1.00	-0.23	0.17	0.09	-0.11
Wood Thick					1.00	-0.05	0.01	-0.09
Dung Diam.						1.00	0.69	-0.06
Dung Thick							1.00	-0.10
Cook's Expos. TSP								1.00

Table 3.16 Correlation Matrix Between Input Variables for Path Analysis

	INDOOR TEMP.	ROOF TYPE	FUEL TYPE	STOVE WALL HT.	COOK'S EXP TSP
INDOOR TEMP.	1.00	0.07	0.00	0.02	0.15
ROOF TYPE		1.00	-0.00	0.09	0.45
FUEL TYPE			1.00	0.03	0.19
STOVE WALL HT.				1.00	0.14
COOK'S EXP TSP					1.00

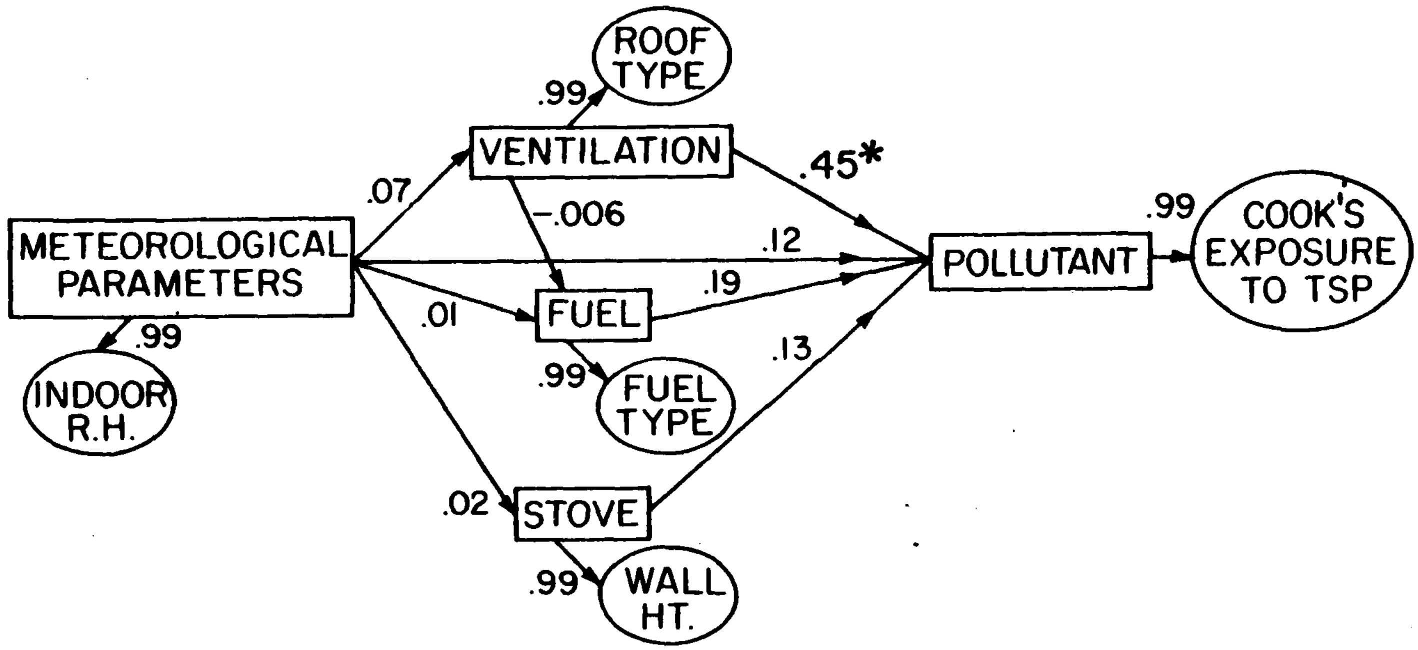


Fig. 3.19 Model with path estimates.

* Parameter estimate should be twice its standard error in order to be significantly different from zero.

IV. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

Indoor air pollution from burning biomass fuels for cooking in the developing world has recently gained increased attention though a few studies already in the 1960s and early 1970s reported high smoke levels inside rural huts. Recently Smith et al., 1983 found rural Indian cooks's mean exposure to BaP (benzo-a-pyrene, a known carcinogen) as high as 4,000 ng/m^3, equivalent to smoking 20 packs of cigarettes per day. Agencies such as the World Health Organisation, the National Research Council in U.S.A., and the Centre for the Environment in India have stressed the need for research in this area.

This dissertation focusses on three indoor air concentrations of combustion generated pollutants TSP, CO, and BaP, emitted by Indian cookstoves. Initial experiments conducted during Fall 1982 through Spring 1983 in a simulated village hut (SVH) on the grounds of the East West Center and the University of Hawaii, determined size distribution of particulates emitted from burning of fuelwood <u>leuceana</u> and cowdung, and investigated the effects of fuel, ventilation condition and sampling location on TSP, CO and BaP concentrations. 84 to 99% of the total particulate mass in wood and dung smoke had aerodynamic diameter less than 3.2 um, which eliminated the need for particle size discriminating sampling. The geometric mean for dung and wood smoke particle size was 0.17 µm. TSP, CO and BaP levels were as high as 83 mg/m^3, 294 ppm and 2000 ng/m^3. Concentrations increased with height. The presence of an open window above chula reduced the concentrations significantly. TSP was about twice as high for dung than for wood smoke. These experiments finalised the field sampling protocol.

The field survey included 291 households in the three central and two south Indian villages. Socio-economic, kitchen ventilation conditions, fuel use and villagers' perception of health problems related to smoke were surveyed. Most kitchens (69%) had tiled roofs with a variety of volumes and open spaces on the walls. Cooks used a mixture of several wood species and dung and were all bothered by smoke, but stressed fuel procurement as their chief concern. Fixed monitoring for TSP was done at three different height (roof, medium and low) about 2 feet by side (where women squat) of the chula. A personal sampler on the cook monitored air in her breathing zone. CO was monitored consecutively at minimum of 6 and maximum of 9 sites (at 2 ft ahead in front of chula) at three different height (high, medium and low) in addition to cook's breathing zone. 129 households in the five villages were sampled for TSP and CO during the monsoon and winter months of 1983. About 300 arbitrarily selected filters were analyzed for BaP using HPLC. Fuel samples were analysed for moisture, ash content and calorific value.

Indoor pollutant levels varied considerably as a result of differences in ventilation, fuel quality, and cook's experience. Mean TSP exposure to cooks was 5 mg/m^3, twenty times higher than the standard specified by regulating agencies, e.g USEPA, WHO and Dept. of Environment, Govt. of India for ambient conditions. Mean CO exposure to cooks was 51 ppm, three times higher than the corresponding standard. However, TSP and CO levels are equal to OSHA (Occupational Safety and Health Adminstration) standards. Mean BaP exposures to cooks was 160 ng/m^3, equal to ambient levels found in urban cities in developed countries. While cook's mean exposure to TSP and CO agrees with earlier studies, her exposure to BaP in is an order of magnitude lower in this study. Pollution levels varied considerably at different locations in the kitchens. The cook's exposure was similar to lowest indoor levels but order of magnitude above ambient (outdoor) concentrations. Next to the stove or chula concentrations increased with height. Concentrations in thatched huts were comparable to those measured in SVH. Tiled hut roofs allowed smoke seepage resulting in much lower concentrations than in thatched huts. TSP (roof) and CO (cook) were significantly (alpha = .01) higher in winter than during monsoon. CO (cook) was significantly higher in morning than evening. Analysis of variance (split-plot analysis) of the spatial CO data showed significant effects of roof type, sampling level and sampling location in addition to significant 2-way interaction effects of roof type with volume and site. A linear model relating cook's exposure to TSP and three independent variables (roof type, fuel type, volume of roof space) explained only 25% of the variance in cook's exposure to TSP, whereas a complex statistical model (Ivakhnenko polynomial) in terms of roof type and the position of door with respect to chula explained it's 70% of the variance. Path analysis was tried and found poor linear relationship amongst the proposed parameters, though the model fit was adequate.

The following steps may help in reducing the cook's exposure to pollutants:

1. Cooks should be encouraged to cover their face with their sari[1] as preventive measure.
2. Build short wall adjacent to chula and place the door on the opposite wall (Fig 4.1).
3. Build mud hoods at about two feet above the chula enabling the smoke to be guided out (Fig 4.1).
4. Glass pane (about 2 sq. ft) on the roof above the chula (Fig 4.1) will help lighting the dark kitchens.

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1 North Indian women do cover their face in front of elders (male In-laws)

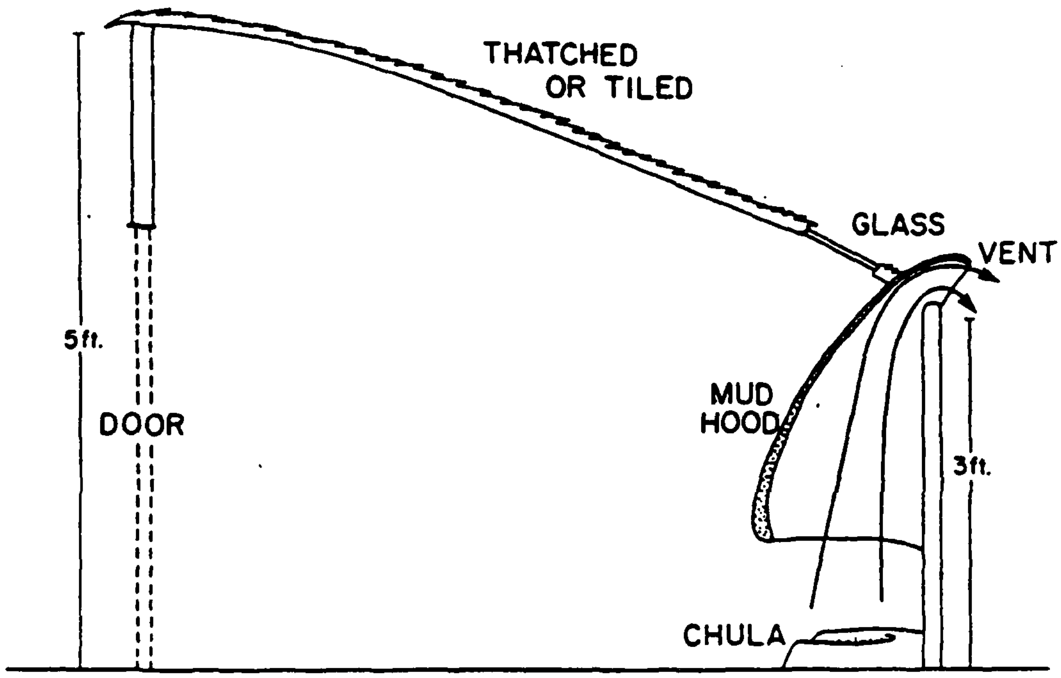

Fig. 4.1 Sketch of proposed rural kitchen with mud hood and shorter wall adjacent to chula, door placed on the wall opposite to chula and a glass pane on the roof.

5. Open area (about 2 sq.ft) on the higher level of the walls adajacent to the chula.
6. Tiled roofs instead of thatched ones.
7. Use of dung as fuel should be discouraged.

4.2 RECOMMENDATIONS FOR FUTURE STUDIES

TSP exposures for the cook and at three heights near the chula were measured during the cooking period. As the kitchens had mud floors and the roofs above chula were covered by soot and dust, the samples might have included resuspended soot and dust along with smoke particulates from fires. Further studies should incorporate background indoor sampling without fire burning to determine the indoor air quality in rural huts to allow a more precise determination of the contribution from cooking.

TSP concentrations were obtained gravimetrically. Future studies might determine dust and soot separately.

Part of the BaP analysis should have repeated Aggarwal's, 1982 and Smith's, 1983 method for a direct comparision. Determining the precision of their method and the one used in this study would make the comparision more meaningful. Filter samples analysed for total POM might be better.

Ventilation from openings in the walls and roof was the most effective factor, in reducing indoor smoke concentrations both in SVH and in the field. A future study might concentrate on different ways to increase ventilation.

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