INDOOR AIR POLLUTION FROM FIREWOOD COMBUSTION IN RURAL KITCHENS OF NORTH EAST INDIA WITH SPECIAL REFERENCE TO SONITPUR DISTRICT, ASSAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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"শেয়হি জ্ঞানমভ্যাশাজজ্ঞানাধ্যানং ৱিশিষ্যতে ।
ধ্যানাৎ কর্মফলত্যাগস্ত্যাগাচ্ছান্তিৰনন্তৰম ।।"

মদ্ভাগৱত গীতা; দ্বাদশ অধ্যায়

"KNOWLEDGE IS SUPERIOR TO PRACTICE, DELIBERATION IS SUPERIOR TO KNOWLEDGE AND THE SACRIFICE AGAINST HARD WORK IN QUEST OF SUCCESS IS SUPERIOR TO DELIBERATION. THIS SACRIFICE WILL LEAD TO ACHIEVE ETERNAL PEACE".

Madbhagabat Geeta, 12th Chapter.

I WANT TO DEDICATE THIS THESIS TO MY FATHER *LATE DEBA PRASAD SAIKIA* WHOSE SKY FULL LOVE AND PRINCIPLE OF LIFE INSPIRED ME TO DO THIS EVENTFUL WORK SUCCESSFULLY.

Prasenjit

Abstract

Indoor air pollution (IAP) refers to the change in physical, chemical, and biological characteristics of air in the indoor environment within a home, building, or an institution or commercial facility. Indoor air pollution is a concern in the developed countries, where energy efficiency improvements sometimes make houses relatively airtight, reducing ventilation and raising pollutant levels. However, last several years study on IAP from several parts of the glob shows severe impact in developing countries particularly in the rural areas. Indoor air problems can be subtle and do not always produce easily recognized impacts on health. Different conditions are responsible for indoor air pollution in the rural and urban areas.

In the north eastern region of India, most of the people in rural areas use firewood for cooking, room heating and other household applications. With the variation in the socio-cultural, housing, climatic conditions, time-activity pattern of household members and fuel use pattern, the exposure of IAP may be different in different region. So, there is a need to study the impact of IAP on human health and the assessment of interventions for reducing exposure.

The present thesis mainly of five chapters viz., Introduction, Literature of review, Materials and methods, Results and discussion and finally Summary.

Introduction chapter mainly deals with the global scenario of IAP. The chapter also includes the phenomenon of wood combustion and wood combustion in stoves. Besides these, based on current literatures emissions of different toxic gases from biomass combustion as well as diseases involved from that exposure were discussed.

Review of literature deals with the current progress of studies regarding fuelwood consumption pattern, emission from the stoves, intervention studies and the knowledge gaps regarding IAP.

Third chapter, materials and methods deals with selection of study site, preliminary questionnaire survey, methods for stove efficiency and fuel consumption study alongwith emission parameter study for CO, CO_2 and $PM_{2.5}$ for both pre/post intervention studies.

As a part of the study, preliminary questionnaire survey has been conducted in the study areas. For present study we have selected ten rural villages of Sonitpur district, namely, Napaam, Jaglouni, Bhaluk jharoni, Baruadoloni, Puthimari, Geruah, Balikhuti, Bapubheti, Pithakhowa and Baligaon. The reason behind the selection of these ten villages was that they represent almost all the major communities living there. They represent the major household design and socio-economic status of the rural areas of the north eastern region. Furthermore, the household of these selected villages are mostly depending on solid fuel use such as firewood and dung for their cooking and heating purpose. The questionnaire was based on the demographic, economic, architectural, fuel use, and health aspects of the households that potentially relevant to IAP. About 10% of the total households were surveyed comprising of a total of 1268 number of households in ten villages. The households survey was done on the basis of Census 2001, Govt. of India. For collection of additional information, sometimes group discussions were also made with the village people about their livelihood, fuel collection and consumption pattern, diseases particularly they suffered in that area, and awareness amongst them about IAP.

After completion of the preliminary field survey; to study the stove efficiency and fuel consumption pattern, stratified households were randomly selected, which mainly use biomass fuels (firewood and dung) for their cooking and heating purposes. After taking the consent from the selected household peoples, we carried out the study on stove efficiency and fuel consumption pattern in the households by adopting standard protocols for Water Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT).

We have considered before and after (without control) for our current study as it requires smallest sample size of all designs and reduces selection bias because the same households are used for intervention studies and accordingly stove efficiency and fuel consumption pattern along with emission parameters were investigated.

For emission study, a stratified and randomized subset of households where preliminary questionnaire was performed, was selected for monitoring of respirable particulates ($PM_{2.5}$), CO and CO_2 and the monitoring was done for approximately 24 - hour period depending on different kitchen environment where stove performance and fuel consumption analysis was also performed. At the end of each monitoring period, a time-activity questionnaire was administered to the household members particularly the main cook of the household.

For intervention study, we have selected a design of *Lakshmi* cookstove (Improved) which is familiar in the southern part of the India. We have little bit modified the design and tested in the laboratory and found the efficiency ~ 30%. The selected design is a two pot cookstove system having a chimney attached in it. We have made the stove with clay, cowdung and dried rice leafs. We have selected and made the design keeping in view that the costs of the stove are minimal and all the required substance is abundant in the rural areas so that people can adopt easily.

To carry out the intervention study, a sub set of the previously monitored households were selected. In these purpose, to motivate the people about the new design of the improved cookstove and its usefulness to their life demonstration and training was given among the peoples particularly women. We had trained some village persons particularly women in making the selected design of the improved cookstove and with the help of them demonstration as well as construction of the cookstove were made in the selected households. Regarding the implementation of the cookstove, it was found very difficult to approach with such a newly designed cookstove among the village peoples who are more familiar to their old ones. So, we had to visit so many times in the households to discuss and convinced them about it and to get their willingness for implementation.

After one month of the installation of the improved cookstove, stove efficiency and fuel consumption analysis was carried out again as per the procedure performed earlier. Similarly, emission studies for $PM_{2.5}$, CO and CO_2 was carried out in the same households, where the improved stove was implemented.

Chapter IV (Results and discussion) again subdivided into four parts. In the first part of the chapters results of preliminary were represented and discussed. In the second part, results of stove efficiency and firewood consumption pattern from WBT, CCT and KPT were presented and discussed. Third and fourth part of the chapter deals with the results of emission studies and overall statistical analysis of the results respectively.

The main conclusions of the first part of Chapter IV is that 9.82% of the total population were found to be children of ≤ 5 years of age which were potentially vulnerable of IAP exposure. Per capita income per year for the ten villages were found to be well below the national average and hence, economic condition of most of the households found poor. 57.81% of the households were found to be using firewood for their preliminary cooking sources with 75% using traditional single pot cooking stoves. Among the households that surveyed, four types of kitchen orientation viz., kitchen attached with living room with partition (KAWLRWP), kitchen attached with living room without partition (KAWLWOP), separate kitchen outside the living room (SKOLR) and open air kitchen (OK) out of which KAWLWP, KAWLWOP, SKOLR contributes more than 99% of the kitchens. Regarding the ventilation in the kitchen, 69.66% were found poorly ventilated, 23.57% moderately ventilated and 6.77% were found good/adequately ventilated. We have tried to collect some evidence regarding disease like cough, asthma, bronchitis, cataract, cancer, tuberculosis etc. and it has been observed that cough, asthma and bronchitis were observed mostly between children of ≤ 5 years of age and females. Cataract, cancer and tuberculosis were found in adults (male and female). Correlating with the ventilation condition with above mentioned IAP related diseases for affected children of ≤ 5 years of age and females it has been found that 82.6% of female from inadequate/poor ventilation and 17.4% from moderate ventilation. In case of IAP related disease affected children of ≤ 5 years of age comes 64.3% from inadequate/poor ventilation, 22.6% from ventilation and surprisingly 11.1% from adequate/good ventilation condition.

In the second part of result and discussion chapter, results of WBT, CCT and KPT study pre and post intervention were represented and discussed. This has to be mentioned that during preliminary questionnaire survey, two types of single pot traditional cook stoves were observed and both the types were selected for this present study. The key conclusion from this chapter is that the average efficiency of these two types of cookstoves was found to be 5.2% (type A) and 4.1% respectively whereas the average efficiency of the improved stoves installed was found to be 23.9%. The result of CCT shows little variation in specific fuel consumption (2.90kg for type A and 2.61kg for type B) whereas improved cookstove shows 1.98kg per kg of food cooked. Hence, fuel consumption reduction by 31.1% and 23% from type A and type B respectively. In case of time required for preparing with a specific quantity of food was found to be reduced by 38.23% (type A) and 33.21% (type B) after installation of the improved stoves. Results of KPT test shows that fuelwood consumption per person-meal served and wood energy consumed per person-meal served were reduced by around 32% and 35.66% in case both types of traditional stoves after installation of improved stoves.

Salient conclusions of third part of chapter IV shows that average 24-hour concentration of CO, $PM_{2.5}$ for KALRWP was found to be higher than the other two types of kitchens viz., KAWLWOP and SKOLR as OK was not considered for the present study and was found in concentration as per WHO air quality guidelines, 2005. Concentration of CO and $PM_{2.5}$ was found to be much higher in all three types of kitchens during cooking period [CO: 23.38ppm (KAWLWP), 20.58ppm (KAWLWOP), 19.74ppm (SKOLR) $PM_{2.5}$: 5.63 mg/m^3 (KAWLWP), 4.71mg/m^3 (KAWLWOP), 4.80mg/m^3 (SKOLR)] than smouldering period [CO: 5.40ppm (KAWLWP), 4.98ppm (KAWLWOP), 4.95ppm (SKOLR) $PM_{2.5}$: 0.82mg/m^3 (KAWLWP), 0.61mg/m^3 (KAWLWOP), 0.61mg/m^3 (SKOLR)]. Time activity pattern among children ≤5 years of age, male and female of 6 – 18 years, 19 – 50 years and >50 years shows that children ≤5 years of age and female of 19 – 50 years has the highest exposure of IAP as they have spent most of their time in the kitchen and the living rooms. Installation f improved stove shows significant reduction of 24-hour average concentration of CO by ~70% - 72% and $PM_{2.5}$ by ~71% - 75%. Considering cooking and non-cooking/smouldering period the average concentration of CO was found reduced by ~73% - 75% and 83% - 86% respectively and in case of $PM_{2.5}$ also found reduced by ~75% - 77% and 84% - 85% respectively. Considering the building materials, kitchen having roof materials: grass and bamboo, wall materials: *Ekora* and mud have the highest concentration of CO and $PM_{2.5}$ than other building materials (Roof materials: GI sheet, asbestos, grass and bamboo; Wall materials: *Ekora* and mud; bamboo and mud; wood, bamboo and mud; wood, bamboo and cement) considered for the current study. From poor ventilation to good/adequate ventilation condition, average 24-hour concentration was found to be low by 20% in CO and 30% - 37% in $PM_{2.5}$.

Last part of chapter IV deals with the statistical analysis of the experimental results. Compilation of parameters (specific fuel consumption, burning rate, fire power and efficiency) during high power hot phase of WBT gives statistically highly significant result at $p = 0.01$ whereas cold and simmering phase shows the significance at $p = 0.05$. For CCT, parameters viz., time to prepare a fixed quantity of food and specific fuel consumption shows highly significance at 95% confidence interval. Similar case was also found in KPT results. Compilation of the parameters viz., wet wood consumed per capita per day, dry wood consumed per capita per day and wood energy consumed per capita per day shows statistical significance at 95% confidence interval. It has been found interesting that when we pooled the data of kitchen attached with living room with partition with kitchen attached with living room without partition and similarly kitchen attached with living room with partition with separated kitchen outside the living room particularly for $PM_{2.5}$ and CO they showed a highly significant results ($p < 0.000$) at 95% confidence level. Compilation of the roof materials and the emission of KAWLWP with other two types for CO and $PM_{2.5}$, shows highly significant difference for all the three types of building roof materials; but for CO_2, no such variation was found for all the types of the kitchen. However, in between KAWLWOP and SKOLR no statistical difference was observed as they shows almost similar trend of concentration levels between them. Compilation of wall and floor materials of KAWLWP with other two types also shows highly statistically significant result at $p < 0.000$. For all the combination of ventilation conditions CO and $PM_{2.5}$ emissions shows statistically significant difference before ($p < 0.000$) and after ($p < 0.005$) installation of the improved cookstoves into the households.

In the last chapter of this thesis (Chapter V), summary of all the results were presented. Apart from these, study limitations for the current study and some important outcomes for IAP study are recorded. Finally, some recommendations for future work of research in IAP research are suggested.

DECLARATION

I do hereby declare that the thesis entitled *"**Indoor Air Pollution from Firewood combustion in rural North East India with special reference to Sonitpur district, Assam**"*, being submitted to the Department of Energy, Tezpur University, is a record of original research work carried out by me. All sources of assistance have been assigned due acknowledgment. I also declare that neither this work as a whole nor a part of it has been submitted to any other University or Institute for any other degree, diploma or award.

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CERTIFICATE BY THE SUPERVISOR

This is to certify that the matter embodied in the thesis entitled ***"Indoor air pollution from firewood combustion in rural kitchens of North East India with special reference to Sonitpur district, Assam"*** submitted by Sri Prasenjit Saikia for the award of degree of Doctor of Philosophy of Tezpur University is a record of bonafide research work carried out by him under my supervision and guidance. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Date: 9.11.2010

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The committee recommends for the award of the degree of Doctor of Philosophy.

Principal Supervisor

Date: 30-04-12

External Examiner

Date: 30/04/2012

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LIST OF ABBRIVIATIONS

ARI	Acute Respiratory Infection
ARC	Aprovecho Research Center
ARTI	Appropriate Rural Technology Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BaP	Benzo[a]pyrene
CCME	Canadian Council of Ministers of the Environment
CCT	Controlled Cooking Test
CFD	Computational Fluid Dynamics
COV	Coefficient of Variation
Delta	Detectable difference in mean
EC	Elemental Carbon
ER	Emission Ratio
ERMD	Emission Research and Measurement Division
ETS	Environmental Tobacco Smoke
FAO	Food and Agricultural Organization of the United Nations
FESEM	Field Emission Scanning Electron Microscopy
GLM	General Linear Model
HVAC	Heating, Ventilation and Air Conditioning
IAP	Indoor Air Pollution
ICS	Improved Cookstove
IGO	Inter Governmental Organization
IAQ	Indoor Air Quality
ISOC	International Scientific Oversight Committee
KAWLWP	Kitchen attached with living room with partition
KAWLWOP	Kitchen attached with living room without partition
KPT	Kitchen Performance Test
KVIC	Khadi Village Industries Development Corporation

LPG	Liquified Petroleum Gas
MNES	Ministry of Non-conventional Energy Sources
MNRE	Ministry of New and Renewable Energy
NEIPTG	National Emissions Inventory and Projections Task Group
NHLBI	National Heart, Lung, and Blood Institute
NGO	Non-governmental Organization
NPIC	National Program on Improved Chulha
PAH	Polyaromatic hydrocarbon
PAHO	Pan American Health Organization
PCA	Principal Component Analysis
PCB	Polychlorinated biphenyl
RCS	Random Component Superposition
RIOPA	Relationship of Indoor Outdoor and Personal Air
RSP	Respirable Suspended Particle
RTFD	Royal Thai Forestry Department
SKOLR	Separate kitchen outside living room
SP	Suspended Particle
SPM	Suspended Particulate Matter
TCS	Traditional Cookstove
TNMOC	Total Non-methane Organic Compound
OC	Organic carbon
OK	Open air Kitchen
OMOE	Ontario Ministry of the Environment
PNA	Polynuclear aromatic
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
USEPA	US Environmental Protection Agency
VOC	Volatile Organic Compound
WBT	Water Boiling Test
WHO	World Health Organization
WRI	World Resources Institute

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CHAPTER I

INTRODUCTION

CHAPTER - I

1.1 Introduction

Energy is essential to human survival for sustaining basic human needs such as temperature regulation, cooked food and lighting etc. In the modern cities of today, sources of energy vary from gas to electricity to solar power. Apart from these, majority of the people across the globe still usage biomass for their primary energy sources. They are still lack in accessing the clean fuel like, biogas, liquid petroleum gas (LPG), solar etc. In fact, an estimated amount of 2.5 to 3 billion people which accounts around 90% of the rural households in developing countries still rely on biomass fuels for their household energy needs (World Resources Institute, UNEP, UNEP and World Bank[220] 1998; Yeh 2004). While with the spread of modern fuels the share of global energy from biomass fuels has declined from 50% (in 1900) to approximately 13% (in 2000). However, most interestingly the recent trends suggest that usage of traditional biomass fuels may actually be increasing among the poor in developing countries (WHO[219], 2002).

In the early 70s, the oil crisis brought a wide interest in renewable energy for supplementing energy demand (Luo and Hulscher, 1999). Consequently, recent concerns are developed about global warming and sustainable energy development which have become amongst the main driving forces in directing energy policy and R&D projects. As a part of the most widely used renewable energy sources, woodfuel has been studied for its role in CO_2 abatement, indoor air quality improvement, etc. In order to clarify the implications of woodfuel emissions, it is necessary to draw a clear picture of what is known and what are the different opinions about woodfuels from past and ongoing studies. Thereafter, fuel strategies can be developed further.

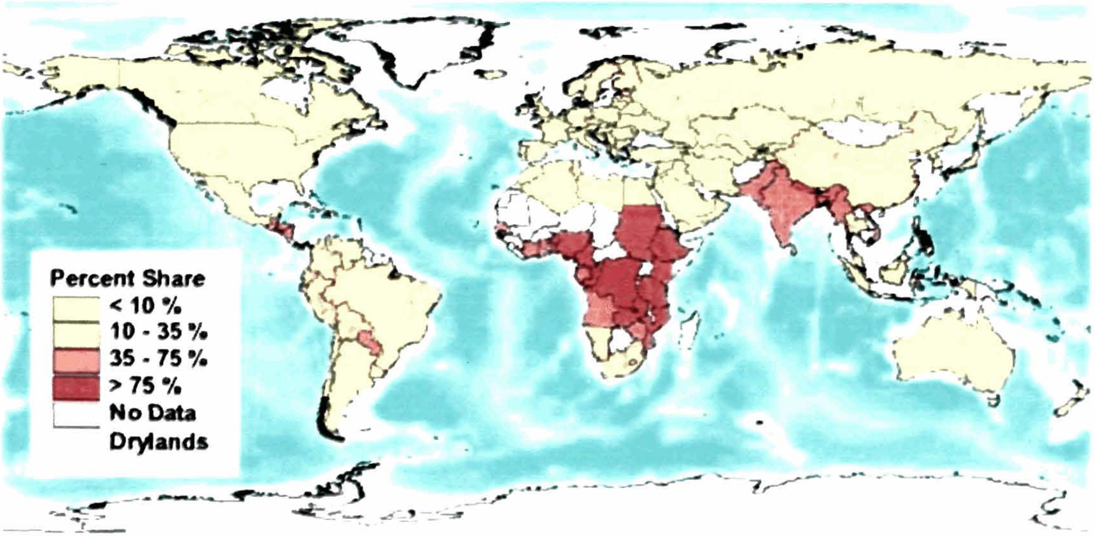

Figure: 1. Share of Biomass Fuels in National Energy Consumption in Drylands, WRI[221] (2002).

Figure 1 clearly indicates that use of wood, charcoal, animal dung and crop wastes is high in Asia, Latin America and especially sub-Saharan Africa, where in many countries over 75% of energy consumed is generated from traditional biomass fuels (Yeh 2004). These countries also have high levels of poverty, suggesting a correlation between poverty and energy. Reddy[168] (2001) suggested that an energy-poverty nexus exists where dependence on traditional biomass fuels is both a cause and result of poverty. He also pointed out that lack of adequate energy can constrain development, while at the same time; poverty prevents the affordability and access to modern fuels.

Since 1968, claims have been made about the impact of indoor air pollution (IAP) on the health of people in developing countries (Cleary and Blackburn[48], 1968; Sofoluwe[194], 1968). According to Bruce[44] *et al.* (2000), around half of the population in developing countries, and 90% of the rural population, rely on coal and biomass (such as wood, dung, crop residues) for domestic energy use and also often using simple biomass stoves that may produce significant amount of toxic components due to incomplete combustion. According to Zhang and Smith[225] (1999), particularly in developing countries, the primary source of IAP is often the combustion of dirty fuels used for cooking and / or heating purposes, which has been found to be responsible for many indoor pollutants, including carbon monoxide (CO), particulate matter (PM), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and various organic compounds. Bruce[44] *et al.* (2000) estimated that IAP from biomass and coal smoke is responsible for approximately 2 million annual deaths across the globe, representing around 4% of the global burden disease among which acute respiratory infections (ARIs) being the greatest cause of mortality in children under five.

1.2 Combustion of wood

Wood consists primarily of two polymers: 50 – 70 weight percent holo-cellulose and approximately 30% by weight lignin (Simoneit[185], *et al.*, 1998). Other biomass fuels (e.g. grasses, wheat stubble) also contain these polymers, with relatively different proportions from the wood. In addition, small amounts of low molecular weight organic compounds (e.g. resins, waxes, sugars) and inorganic salts are also present in wood. During combustion, pyrolysis occurs and the polymers were breaks down producing a variety of smaller molecules. Biomass combustion is typically inefficient and a multitude of partially oxidized organic chemicals are generated in biomass smoke.

Browne (1958) made a comprehensive study on wood combustion. In general, wood does not burn directly (Hawley and Lee[83], 1952; Schuyten[181] *et al.,* 1954; Schuyten[180] *et al.,* 1955; Martin[114], 1956). During the first phase it undergoes thermal degradation called pyrolysis. Some of the products formed during the process are combustible gases, vapours or mists. Under appropriate conditions the products may be set afire and, if enough of their heat of combustion is retained by the wood to maintain the pyrolysis, the burning may continue of its own accord until the wood has been consumed except for inorganic products left as ash.

Ordinarily, wood is set afire by bringing to bear enough heat to start active pyrolysis, and then applying a pilot flame or other source of high temperature to the combustible gaseous products after they have escaped and become mixed with air. In the absence of a pilot flame, much more heat must be supplied before the pyrolysis products will take fire simultaneously. The minimum rate of heating necessary for ignition by pilot flame is of the order of 3 cal/cm^2-sec, but for spontaneous ignition it is of the order of 0.6 cal/cm^2-sec (Lawson and Simms[101], 1952).

Wood may be said to burn directly, if its surface is irradiated so intensely that the temperature is raised to the point of spontaneous ignition within a fraction of a second, so that pyrolysis and combustion are practically simultaneous. Even then direct combustion is confined to a thin surface layer. Thin sheets of α-cellulose that are exposed to short pulses of radiant power of 20 to 30 cal/cm^2-sec lose only part of their thickness in flame, leaving an extremely shallow layer of char that is backed by apparently unchanged cellulose (Martin[114], 1956). Direct combustion of explosive violence can occur when fine, dirty particles of wood are distributed in air in such proportions that each particle is in contact with enough oxygen for its combustion and is close enough to its neighbours to ignite them quickly in a manner analogous to a branching chain reaction (Hawley and Lee[83], 1952).

When a piece of wood is heated out of contact with air, zones (Hawley and Lee[83], 1952; Martin[114], 1956; Metz[123], 1942) develop parallel to the heat-absorbing surface, delimited by temperatures attained. The zones are well marked in wood because of its relatively low thermal conductivity (Mac Lean and James[104], 1941) and density and also relatively high specific heat (Dunlap[58], 1912). Pyrolysis reactions depends on the relative proportions of gases, vapours, tars and charcoal and the relative proportions of flammable and non-flammable gases produced and will vary widely according to the conditions of temperature, pressure, time, geometry and environment under which pyrolysis occurs. The yields of products may also be altered greatly by the presence of retardants or combustion catalysts in the wood or on its surface.

The course of combustion events when wood is heated in air is similarly zonalized but is modified by oxidation reactions and, after ignition, by combustion of pyrolysis and oxidation products.

1.3 Combustion of wood in stove

Ndiema *et* al. (1998) revealed details information of physical and chemical processes during combustion of wood in stove. There are varieties of stoves, among which some recently modified were designed to minimize the heat loss and to increase its thermal efficiency. In the combustion chamber of a stove, a number of physical and chemical processes occur during the combustion which includes drying and preheating of fuel, release of volatile flammable matter, flaming combustion of the pyrolyzates and glowing combustion of fixed carbon (Bridgwater[40], 1992). These can be illustrated as a two-stage process, as shown in Figure 2.

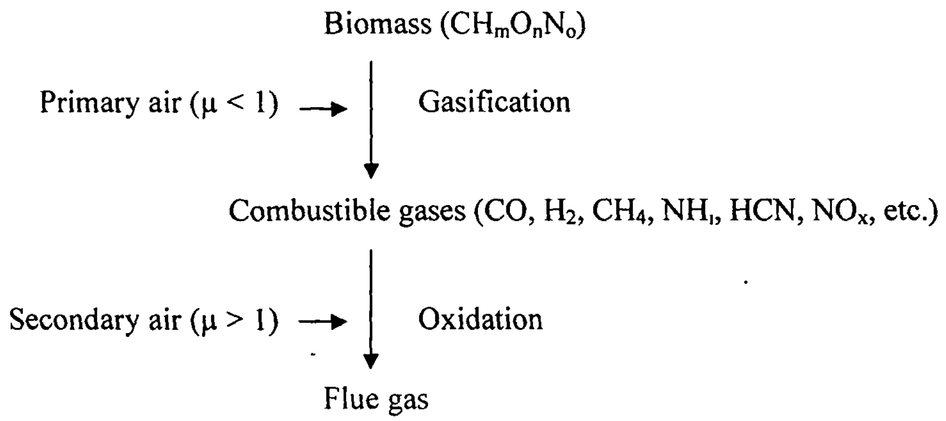

Figure: 2. Biomass combustion in a stove: A two-stage process

Biomass fuels generally contain very less amount of sulphur content than most of the coal. Although thermal energy extraction as heat is the ultimate goal of the stove, the nature and quantity of emissions including ash residue left behind at the end of combustion, are also the preliminary concern of it. Contaminants such as sand, dirt and inorganic compounds, such as potassium salts, are usually present as trace elements which contribute to slagging of ash in the stove.

The formation of combustion emissions is influenced largely by the fuel properties, which can be determined by proximate analysis of the fuel, and by the stove design parameters such as excess air, particle size, fuel bed, etc. The combustion air which is supplied by natural circulation depends very much on ambient conditions and architectural configuration of the stove location (usually in the kitchen). Other parameters, such as particle size and bed depth, can readily be varied to achieve a desired performance (Kanury[91], 1994; Ndiema[139], 1992). Apart from these, emissions from the biomass stoves that frequently used by the rural people are difficult to measure for a number of reasons (Ahuja *et al.*, 1987). The main reasons are that often found is that in developing countries stoves do not have chimneys and therefore have no easy place to measure emission concentrations. Secondly, biofuels do not burn evenly and the resulting fire is transient and largely unrepeatable. Most importantly but not the least, preparation of foods on a stove involves a number of variations in operation depending on human behaviour/operation. Hence, measurements of the emissions need to be made over a range of processes to ensure the results of emissions which can represent of actual use of the stove-fuel combination (Tremeer, 1997).

In general perception, the products of biomass combustion should contain CO_2, water (H_2O) and ash in a complete combustion process. Combustion process of biomass materials leads to form a small quantity of residual ash and depending on the type of biomass, traces of other compounds such as sulphur oxides (SO_x) may also be present. However, in practice, this is not found to be happening during any biomass combustion process, rather found release of CO, unburnt hydrocarbons, oxides of nitrogen (NO_x), smoke and soot. The formation of the pollutants in the stove can be summarize as follows as described by Tremeer (1997):

1. CO is one of the most toxic elements resulting from the incomplete combustion of the biomass material. It is usually produced when the combustion air is supplied at less than the stoichiometric requirement (at $\mu < 1$, where the excess air ratio, μ = actual air / stoichiometric air). There are two routes of formation of CO that have been postulated by Bridgwater[40] (1992), Driscoll[55] (1974) and Hubbard[86] (1995). According to the first route, CO is formed during the primary attack by oxygen on hydrocarbons, by a fast reaction mechanism as shown in equation (1). The subsequent reaction of CO

to CO_2 in equation (2) is slow and requires adequate residence time to achieve completion. Thus, in a poorly designed or overloaded stove, it is possible to produce significant CO emissions even in the presence of large amounts of excess air:

$$C + \frac{1}{2} O_2 \longrightarrow CO, \quad \text{exothermic} \quad (1)$$

$$CO + \frac{1}{2} O_2 \longrightarrow CO_2, \quad \text{endothermic} \quad (2)$$

The second route of CO formation occurs during the combustion process through out the fuel bed after the primary reaction. During this phase, the oxygen in the combustion chamber is very much depleted resulting reduction of CO_2 by the Boudouard reaction (Driscoll[55], 1974).

$$CO_2 + C \longrightarrow 2CO, \quad \text{endothermic} \quad (3)$$

As the gases pass through the regions of unburnt fuel the combustion gases formed in the primary zone containing high CO_2 concentration may equilibrate under suitable conditions of temperature and oxygen concentration. Since, the third equation is a endothermic reaction, it will cooled down the gases as the reaction proceeds. When the temperature drops to the level where the rate of reaction becomes negligible, the equilibrium process will stop, and the concentration of CO will be frozen. This has been occurs in the temperature range of 600 – 700 °C (Driscoll[55], 1974 and Kanury[91], 1994).

2. NO_x (NO and NO_2) is also a significant air pollutants that released during the combustion process of biomass. It is found to be formed in three different reactions during combustion process. Thermal NO_x is formed at high temperature by oxidation of nitrogen contained in the air; prompt NO_x is formed during the combustion of hydrocarbons in reactions of molecular nitrogen with free radicals in the flame; and fuel NO_x is formed from nitrogen

contained in the fuel. Apart from above, the nitrogen containing compounds likely to be found includes: NH_2, HCN, CN and NH_3 from the biomass fuel (Kanury[91], 1994; Levy[104] *et al.*, 1979 and Williams[212] *el al.*, 1994). As the flame temperature in most of the stoves are in the range 800 – 1200 °C, it can be assumed that only the formation of fuel NO_x is of significance. However, the mechanisms of fuel nitrogen conversions during combustion of wood are not clearly understood. Several routes of formation have been suggested for coal combustion, which can be extended to wood combustion. Levy[104] *et al.* (1979) suggested a mechanism for NO formation during coal combustion. According to his observation, it is a first order approximation assuming volatile nitrogen conversion whereas the char nitrogen conversions are independent as shown in Figure 3. Besides these, another scheme that involves the formation of NO_2 represented by equation (4) and (5) was suggested.

$$NO + HO_2 \longrightarrow NO_2 + OH \quad (4)$$

$$NO_2 + O \longrightarrow NO + O_2 \quad (5)$$

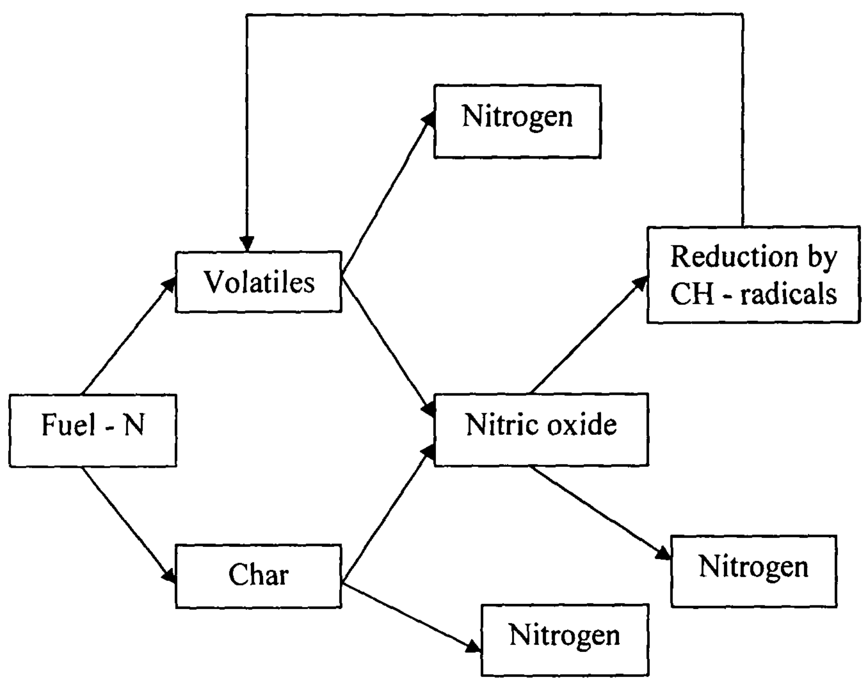

Figure: 3. Schematic representation of fuel nitrogen conversion (Levy[104] *et al.*, 1979).

3. Another important toxic component that forms during the combustion of biomass fuels are the carboneous materials such as charcoal and non-condensable gases which includes aliphatic compounds, where methane (CH_4) being the major product. CH_4 may further involve in the combustion process leading to the formation of CO or CO_2 and water. It is also to be noted that incomplete combustion of CH_4 also may lead to the formation of higher molecular species, such as ethylene and acetylene (Shafizadeh and Chin[183], 1975). Formation of CH_4 during biomass combustion depends on a several factors such as stove design, complexity of the biomass chemistry, particle size and decomposition temperature. Most wood based biomass fuels contain cellulose, hemicellulose and lignin, which will react differently during combustion, pyrolysis and gasification processes. According to Shafizadeh and Chin[183], (1975) CH_4 is formed either by the decarboxylation reaction of acetic acid (in equation 6) or by decarboxylation reaction of acetaldehyde (in equation 7).

$$CH_3COOH \longrightarrow CH_4 + CO_2 \qquad (6)$$

$$CH_3CHO \longrightarrow CH_4 + CO \qquad (7)$$

4. Last and most important component is the particulate materials that formed due to the incomplete combustion of biomass materials. It consists of fly ash, smoke and soot. Smoke composed of small gas borne particles predominantly, of carbon and other combustible materials which are present in sufficient quantity and are observable independently of other solids. Soot is an agglomeration of carbon particles impregnated with tar.

1.4 Indoor air pollution and its preliminary background

Indoor air pollution (IAP) refers to the change in physical, chemical, and biological characteristics of air in the indoor environment within a home, building, or an institution or commercial facility. IAP is a concern in the developed countries, where energy efficiency improvements sometimes make houses relatively airtight, reducing ventilation and raising pollutant levels. It can be subtle and do not always produce easily recognized impacts on health. Different conditions are responsible for IAP in the rural areas and the urban areas.

In the developing countries, it is the rural areas that face the greatest threat from IAP, where around 3.5 billion people continue to rely on traditional fuels such as firewood, charcoal, and cowdung for cooking and heating (Fugas[71], 2003). Burning such fuels produces large amount of smoke and other air pollutants in the confined space of the home, resulting in high exposure. Concentrations of indoor pollutants in households from burning of traditional fuels are alarming: Women and children are the groups most vulnerable as they spend more time indoors and are exposed to the smoke. In 1992, the World Bank designated IAP in the developing countries as one of the four most critical global environmental problems. Although many hundreds of separate chemical agents have been identified in the smoke from biofuels, the four most serious pollutants are particulates, CO, polycyclic organic matter, and formaldehyde. Unfortunately, little monitoring has been done in rural and poor urban indoor environments in a manner that it's found to be statistically rigorous (Fugas[71], 2003).

As the history of IAP in concern, cave dwellers were perhaps the first to be concerned with the quality of indoor air, when they built fires inside their caves. By cooking and heating over open flames, they probably exposed themselves to toxic vapours from various chemicals, including formaldehyde. They may have partially solved the problem simply by building the fire at the entrance to the cave (Beall' and Ulsamer[25], 1981). Modern man confronts problems of indoor air quality that resemble homes and install insulation and other materials to conserve energy. This reduces movement of air through a building and increases the concentration of many indoor pollutants. Our problems of IAP are more complex than those faced by our ancestors.

On the basis of literature data (Benson[27], *et al.*, 1972) it can be stated that the interest in IAP started as early as in 1903, but at first it was limited to the airborne microflora and to the effect of air filtration in relation to asthma and hay fever. Measurements of chemical contaminants indoors or both indoors and outdoors started in the middle 1950s. The measurements have been conducted for the following three reasons:

a) to determine the dust balance in houses with or without air cleaning systems;
b) as a background for investigation of the health status of chronic patients;
c) as a basis for establishing safe distance of residences from pollution sources.

At the time the penetration of outdoor air pollution to the indoor environment was the main preoccupation, and only water vapour, CO_2, odours, microorganisms and redispersed dust were considered as indoor generated pollutants. It was around 1965 when it was established for the first time (Biersteker[34], *et al.*, 1965) that indoor generated air pollutants might be responsible for health effects attributed to the outdoor air pollutants. First attempts to evaluate the real human exposure to air pollutants were carried out in 1963 by Goldsmith[74] *et al.*, 1963. It was attempted to correlate the CO exposure of two subjects, a smoker and a non-smoker, over 24 hours in various places and during various activities, measuring carboxyhemoglobin levels simultaneously. However, no one seemed to be ready to grasp entirely these considerations at that time. It has been also attempted by Goldsmith and Hexter[73] (1967) to assess the total workers exposure to lead levels as a measure of their non-occupational part of exposure, aiming at obtaining a generals relationship between lead in air and lead in blood.

Investigations on indoor-outdoor air quality relationships were also carried out by Yocom[224] *et al.* in 1971. It has been noticed that "the exposure of a person to air pollutants does not stop as soon as he enters an enclosed space". The real problem was that it's very difficult to change the traditional beliefs, and also established over many years. A turning point in human exposure assessment philosophy was finally reached at the International Conference on Environmental Sensing and Assessment in Las Vegas in 1975 where a critical appraisal was made of air pollution measurements carried out in the past with the aim to relate them to health effects in order to develop air quality standards. It became obvious that measurements made at monitoring stations, giving levels and trends of air pollution outdoors on which air quality preservation and control policy in an area were based, explain only a small part of actual human exposure. This is due to the fact that most of the people spend their time at an average of 80% at the indoor and move from one place to another. Next important point was that people were exposed simultaneously to more than one pollutant. Finally many toxic materials reach the human body through more than one route. Hence, a detailed and systematic study for household exposures is required for fulfilling these knowledge gaps.

1.5 Indoor pollutants from combustion of wood and their significance

In earlier times the focus has been on the "classical" pollutants as measured in outdoor air for the study of indoor air. As the time passes on, new insights on and concerns about, health effects, and the advances in analytical techniques have contributed to broaden the view and draw a more complex picture of indoor pollutants. The types of pollutants that have been determined indoors have changed over the years depending on the focus in R&D activities. The sentiment that woodsmoke, being a natural and ancient substance, must be benign to humans is still sometimes heard (Naeher *et al.*, 2005).

It is now well established, however, the woodburning stoves and fireplaces as well as wildland and agricultural fires emit significant quantities of known health-damaging pollutants. It includes carcinogenic and other toxic organic compounds such as polyaromatic compounds, benzene, and aldehydes; respirable particulate matter with diameters allowing it to penetrate deep into the lung; CO; NO_X; and free radicals, among many other pollutants (NEIPTG[140], 2000; Larson and Koenig[100], 1994; ERMD[64], 2000; Tuthill[203], 1984; Koenig and Pierson[95], 1991; Leonard[103] *et al.*, 2000; Dubick[57] *et al.*, 2002; Smith[189], 1987; Traynor[202] *et al.*, 1987).

Wood smoke contains a vast array of solid, liquid, and gaseous constituents that change, sometime rapidly, with time, temperature, sunlight, and interaction with other pollutants, water vapor, and surfaces. Many of the constituents are known to be hazardous for human health, but are not specifically regulated or even fully evaluated (Naeher *et al.*, 2005). The summary of the pollutants released in the wood smoke is shown in Table 1.

Table 1: Toxic Chemical Agents Identified in Wood smoke.

Chemical class	Number of compounds	Mode of toxicity	Representative compounds *
Toxic gases	4+	Irritant, acute toxicity	Carbon monoxide, ammonia, nitrogen dioxide, sulphur dioxide
VOCs (C2 – C7)	3+	Irritant, possibly carcinogenic	Methyl chloride, methylene chloride
Saturated hydrocarbons	25+	Irritant, neurotoxicity	Hexane
Unsaturated hydrocarbons	40+	Irritant, carcinogenic, mutagenic	1,3 – butadiene, acrolein
Monoaromatics	28+	Irritant, carcinogenic, mutagenic	Benzene, styrene
PAHs	20+	Carcinogenic, mutagenic, immunotoxic	Benzo[163]pyrene, dibenzo[a,h]anthracene
Organic alcohols and acids	25+	Irritant, acute toxicity, teratogenic	Methanol, acetic acid
Aldehydes	20+	Irritant, carcinogenic, mutagenic	Formaldehyde, acetaldehyde
Phenol	33+	Irritant, carcinogenic, mutagenic and teratogenic	Catechol, cresol (methyl phenols)
Quinones	3	Irritants, allergenic, redox active, causes oxidative stresses and inflammation response, possibly carcinogenic	Hydroquinone, fluoroquinone, anthraquinone
Free radicals		Redox active, causes oxidative stresses and inflammation response, possibly carcinogenic	Semi-quinone type redicals
Inorganic compounds	14+	Carcinogenic, acute toxicity	Arsenic, lead, chromium
Fine particle matter		Inflammation, may be a allergic	PM_{25}
Chlorinated dioxins		Irritant, may be carcinogenic or teratogenic	
Particulate acidity		Irritant	Sulphuric acid

Ref: Naher[135] *et al.*, (2005); A report on "Critical review of the health effects of wood smoke" Air health effects division, Health Canada, Ottawa.

Most of the indoor air pollutants directly affect the respiratory and cardiovascular systems. Increased mortality, morbidity and impaired pulmonary function have been associated with elevated levels of sulphur dioxide and particulate matter (PM), especially suspended particles (SPs) (Sandoval *et al.*, 1993; Larson and Koenig, 1994). Acute and sub-acute health effects of the inhalation of smoke include conjunctivitis, acute respiratory irritation/inflammation, and acute respiratory infection (ARI), particularly in infants and young children. Chronic effects of the inhalation of smoke are chronic obstructive pulmonary disease, chronic bronchitis, adverse reproductive outcomes, and lung cancer. An estimated 98% of the total PM emitted by residential wood combustion is in the respirable category, $PM_{2.5}$ (OMOE[147], 1999). $PM_{2.5}$ can be respired deep into the human lung, causing lung irritation in healthy people and exacerbating asthma and other respiratory illnesses in at-risk groups such as children, the elderly and those with pre-existing illness. This very fine PM has a greater impact on health than the coarser fractions, highlighting the importance of reducing wood smoke emissions both indoors and outdoors (Basrur, 2002).

Acute exposure to NO_2 can cause inflammatory and permeability responses, lung function reduction and increases in airway resistance. Studies on human populations indicate that long-term exposure to NO_2 levels currently observed in Europe may decrease lung function and increase the risk of respiratory symptoms such as acute bronchitis, cough and phlegm, particularly in children (WHO, 2003a). Even though some studies have shown associations between NO_2 exposure and mortality, present evidence is not sufficient to conclude that effects on mortality can be attributed to long-term exposure to NO_2 itself. NO_2 alone has been shown to cause acute health effects in controlled human exposure studies. Studies on human populations have not been able to isolate potential effects of NO_2, because of the complex link between concentrations in ambient air of NO_2, PM, and ozone. Several studies have shown that NO_2 exposure increases allergic responses to inhaled pollens. People with asthma and children in general are considered to be more vulnerable to NO_2 exposure (Beckett *et al.*, 1995; van Strien, 2004; Belanger *et al.*, 2006). However, there is no evidence for a threshold for exposure to NO_2 below which no effects on health are expected.

CO is a colourless, odourless gas and closely associated with adverse effects on the heart. Exposure of CO is a problem of indoors, where concentrations can build up undetected, potentially causing death. It binds with haemoglobin in the blood, reducing the ability of the blood to carry oxygen. People with heart disease are most at risk, as well as pregnant women, fetuses, infants, children, elderly persons and people with anemia and respiratory disease. In rare cases acute poisoning can be observed (Basrur, 2002).

Health effects reported for volatile organic compounds (VOCs) range from sensory irritation to behavioural, neurotoxic, hepatoxic, and genotoxic effects. Concentrations at which identified health effects occur are, however, usually much greater than those measured in indoor air. Exposure to mixtures of VOCs may be an important factor for sick building syndrome complaints. The direct human health effects of IAP on the respiratory system vary according to both the intensity and duration of exposure and also with the health status of the population exposed. Certain parts of the population may be at greater risk, e.g., the very young, the elderly, those already suffering from respiratory disease, hyper responders and people exercising (Namieśnik *et al.*, 1992).

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals that are formed during the incomplete combustion of organic materials including coal, wood, garbage etc. This group of compounds covers a wide range of physico-chemical properties, some PAHs are found in air on particles while others are gaseous. PAH of both forms may be deposited in the lung. Potential health effects of mixtures of PAHs include lung or bladder cancer by inhalation and skin cancer by dermal contact (Basrur, 2002).

Polychlorinated biphenyls (PCBs) are of concern because of their wide range of possible cancer and non cancer effects. Exposure to PCB mixtures has been associated with chlorine, diverse hepatic effects, pulmonary function decrease, and decrease in birth weight in children of occupationally exposed mothers, eye irritation and cancer. Further health effects include effects on neurological development and immune function (WHO, 2003b).

Dioxins are carcinogenic to humans. They are extremely toxic; persist in the environment and bioaccumulated in the tissues. Exposure to dioxins has been linked to a number of adverse health effects including developmental, reproductive, hormonal, respiratory and cardiovascular problems (CCME[46], 2001; Basrur, 2002).

1.6 Indoor air pollutants and diseases

In developing countries, toxicological and exposure evidence would be more than enough to warrant major and urgent protective action, even without detailed direct evidence on human health effects. There are hundreds of epidemiologic studies were carried out in Europe, Asia, North America and Latin America about the detail of health impacts of pollutant in urban outdoor setting. These studies are remarkably consistent around the world (Cohen[50] *et al.*, 2004; ISOC[87], 2004; PAHO[149], 2005) and show major health effects even at particle levels as low as 10 $\mu g/m^3$. A recent review by WHO, for example, found that a long-term drop from 25 to 15$\mu g/m^3$ produces a 6% drop in non-accidental mortality rates (WHO[211], 2005).

Exposure to indoor smoke from cooking and heating has been linked with several respiratory diseases, e.g., acute respiratory infections, chronic bronchitis, asthma and tuberculosis. It has also been linked to lung cancer, adverse pregnancy outcomes, cataract and blindness. Moreover, there is reason to expect an association with heart disease too.

The major diseases associated with biomass smoke and a summary of the evidence are shown below in Table 2.

Table 2: Health effects of the use of solid biomass fuels in the households of developing countries.

Disease	Population affected	Relative risk (95% confidence interval)	Strength of evidence
Chronic obstructive pulmonary disease	Women > 15 years Men > 15 years	3.2 (2.3, 4.8)* 1.8 (1.0, 3.2)*	Strong Intermediate
Acute lower respiratory infection	Children < 5 years	2.3 (1.9, 2.7)*	Strong
Lung cancer (coal smoke only)	Women > 15 years Men > 15 years	1.9 (1.1, 3.5)* 1.5 (1.0, 2.5)*	Strong Intermediate
Blindness (cataract)	Women > 15 years	1.3 – 1.6**	Intermediate
Tuberculosis	Women > 15 years	1.5 – 3.0**	Intermediate

Note: For illustration, a relative risk of 1.5 indicates that a population living in solid fuel-burning households have a rate of the disease in question to 1.5 times that of people living in clean fuel burning households.

* Based on formal meta-analysis **Range of results in published studies

Source: Based on review and meta-analysis of published epidemiologic studies, Smith[193] *et al.*, 2004.

Misra (2004) illustrated briefly about the diseases that caused from the exposure of biomass combustion particularly in the rural areas from developing countries. Some of the aforesaid health effects are described:

1.6.1 Acute respiratory infection (ARI) in children

It includes infections from a range of viruses and bacteria but with similar symptoms and risk factors. At one-eighth of the total burden, ARI is the largest single disease category for India, as well as for the world at large where it causes about one-twelfth of the total burden disease. It is the cause of childhood illness and death worldwide, accounting for an estimated 6.5% of the global burden disease and more than 3 million children under the age of 5 die from ARI every year, mostly in developing countries (Smith, 2002).

Studies from several parts of the developing countries confirms that young children living in homes and exposed to burning of biomass fuels have two to three times the risk of developing serious respiratory infections than children who are not exposed. Most of the studies were conducted among pre-school age children have observed a positive association between exposure to biomass smoke and ARI (Misra[126], 2003a; Ezzati and Kammen[66], 2001; Robin[172], *et al.*, 1996; Armstrong and Campbell[12], 1991; Pandey[152], *et al.*, 1989; Kossove[98], 1982), but others have failed to find relationship (Aldous[6], *et al.*, 1996; Samet[178], *et al.*, 1993). Some studies of school-age children also failed to find a relationship between biomass smoke and ARI (Azizi and Henrey[13], 1991; Tuthill[203], 1984; Anderson[8], 1978).

In contrast to India, a national household survey pointed out that the effect of cooking smoke on ARI were greater among boys than girls (Mishra and Retherford[129], 1997). The study make the conclusion because of the fact that due to discrimination against daughters and strong preference for sons, mothers in India are more likely to carry young boys than girls or keep them in kitchen area while cooking. The finding from the Indian study on gender differential in the effect of cooking smoke on ARI is opposite to the finding from a Gambian study, which found a significant association between cooking smoke and ARI in girls, but not in boys (Armstrong and Campbell[12], 1991). Hence, the results show inconsistent behavioral factors among the people of different parts of the world.

1.6.2 Chronic obstructive pulmonary disease (COPD)

COPD is one of the most important causes of global burden disease in people older than 40 years and is found increasing. In developing countries COPD is also a prevalent condition (Torres-Duque *et al.*, 2008). In general perception, COPD occurs due to the tobacco smoke among the peoples. There is strong evidence from laboratory studies that wood smoke exposure causes broncho-constriction, emphysema, bronchiolitis, and lung fibrosis (Hsu[85], *et al.*, 1998; Lal[99], *et al.*, 1993). A number of studies also have been reported which shows ample association between biomass smoke and chronic bronchitis and chronic obstructive pulmonary disease (Albalak[5], *et al.*, 1999; Bruce[43], *et al.*, 1998; Perez-Padilla[159], *et al.*, 1996; Dennis[53], *et al.*, 1996; Sandoval[179], *et al.*, 1993; Dhar and Pathania[54], 1991; Behera and Jindal[27], 1991; Pandey[151], *et al.*, 1988; Malik[112], 1985; Pandey[150], 1984; Padmavati and Arora[148], 1976). It has to be noted that *core pulmonale*, a serious heart condition secondary to COPD, is often found among rural women non-smokers in India and has long been attributed to chronic biomass smoke exposures (Smith, 2000).

1.6.3 Asthma

Asthma is a complex multifactorial disease with both genetic and environmental components. It is characterized by sudden attacks of labored breathing, chest tightness, and coughing (Misra, 2003). A rapid increase in the prevalence of asthma in recent years cannot be ascribed to changes in genetic (heritable) factors; the focus, therefore, should be on environmental factors (WRI[220], 1998; Platts-Mills and Woodfolk[163], 1997). A number of studies have suggested that ambient air pollution can enhance asthma attacks (Bjorksten[35], 1999; Koren and Utell[96], 1997). Exposure to several specific air pollutants, such as PM_{10}, CO, ozone (O_3), SO_2, and NO_2, all of which except O_3 are commonly found in cooking smoke, have been associated with increased asthma symptoms (Baldi[19], *et al.*, 1999; Bates[24], 1995; Castellsague[45], *et al.*, 1995; de Deigo[52], *et al.*, 1999; Greer[78], *et al.*, 1993; Hajat[82], *et al.*, 1999; Koren[97], 1995; Zhang[227], *et al.*, 1999).

Adults with asthma who have chronic airway inflammation may be particularly susceptible to the effects of indoor air pollutants. Despite these potential health risks, few studies have examined the effects of IAP on adults with asthma. The evidence on the effect of smoke from solid fuels on asthma is mixed (Bruce[44], *et al.*, 2000), even though it has some of the same pollutants that are found in ambient air pollution or tobacco smoke, both of which have been associated with the disease. Anecdotal association of asthma with cooking smoke is common, but few epidemiological studies seem to have been done (Smith[191], 2002). From the limited research that does exist on this subject, some studies find a positive association between cooking smoke and asthma (Mishra[125], 2003b; Thorn[201] *et al.*, 2001; Mohamed[130], *et al.*, 1995; Pistelly[162], 1997; Xu[222], *et al.*, 1996), while others fail to find any relationship (Maier[109], *et al.*, 1997; Azizi[14], *et al.*, 1995; Noorhassim[142], *et al.*, 1995; Qureshi[165], 1994) or find a protective effect (von Mutius[207] *et al.*, 1996; Volkmer[206], *et al.*, 1995). A recent study of self-reported asthma among elderly in India observed a strong association between cooking smoke from biomass fuel use and asthma. Consistent with the expectation, the effect of cooking smoke on asthma was considerably greater among women than men (Mishra[125], 2003b).

1.6.4 Tuberculosis

It is an airborne contagious disease that is transmitted by coughing, sneezing, or even talking. World wide 2 million people die of tuberculosis each year. In perception, enhancement of exposure to the pollutants contained in biomass smoke can weaken the immune system, impair the lungs, and make them more susceptible to infection and disease. Cooking smoke also tends to increase coughing, which contributes to the spread of tuberculosis infection.

Till now, studies linking tuberculosis with biomass smoke is found to be very limited. A study of more than 200,000 Indian adults observed that people living in households that use biomass fuels for cooking are 2.6 time more likely to suffer from active tuberculosis than those living in households using cleaner cooking fuels (Mishra[127], *et al.*, 1999a). Another study, designed to test the Indian findings, found a similar effect of biomass fuel use on active tuberculosis from a hospital based case-control study in Mexico (Perez-Padilla[160], *et al.*, 2001).

1.6.5 Cataract and blindness

Annually, about 2 million people become blind worldwide and half of the cases accounts for cataract-related blindness (West and Sommer, 2001; Javitt *et al.*, 1996). Long-term exposure to cooking smoke probably contributes to impaired vision and blindness mainly through oxidative damage to the eye lens and severe eye irritation, leading to cataract and other disorders. In India, for example, cataract accounts for more than 80 percent of complete blindness. Another direct cause of blindness, conjunctivitis, may also be aggravated by long-term exposure to cooking smoke. Trachoma, which also can cause blindness, can be contracted when irritation from exposure to smoke causes people to rub their eyes frequently (Pokhrel *et al.*, 2005).

There are few laboratory studies that have linked cataract to wood smoke (Shalini[184], *et al.*, 1994; Rao[166], *et al.*, 1995). A case-control study of patients at a New Delhi ophthalmic clinic showed that, after controlling for several physiological, behavioral, environmental, and biochemical factors, use of wood and dung for cooking was significantly associated with cortical, nuclear, and mixed types of cataract (Mohan[131], *et al.*, 1989). Another study based on data from a large national household survey in India found that women cooking with biomass fuels were considerably more likely to suffer from both partial and complete blindness than those cooking with cleaner fuels (Mishra[128], *et al.*, 1999b).

1.6.6 Adverse pregnancy outcomes

Adverse pregnancy outcomes and early infant death have been associated with outdoor air pollution and active and passive smoking in developed as well as in the developing countries using solid fuels (Smith, 2002; Boy[39], *et al.*, 2002). Smoke from combustion of solid fuels in simple, poorly vented cookstoves produces large volumes of CO, which binds to hemoglobin and forms carboxyhemoglobin. This reduces oxygen carrying capacity of blood to body tissues. A developing fetus, deprived of adequate oxygen, suffers intrauterine growth retardation and subsequent reduced birth weight. PM and other pollutants in biomass smoke may also increase the risk of adverse pregnancy outcome by reducing mother's lung function and increasing the risk of maternal lung disease, and in turn reducing oxygen delivery to the fetus (Boy[39], *et al.*, 2002).

Figure 4 shows the possible mechanisms by which exposure to cooking smoke and tobacco smoke might cause adverse pregnancy outcomes.

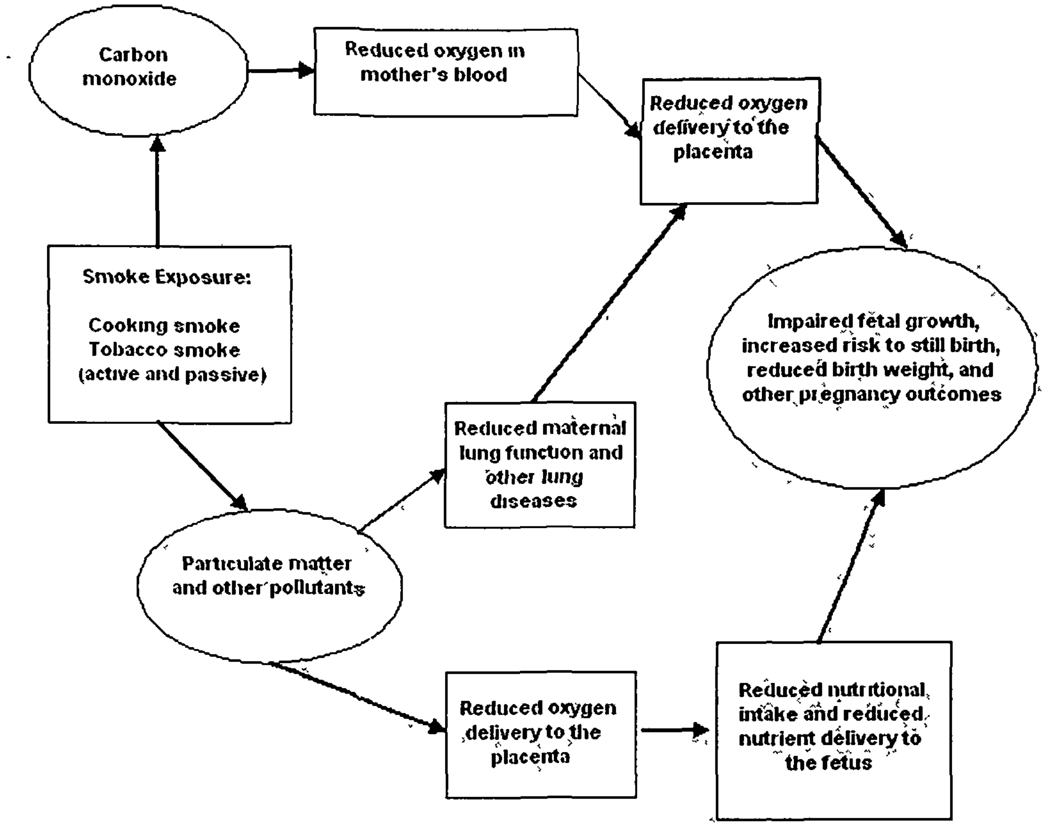

Figure: 4. Possible mechanisms by which exposure to cooking smoke and tobacco smoke might cause adverse pregnancy outcomes. (Source: Anonymous[10], 2005, WHO)

Several studies have been reported which linked exposure to both active and passive tobacco smoke to fetal growth and adverse pregnancy outcomes, including reduced birth weight (Windham[214], *et al.*, 2000; Windham[213], *et al.*, 1999a; Windham[215], *et al.*, 1999b; Walsh[208], 1994; Windham[216], *et al.*, 1992; Mathai[118], *et al.*, 1992; Rubin[174], *et al.*, 1986; Martin and Bracken[115], 1986). In recent years, an increasing number of studies have found an association between maternal exposure to ambient air pollution and fetal growth and various adverse pregnancy outcomes at levels of pollution substantially lower than found in solid fuel-burning homes (Ritz[171], *et al.*, 2002; Ritz and Yu[170], 1999; Ha[81], *et al.*, 2001; Maisonet[111], *et al.*, 2001; Wang[209], *et al.*, 1997; Bobak and Leon[37], 1999; Bobak[36], 2000; Rogers[173], *et al.*, 2000; Chen[47], *et al.*, 2002; Maroziene and Grazuleviciene[113], 2002; Xu[223], *et al.*, 1995; Sram[195], *et al.*, 1999; Pereira[157], *et al.*, 1998; Woodruff[217], *et al.*, 1997; Loomis[107], *et al.*, 1999; Lipfert[105], *et al.*, 2000; Perera[158], *et al.*, 1999).

A recent study of newborn children in rural Guatemala reported that babies born to mothers using wood fuels were 63 gm lighter, on average, than those born to mothers using gas or electricity (Boy[32], *et al.*, 2002). Another study from a recent national household survey in Zimbabwe observed that babies born to mothers using biomass fuels (wood, dung, or straw) were 133 gm lighter, on average, than those born to mothers using electricity or biogas/LPG, after controlling for a number of potential confounders. There is only a single study that has reported an association between cooking with biomass fuels during pregnancy and stillbirths (Mavlankar[119], *et al.*, 1991).

1.6.7 Cancer

As discussion earlier, people from the rural areas particularly in developing countries use traditional cookstoves which is inefficient. Hence, combustion of biomass fuel during cooking in those inefficient stoves results release of substantial carcinogenic compounds, such as polycyclic aromatic hydrocarbons, formaldehyde, and other organic matter due to incomplete combustion. Till now, there is little epidemiological evidence connecting biomass smoke to lung cancer (Smith[191], 2002). However, a large majority of women with lung cancer in several developing countries are found to be non-smokers (Gao[72], 1996; Medina[121] *et al.*, 1996; Gupta[80] *et al.*, 1998), suggesting that cooking smoke might play a role. There is also some evidence to implicate biomass smoke in oral, nasopharyngeal and laryngeal cancers (Pintos[161], *et al.*, 1998; Franco[70], *et al.*, 1989; Clifford[49], 1972), although the evidence is not conclusive (Yu[225], *et al.*, 1985).

There is more consistent evidence linking smoke from household use of coal to lung cancer. Several studies in China have reported an association between household use of open coal stoves for cooking and lung cancer among non-smoking women(Mumford[134], 1995; Xu[223] *et al.*, 1995) In addition, some coals produce large indoor exposures to arsenic and fluorine (Finkelman *et al.*, 1999).

North – East India has a large canopy of green cover. About 54% of the total geographical area of this region is covered by forests, although there are inter-state variations. Hence, the people of north eastern region particularly in the rural areas mostly use firewood for their cooking and heating purposes. Subsequently, use of such firewood in the traditional stoves might create indoor air pollution resulting problems to their health. As the socio-cultural, housing and climatic conditions along with time-activity pattern of household members and the nature of biomass fuel uses are different, the exposure of indoor air pollution also might be different in different region. So, there is a need to study the characteristics of their household traditional stoves, exposure of polluting materials that released from the burning of firewood in the kitchen and the assessment of interventions for reducing exposure. Keeping in view of the following points, we have taken following objective for the current study.

The objectives of the study are –

1. ***To investigate and characterize different types of fuel use in the study area with relation to various socio-economic background.***
2. ***To quantify the pollutants (particularly CO, CO2 and particulate matter PM2.5) released during the combustion of firewood in the rural kitchens.***
3. ***To identify the groups of people, affected by the exposure in the indoor environment.***
4. ***To investigate the structural environment of the households in relation to indoor air pollutants.***
5. ***To investigate the impact of indoor air pollution by making an intervention study through replacement of traditional stove with improved stove.***

CHAPTER II

REVIEW OF LITERATURE

CHAPTER – II

Review of Literature

Indoor air pollution (IAP) can be traced to prehistoric times when humans first moved to temperate climates and it became necessary to construct shelters and use fire inside them for cooking, warmth and light. Fire led to exposure to high levels of pollution, as evidenced by the soot found in prehistoric caves (Albalak[3], 1997). Approximately half the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels in the form of wood, dung and crop residues (World Resources Institute, UNEP, UNDP, World Bank.[220], 1998–99). These are typically burnt indoors in open fires or poorly functioning stoves. As a result there are high levels of air pollution, to which women, especially those responsible for cooking, and their young children, are most heavily exposed (Yeh[225], 2004).

In the past two decade, the literature on indoor air pollution and health – including analyses of the magnitude of the problem; the correlation among fuel use, air quality and health and the physical impacts of interventions (e.g. changed fuel efficiencies, cooking times, etc.) – has grown rapidly. There has been little analysis to date, however, of household-level demand for indoor air pollution interventions. The public health officials, researchers and program implementers working in the area of IAP abatement therefore lack a critical piece of information. To achieve widespread health improvements, interventions that reduce exposures to IAP will need to be adopted and consistently used by large numbers of households in the developing world (Pokhrel[163] *et al.*, 2005; Misra[125], 2004).

A number of interventions have been developed to reduce household exposure to IAP. The most widely implemented is the introduction of improved stoves that emit fewer pollutants than traditional stoves. Other interventions include fuel-switching (e.g. from wood to coal or kerosene), improving household ventilation, fuel use practices and cooking practices (i.e. lids on pots), and altering childcare practices to keep children away from the kitchen during cooking times (Masera[115] *et al.*, 2000).

Regarding the use of biomass as cooking fuel, the understanding of the emissions from most of the known biomass burning-related sources has advanced significantly in last few decades (Kituyi[92] *et al.*, 2001a). However, there are diverse knowledge gaps in our understanding of the role that domestic biomass burning in developing countries plays in influencing the overall biomass burning emission budgets. Most important is the lack of reliable biofuel consumption data for most developing countries, which hampered the efforts to quantify the contribution of emissions from domestic biomass burning to the global atmospheric trace gas budgets. Apart from being very costly, energy surveys are difficult and time-consuming to carry out accurately (Scurlock and Hall[182], 1990). Despite these difficulties, Kituyi[92] *et al.* (2001a), carried out a study on fuel consumption pattern in Kenya in 1997, and they states that about 15.4 million tones of firewood (air-dried) were consumed and an equivalent of 17.1 million tones of round wood (wet weight) was converted to charcoal and at the same year, 1.4 million tones of a variety of crop residues were also consumed as domestic fuel. Besides these, they (Kituyi[93] *et. al.*, 2001b) also studied the biofuel consumption rates and patterns in Kenya. They have found that firewood was the main biofuel that used by the rural households, who consumed the commodity at average consumption rates in the range 0.8 – 2.7 kg cap^{-1} day^{-1} where as charcoal was mostly consumed by the urban households at weight average rates in the range 0.18 – 0.69 kg cap^{-1} day^{-1}. They also revealed that biofuel availability is one of the major factors that determine biofuel consumption rates and patterns. They also pointed out that there was the tendency by households to carelessly utilize fuels when they were in abundance and sparingly where there was scarcity. Other factors affecting per capita biofuel consumption rates were ambient temperature, population density, family size and stove types. Some other factors that may have influence the consumption rates and patterns include fuel cost, distance to source, meal types, frequency of cooking and the general household socio-economic class. These factors influence the biofuel consumption rates and patterns through their impact on combustion characteristics such as the duration of fire sessions, frequencies of these sessions and the burning efficiencies. These in turn influence the amount and also to some extent, the composition of important trace atmospheric gases and aerosols emitted during combustion.

Tanooka[200] *et al.* (2006) conducted a survey in the form of a questionnaire in residential households in the rural fringe of Xian city during the winter of 2003-04. Their main objective was to clarify the status of energy consumption and to estimate emissions of greenhouse gases and air pollutants in rural areas of China; from the environmental perspective of climate change and indoor to continental scale air pollution. In rural areas of China, wood and agricultural waste, such as stalks, corn canes and twigs, branches of wood is the type of fuel that most commonly used by the rural households. It emits several air pollutants like PM, CO, non-methane hydrocarbons, CH_4 and high levels of black carbon which is a greenhouse effect aerosol, and organic carbon which is a cooling effect aerosol. They have attempted to correlate income per household and energy consumption as the input but found no correlation between them. They further attempted secondary correlation between income per capita and effective energy consumption, but the result was the same.

In Indian context, Joon[89] *et al.* (2009) has recently reported about their study on household energy consumption pattern and the socio-cultural dimension of the people, which was carried out in Jhajjar district of Haryana. In the study they revealed that although income was an important factor in determining the choice of fuel for cooking, but there were some socio-cultural factors that equally important in making fuel preferences at household level. Rawat[167] *et al.* (2009), also carried out similar kind of study in the extremely low temperature and xeric climatic conditions of cold desert of the Lahaul valley (Khoksar – 3200 m, Jahlma – 3000 m, Hinsa – 2700 m and Kuthar – 2600 m) of north – western Himalaya, which has led to serious deforestation due to excessive use of fuel wood in the past. They have pointed out that fuel wood consumption was highest in high altitude villages as compared to low altitude villages

irrespective of family size. They have also found that fuel wood consumption in the study region was influenced by the local cold climate and season of the year.
Regarding North East Indian context, Maikhuri[110] (1991), did a comprehensive study on fuelwood consumption pattern in Arunachal Pradesh among different communities. Besides the estimation of fuelwood consumption by the households of different tribal communities, his other primary objectives was to evaluate the influence of climate, season, festival celebration and family size on fuelwood consumption. His other objective was to estimate the labour energy spent on fuelwood collection and to collect information on the preferred tree species as fuel and the types of stoves used by different communities.

In developing countries, although traditional small-scale combustion of biomass in stoves degrades air quality and is also thermally inefficient. However, high price of cleaner substitutes and their unavailability in many locations make rapid shifts away from the use of the traditional fuels unlikely. Thus biomass fuels are likely to continue to meet the cooking needs of a majority of people in the poorer countries (Ahuja[2] *et al.*, 1987). In order to overcome the two major drawbacks of traditional stoves, namely low efficiency and indoor air pollution, a large number of improved biomass fired stoves have been deployed in different countries. However, besides improvements in design, it is also important to understand how operation of stoves influences its performance in terms of efficiency and emissions of pollutants.

Concomitantly, indigenous development of efficient and convenient biomass stoves does not appear to be occurring spontaneously in many developing countries, even when woodfuel prices are high, because the population's generally low income inhibits them from investing in stoves. Yet the motivation for dissemination of improved stoves is much greater from the national perspective of today's developing countries, because the population pressure on the biomass resources base is much higher.

The recent spate of improved stove programs focusing on energy efficiency began in the 1970s after the large rise in oil prices. Before the oil shocks, households in many countries were able to shift up the energy ladder to the modern fuels when biomass fuels became more expensive and difficult to obtain. This occurred in South Korea in the 1960s, for example. But because of the increased prices and supply uncertainties of fossil fuels following the oil shocks, developing-country households became less able to make the shift, and some had to fall back on biomass fuels. Thus, it seems that people may have to rely on biomass fuels longer than was typical in the past.

There were several works conducted on performance and emission characterization on stoves by various researchers. According to a recent work, Granderson[76] *et al.* (2008) examined the fuel use and design of an improved wood-burning cookstove (*plancha*), and to make its comparison to the traditional cooking over an open woodfires. They conducted the measurements through Kitchen Performance Test (KPT) by introducing the *plancha* stove randomly into the households in the Guatemalan Highlands that had been previously used open woodfires. Although they have not got any statistical differences in fuel use between the two cooking methods, but they proposed that increase of study power through a large sample size (as they have conducted the test for only 12 households) may have resulted in a statistical significant difference.

Jetter and Kariher[88] (2008), carried out a work on 14 solid-fuel used households with cookstove and fuel combinations, which included 10 stoves (viz. Ecostove, VITA stove, UCODEA charcoal stove, WFP rocket stove, 3-stone fire, Philips stove, 6-brick rocket stove, Lakech charcoal stove, New Lao stove and UCODEA rocket stove) and 5 fuels (viz. Kiln dried Douglas fir, air-dried red oak, high-resin pine, charcoal and garment waste), and were tested for performance and pollutant emissions using a Water Boiling Test (WBT) protocol. Results from this study showed that some cookstoves have improved fuel efficiency and lower pollutant emissions compared with the traditional 3-stone fire. Stoves with smaller-mass components exposed to the heat of fuel combustion tended to have faster time to boil, better fuel efficiency and lower pollutant emissions. They also stated that it is the challenge to design stoves with smaller-mass components that also have acceptable durability, affordable cost and meet user needs.

Another significant work was carried out by Bhattacharya[32] *et al.* (2002a) to investigate the effects of different parameters such as moisture content of fuel, size of fuel, size of pot and method of ignition on performance and emissions of three biomass-fired stoves. The stoves they have considered for the study was an improved Indian stove (*harsha*), a Vietnamese traditional stove and an improved stove developed by the Royal Thi Forestry Department (RTFD stove). From the study it was found that increase in fuel moisture content resulted in decrease in stove efficiency, increase in the emission factor of CO and decrease in the emission factor of NO_x. Moreover, a slight decrease in CO_2 emission factor was also observed, while emission of CH_4 was not significantly effected. The fuel size did not show any significant influence on the efficiency of the stove; however, it showed significant influence on the emission of CO for the size range that investigated. The size of pot also did not affect the efficiency of the stoves tested. There are two methods of stove ignition i.e., conventional bottom ignition and top ignition were investigated and it was observed that emission of CO and NO_x was significantly less in case of top ignition in comparison with conventional bottom ignition. In general, burn rate was found to increase with increase in fuel batch size. The NO_x emission factor slightly increased as batch size was increased; changes in emissions of the other gases such as CO and CO_2 along with stove efficiency with change in batch size was not significant.

In 1996, Ballard-Tremeer and Jawurek[21] made a comparative study on five rural wood-burning cooking devices viz., an open fire built on the ground, an improved open fire built on a raised grate, a one-pot metal stove, a two-pot ceramic stove and a two-pot metal stove; regarding their efficiencies and emissions. Efficiencies of such cookstoves were determined by carrying out a computer-controlled version of the standard Water boiling Test and the emission concentrations of smoke, CO and SO_2 were measured by means of a fume extraction hood, an optical smoke-density meter and an electrochemical flue-gas analyzer. From the study, they concluded that the average emissions of smoke were lowest for the improved open fire and the two-pot ceramic stove, with the remaining devices higher emitting factors from 1.5 to 3. Emissions of CO and SO_2 were lowest for the two open fires. Average efficiencies of the cooking devices were 14% for the open fire, 21% for the improved open fire, and for the rest of the stoves it's ranging from 20% to 24% with no statistical significance.

In 2002 Bhattacharya[33] *et al.* (2002b) carried out a study on the emission from a number of traditional and improved cookstoves collected from different Asian countries using wood and charcoal as fuel. From the study, they have found that in case of wood combustion, CO_2 emission factor is in the range of 1560 – 1620 g kg $^{-1}$. The emission factors for pollutants such as CO, CH_4, TNMOC (total non methane organic carbon) and NO_x were in the ranges 19 – 136 g kg $^{-1}$, 6 – 10 g kg $^{-1}$, 6 – 9 g kg $^{-1}$ and 0.05 – 0.2 gkg^{-1}, respectively. On the other hand, in case of charcoal combustion, CO_2 emission factor is in the range of 2155 – 2567 g kg $^{-1}$ and the emission factors for pollutants CO, CH_4, TNMOC were in the ranges 35 – 198 g kg $^{-1}$, 6.7 – 7.8 g kg $^{-1}$ and 6 – 10 g kg $^{-1}$, respectively.

Kituyi[94] *et al.*, (2001c) made a brief study on CO and nitric oxide (NO) from biofuel fires in Kenya. They have reported the emission ratios (ER) of CO and NO relative to CO_2 from real time emission measurements on biofuel fires. The experiments were based on available fuels burning in local popular traditional and improved stoves. The work narrows the gap in the understanding of CO and NO emission characteristics from biofuel fires. The dCO/dCO_2 ratios for firewood, charcoal and crop residues were 71, 79 and 74 mmol mol $^{-1}$, respectively, while those for dNO/dCO_2 were 1.8, 2 and 2.2 mmol mol $^{-1}$. They observed that most of the NO was formed in the flaming phase of wood burning, during which the NO ER decrease with decreasing combustion efficiency. However, as glowing sets in and proceeds to extinction through smouldering, the NO ER decrease with decreasing CO ER (increasing combustion efficiency). Charcoal fires are also characterized by decreasing NO with decrease in the CO ER, though at different rates of production between smouldering and the dominant glowing phases. Kituyi[94] *et al.*, (2001c) also stated that stove design parameters such as chimneys, air inlets, ceramic walls etc. influence the rate and quantity of CO and NO formation from biofuels. These parameters influence the major operational parameters, such as air/fuel mixing, pre-heating of inlet air and fuel loading. Whereas improved stoves are efficient with respect to quantity of fuel used, they do not necessarily promote efficient processes with respect to their traditional counterparts. The carbon content of biofuels is stable and does not; therefore influence the dCO/dCO_2 ratios. These ratios are largely a factor of combustion characteristics. However, the emissions of NO depended on the fuel nitrogen content through the statistically significant linear relationship $dNO/dCO_2 = 1.1N + 1.3$, where N is the percentage of nitrogen content in the firewood. The NO ER for all biofuels, in general, is related to the fuel nitrogen content through statistically significant relationship $dNO/dCO_2 = 0.95N + 1.5$. Measuring only the fuel nitrogen content and using any of the household woodstoves reported, these relationships may be reliably used to determine the biofuel NO ER and molar N/C ratios necessary for emission factor calculations. Kituyi[94] *et al.*, (2001c) also pointed out that the dNO/dCO_2 ratios based on fuel nitrogen derived NO are not affected by fire temperature. However, the NO formed at very high temperatures that result from oxidation of atmospheric nitrogen, which occurs anywhere in the high temperature zones, provided the constituent concentrations and residence times are favourable. However, this does not significantly affect the overall fuel nitrogen derived NO concentrations. Fuel related factors that influence the CO and NO ER include moisture content, fuel size and volatile matter content in charcoal.

Ezzati[67] *et al.*, (2000) compared the emissions of suspended particulate matter (SPM) and CO from traditional and improved (ceramic) biofuel stoves in Kenya under the actual conditions of household use. Their analysis showed that improved (ceramic) wood-burning stoves reduce daily average SPM concentration by 48% during the active burning period and by 77% during the smouldering phase. Ceramic stoves also reduce the median and the 75th and 95th percentiles of daily emission concentration during the burning period and the 95th percentile during smouldering phase, and therefore shift the overall emission profile downward. Improved charcoal-burning stoves also offer reductions in IAP compared to the traditional metal stove, but these are not statistically significant. The greatest reduction in emission concentration was achieved as a result of transition from wood to charcoal where mean emission concentration drop by 87% during the burning phase and by 92% when smouldering as well as reductions in the median and 75th and

95th percentiles. Such result indicates that transition to charcoal, followed by the use of improved wood stoves, are viable options for reduction of human exposure to IAP.

The problems of viewing household development and fuel choice strictly in terms of energy ladder lead to an obvious but important conclusion. The availability and development of appropriate stove technologies is less critical in combating health risk due to IAP than the general education regarding these risks. Saatkamp[176] *et al.*, (2000) made an intregated study of the energy, health and economic implications of fuel switching in the small village of Jaracuaro, Michoacan State, Mexico that challenges and extends the traditional energy ladder model. They monitored fuel and stove use, economic status, exposure to respirable suspended particulates (RSP) and trace gases such as CO, CO_2, NO_x, SO_2 and morbidity during both wet and dry seasons for a sample of 141 persons living in 21 households. The families they had surveyed normally used simple "three stone" fires, traditional enclosed or improved stoves. In the study they observed that in Jaracuaro, where the people who normally cook twice daily as likely as non-cooks exhibit acute respiratory infection (ARI), (relative risk = 2.0, 95% CI = 1.3 – 2.7). They also observed that the use of improved stoves correlates with reductions in indoor concentrations of RSPs and CO, and decreases in reported cases of ARI, eye infections, and intestinal disorders. These changes are consistent with the technology component of the energy ladder, relating improvements in stove and fuel type to emissions and then to respiratory ailments which suggests an associated "health ladder" for families adopting improved stoves or kitchen designs. The study reveals that the energy ladder framework, while useful, is also an oversimplification that masks some of the strategies used in household decision-making which reflected in Jaracuaro, where the socioeconomic correlation of stove "quality" and income breaks down i.e., the more affluent families do not necessarily use cleaner fuel and stove combinations or invest in kitchens that are more healthy or energy efficient. Some of the most affluent households even exhibited the highest RSP and CO concentrations. These findings lead to a more eclectic model of fuel and stove adoption and use that has implications for integrated health and development policies. One of the most familiar conclusions that can be brought from this study is the need and the opportunity for educational programs to facilitate transitions to more efficient stoves and cleaner fuels for the rich and poor alike.

Lodhi and Abdin[106] (1999) carried out a very effectual study on indoor air pollutants (SPM and CO) from fossil fuel and biomass in Malaysian rural households. The results obtained from the study showed that cooking activities using firewood produced higher concentrations of SPM and CO than from using gas (LPG). It was also observed that the indoor concentrations of SPM and CO (during cooking) were generally higher than those obtained outdoors. Nevertheless, the outdoor concentrations of these pollutants sometimes could and did have a positive influence on the indoor concentrations. They also remarked that the pollutants in those households had not reached levels as high as in India and Guatemala. This was due to the fact that the kitchens in those households were specious and to the housewife's practice of leaving the windows (and sometimes doors) open, leading to a well-ventilated situation during cooking. Nevertheless, one should not be complacent about it as the situation can turn for worse, if no deliberate effort is made to improve lot of the households using firewood.

In 1996, Moriske[133] *et al.*, made an investigation on IAP by different heating systems such as coal burning, open fireplace (wood burning) and central heating in private homes. The investigation consists mainly for CO, sedimented dust material, heavy metals (inside the sedimented dust) and sometimes, polycyclic aromatic hydrocarbons (PAHs). They have found that such pollutants were higher in concentration particularly in the homes with coal burning than in the homes with central heating. The same results were observed for the open fireplace also. In contrast, the concentrations of CO_2 in each home were found similar. The reason may be that CO_2 is exhausted by man and it may be more important to consider the reason of increase of CO_2 concentration from "human emission source" than the additional contamination by the heating systems.

In India, fuelwood and animal dung cakes are the two commonly used biofuels in rural areas. The use of charcoal is preferred over fuelwood in small towns and semi-urban areas for a variety of practical reasons, which include its higher calorific value, reduced smoke and relative ease of utilization. Similarly, anaerobic digestion of animal dung is being promoted through National Biogas Mission in India. In 1995, Kandpal[90] *et al.*, made an investigation to study the emission of air pollutants from the combustion of fuelwood, charcoal, animal dung cakes and biogas in respective cooking appliances. The air pollutants studied are CO and SPM which was further analyzed to study the concentration of benzo[a]pyrene. During the observation, they have found that in all the four cases viz. firewood, dung cake, charcoal and biogas, the concentration of CO was found to increase linearly with time. However, the rate of addition of CO in the indoor environment was quite different for the different fuels. While the CO concentrations in the beginning of the experiment are very close to each other but towards the end of the experiment, these values differ considerably. They also found that among all the four fuel sources, dung cake released maximum quantities of CO, SPM and benzo[a]pyrene. Another important remarks they have drawn that a shift from dung cakes to biogas reduces the particulate level by about 90% particularly in the kitchen.

Particulate matter (PM) is one of the major indoor air pollutants that releases from domestic wood burning. People spend the majority of their time indoors mostly in the domestic environment, where their health may be effected by significant airborne particulate pollution. BéruBé[30] *et al.*, (2004) investigated the indoor/outdoor air quality at six households in Wales and Cornwall, UK, based on different locations viz. urban, suburban, rural and household characteristics such as smokers and non-smokers. During the study, the spatial and temporal variations in PM_{10} mass were monitored for a calendar year 1998 – 1999, including ambient weather conditions. The activities of the individuals within a household were also recorded. Monitoring was done for PM_{10} in three different locations inside the households' viz. kitchen, living room and bedroom, along with concomitant collections of outdoors. From the study it was observed that at low outdoor levels of PM_{10}, mean indoor air concentrations were found to be nearly twice as high as outdoor levels. Indoor concentrations were considerably higher during the day, when people were at home and active, than overnight. The data obtained from field emission scanning electron microscopy (FESEM) suggested that the outdoor PM_{10} composition consisted of mineral, salt, soot and biological particles. Another important point that had been observed from the FESEM data was that the households situated in the same geographical locations, e.g. urban, suburban and rural exhibited the same particle profiles regardless of personal activities or smoking habits. For example, indoor PM_{10} from all households in urban/suburban locations were dominated by soot and smelter particles, whereas in houses located in the rural areas, indoor PM_{10} composition consisted mainly of salt and gypsum particles.

McCracken and Smith[120] (1998), has made a comparative study of the thermal efficiency and emissions of the traditional three-stone fire and the "*Plancha*" improved wood-burning stove. Simultaneous measurements of efficiency and emissions of suspended particles (SP) and CO was also taken in order to incorporate both of these factors into a single standard of performance – emissions per standard task. These factors were measured during both a Water Boiling Test (WBT) and a Standard Cooking Test (SCT). During the observation no statistical difference was found in the efficiency between *Plancha* and traditional stove. *Plancha* required more time to perform both the tests, and this difference was statistically significant ($p = 0.048$) for the WBT. They have found that the *Plancha* stove emitted 87% less SPs of $PM_{2.5}$ and 91% less CO per kJ of useful heat delivered in comparison to the open fire stove during the WBT. The relative environmental performance of the *Plancha* improved stove during the SCT, resulting in a 99% reduction of TSP emissions and a 96% reduction of CO emissions per standardized cooking task. A strong correlation ($r^2 = 0.87$) was found between the average kitchen concentrations of CO and $PM_{2.5}$ during the WBTs, indicating the usefulness of CO measurements as an inexpensive and accurate way of estimating $PM_{2.5}$ concentrations.

Molnar[132] *et al.*, (2005) did a work on personal exposures as well as indoor and outdoor levels of $PM_{2.5}$ during the winter of 2003 in the residential area of Swedish town Hagfors, where wood burning for domestic space heating is common. In this study, they had attempted to compare the exposures and levels between wood burners and a reference group who lived in a clearly defined area where wood burning was prevalent. The study reveals that $PM_{2.5}$ mass and Sulphur (S) levels were not significantly elevated in wood burners, probably due to large variations in outdoor concentrations from long-distance transported air pollution. Personal exposure and indoor levels showed high concentrations for all the species, and the personal exposure levels were usually higher than or equal to the outdoor levels. The associations between personal exposure and outdoor levels were generally weak except for outdoor S and $PM_{2.5}$ levels that were both highly correlated with personal S exposure levels ($r_s > 0.8$).

In 2005, the Relationship of Indoor, Outdoor and Personal Air (RIOPA) study was designed by Meng[122] *et al.* to investigate residential indoor, outdoor and personal exposures to several classes of air pollutants, including volatile organic compounds (VOC), carbonyls and fine particles ($PM_{2.5}$). In this study, the contributions of ambient (outdoor) and non-ambient sources to indoor and personal concentrations were quantified using a single compartment box model with measured air exchange rate and a random component superposition (RCS) statistical model. The mean of the distribution of ambient contributions across study houses agreed well for the mass balance and RCS models, but the distribution was somewhat broader when calculated using the mass balance model with measured air exchange rates.

Another RIOPA study was undertaken by Weisel[210] *et al.*, (2005) to evaluate the contribution of outdoor sources of air toxics, as defined in the 1990 Clean Air Act Amendments, to indoor concentrations and personal exposures. During this study, the concentration of 18 VOCs, 17 carbonyl compounds and $PM_{2.5}$ were measured using 48-h outdoor, indoor and personal air samples were collected simultaneously. From the observations, they concluded that RIOPA study can potentially provide information on the influence of ambient sources on indoor air concentrations and exposure for many air toxics and will furnish an opportunity to evaluate exposure models for these compounds.

In Indian context, Srivastava and Jain[196] (2007) carried out a study to characterize the SPM in an indoor environment in Delhi. Their main objective was to investigate potential PM exposure, and the possible effective measures for interventions and assessment of sources in indoor environments. In this regard, a pilot study had been carried out at Jawaharlal Nehru University (JNU), New Delhi. From the study, they had concluded that the most of the indoor SPM are outdoor born, which are either ventilated inside the indoor or are due to the re-entrainment of the existing particles. Furthermore, the chemical analysis revealed that the Ca, Mg and Fe (these metals are of crustal origin) have the maximum in the indoor concentrations; while the morphological interpretations showed silicate (crustal origin) and soot particles (vehicular origin) are dominant. The ambient air of Delhi contains high amount of crustal dust, which in the course of time founds its way into the indoor environment but this may not be the case in the rural areas where vehicular pollution could not play a role as such.

Dutta[60] *et al.*, (2007) made an effective study on impact of improved biomass cookstoves on indoor air quality near Pune, India. Their primary motive was to reduce the IAP and improve fuel efficiency. In this regard, her organization, the Appropriate Rural Technology Institute (ARTI), in conjunction with ten other non-governmental organizations, helped to establish rural enterprises that subsequently distributed 30,000 improved cement cookstoves in Maharastra, India. In a subset of these households (n = 110), ARTI undertook a comprehensive assessment of the impact of the improved Laxmi (vented) and Bhagyalaxmi (unvented) stoves on the indoor air quality. Measurements of CO and $PM_{2.5}$ were taken for a 48-hour period in kitchens before and after installation of improved stoves. One year after the installation of the improved stoves, they have found that the 48-hour mean CO concentration was reduced, an average by 39% for the Laxmi and 38% for the Bhagyalaxmi. Similarly, 48-hour $PM_{2.5}$ concentration was reduced, on average by 24% for the Laxmi and 49% for the Bhagyalaxmi. They had quoted some key challenges that faced during the installation of ICSs such as motivating household members to purchase the ICSs; ensuring that the households made the transition to using the ICSs; and maintaining high standards of data quality as a field team.

Bailis[15] *et al.* (2007) reported a very effective measure of monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance. They have developed standardized techniques for monitoring and evaluating changes in indoor air quality and stove performance and deployed in two NGO-led programs to disseminate ICSs in India and one in Maxico. They have carried out an intervention study by installing ICSs in the reference households. For evaluating stove performance, the Kitchen Performance Test (KPT), an effectiveness test (CCT), was chosen for primary measures, which involves measurements of fuel use in real households over several days. An improved protocol was developed for WBT, KPT and CCT (Smith[190] *et al.*, 2007). For indoor air quality monitoring a longitudinal "before and after" design was used for field survey in actual households that were part of the stove disseminations was developed and implemented. Smith[190] *et al.*, (2007) further also reported that their result showed major and mostly statistically significant improvements in 48-hour indoor air pollution concentrations in those households using the stoves one year after installation. In the kitchen, they have found that the concentration of CO and $PM_{2.5}$ reduced by 30 – 70% and 25 – 65% respectively. Results of stove performance were found mixed, with some stoves achieving improvement in one or another of the short-term metrics that are part of the WBT used to evaluate stove in laboratory (controlled) settings. The result was also promising for KPT, as it was less easily conducted because of high variation and difficult field logistics, however, the statistical significant reductions in fuel use per person ranging from about 20 – 67%. They also pointed out that several indicators of stove performance derived from the WBT are not good predictors of actual fuel use and thus should be confined to evaluations during the design stage of stove development. From the study they have made some recommendations for future monitoring and evaluation efforts such as with the primary one being to combine efficacy tests (small number of carefully monitored households under normal conditions) with larger well-designed surveys (questionnaire only) to determine actual usage and household perception. They have also recommended that only those NGOs planning to develop significant long-term capability in measuring air pollution and stove performance under field conditions be expected to undertake effectiveness testing, i.e., evaluate population-wide changes from real large-scale dissemination program.

Earlier in 2004, Balakrishnan[18] *et al.*, carried out a brief exposure study with a different approach by determining 24-hour average concentration of respirable particulates (50% cut-off at 4 μm) with low volume samplers for various household microenvironments such as the kitchen, living room and outside. During the study, they have considered four types of kitchen orientations viz., indoor enclosed kitchen without partition, indoor enclosed kitchen with partition, separate enclosed kitchen outside house and open air kitchen outside house. They have carried out the sampling for $PM_{2.5}$ in three districts of Andhra Pradesh with 450 households (150 each). For the sampling procedure they have adopted a three-stage cluster sampling method as –

a) Selection of *mandals* as first-stage sampling unit (five from each district),
b) Selection of *habitations* as second-stage sampling unit (one from each *mandal*),
c) Selection of households as third-stage sampling unit (30 from each habitation).

A questionnaire was administered to the households for gathering additional information on exposure determinants and record time activity schedule. Time activity records were obtained from household members on the basis of a 24-hour recall. With the questionnaire survey, some household-parameters were also collected which include fuel type, fuel quantity, household ventilation, cooking duration and other potential sources of particulates inside homes such as cigarettes, incense, and mosquito coils. Exposure was reconstructed on a case-by-case basis taking into account individual time budgets in various microenvironments using a modification of the approaches of earlier studies (Duan[56] *et al.*, 1989) according to the following formula –

$$\text{Average 24-hr exposure} = \frac{K1a \times T1a + K1b \times T1b + L1a \times T2a + L1b \times T2b + O1 \times T3}{T1a + T1b + T2a + T2b + T3}$$

Where,

K1a is the average concentration in the kitchen during cooking periods,

T1a is the total time spent in the kitchen during cooking periods,

K1b is the average concentration in the kitchen during non-cooking periods,

T1b is the total time spent in the kitchen during non-cooking periods,

L1a is the average concentration in the living area during cooking periods,

T2a is the total time spent in the living area during cooking periods,

L1b is the average concentration in the living area during non-cooking periods,

T2a is the total time spent in the living area during non-cooking periods,

O1 is the 24-hr average concentration outdoor, and

T1a + T1b + T2a + T2b + T3 = 24.

From the study they have found that the mean 24-hour average concentrations ranged from 73 – 732 μg/m^3 in gas *versus* solid fuel-using households, respectively. The mean 24-hour average exposure was also found in the range from 80 – 573 μg/m^3. Concentrations were significantly correlated with fuel type, kitchen type and fuel quantity. Among the solid fuel users, the mean 24-hour average exposures were the highest for women cooks and were significantly different from men and children. Among the women, exposures were the highest in the age group of 15 – 40 years (most likely to be involved in cooking or helping in cooking), while among men, exposure were highest in the age group of 65 – 80 years (most likely to be indoors). They also revealed that the results of the qualitative assessment provided additional evidence of the importance of intervention studies other than fuel switching. They also stated that ventilation and behavioral initiatives may offer a potential for substantial exposure reduction and these are likely to be the short-term alternatives for a great majority of the rural population.

Another interesting work was carried out in Mysore, India by Andersen[9] *et al.*, (2005); to determine whether exposures to $PM_{2.5}$ differed according to fuel use patterns or not. During the study, 24-hour gravimetric personal and indoor $PM_{2.5}$ exposures were measured for 15 women using kerosene and 15 women using liquefied petroleum gas (LPG) as their main cooking fuel. A questionnaire was also administered to the women regarding their residential housing characteristics, health status, cooking practices and socioeconomic status. They had made a repeated measurement of it for two consecutive seasons and a general linear model (GLM) was used to analyze the data. From the result, they concluded that the women using kerosene as their primary cooking fuel had significantly higher exposures than LPG users. Their data showed that during summer, the arithmetic mean (± standard error) for kerosene and LPG users, the personal exposure was 111 ± 13 μg/m^3 and 71 ± 15 μg/m^3 respectively. Kerosene users had higher exposures in winter (177 ± 21 μg/m^3) compared to summer exposures. However, for LPG users there was no difference in their seasonal geometric mean exposures at 71 ± 13 μg/m^3. Indoor concentrations followed similar patterns. In summer, households of kerosene and LPG users had an arithmetic mean concentration of 98 ± 9 μg/m^3 and 71 ± 9 μg/m^3 respectively. Winter concentrations were significantly higher than summer concentrations for kerosene users (155 ± 13 μg/m^3). Again, LPG users showed only slightly higher indoor concentrations (73 ± 6 μg/m^3) than kerosene users. Finally, they made another statement that socioeconomic status, age, season and income are the significant predictors of cooking fuel choice.

In the past, when human bioeffluents were considered to be the most important pollutants of indoor air, CO_2 was generally accepted as an indicator for indoor air quality (IAQ). CO_2 has lost this function partly because today many more sources than human beings emit pollutants into indoor air. In fact the widespread use of new products and materials in our days has resulted in increased concentrations of indoor pollutants, especially of VOCs, that pollute indoor air and maybe affect human health. Among the pollutants such as CO and particulate matter; hydrocarbons, particularly polycyclic hydrocarbons (PAH) have also a special interest of indoor air pollution. PAHs constitute a large class of compounds released during the incomplete combustion or pyrolysis of organic matter. They are often called polynuclear aromatic (PNA) because they contain three or more aromatic rings that share carbon atoms. Benzo[a]pyrene (BaP) is one of the most important carcinogens of the group. Anthracene and phenanthracene are not carcinogens but methyl additions may render them carcinogenic. PAHs are activated by the hepatic microsmal enzyme system to carcinogenic forms that bind cavalently to DNA (Perera[157] *et al.*, 1998).

In 2005, Oanh[145] *et al.* carried out a study on PM and PAHs from 12 selected cookstoves of Asia with firewood (pine tree logs), rice husk briquettes and anthracite coal as the burning fuel. Monitoring was done using a hood and a semi-VOC sampling train. 17 PAH (16 US EPA priority plus BaP) were analyzed by HPLC-UV to yield PAH in the PM and gas phase samples separately. The result of the study showed that the PM emission factor for firewood, rice husk briquettes and anthracite coal was found around 2 – 5 g Kg^{-1}, 5 g Kg^{-1} and 7 g Kg^{-1}, respectively. Emission factor of 17 PAH for the two biomass fuels (firewood and rice husk briquettes) was found in the range of 24 – 114 mg

Kg^{-1} and 140 mg Kg^{-1} respectively. They have also found that the majority of PAH in the biomass fuel smoke was of light and more volatile PAH with above 86% of the total 17 PAH found in the vapour phase. For the anthracite coal, emission factor of 17 PAH was low (2 mg Kg^{-1}) and found only in the PM phase. They also found that PAH content in PM varies with cookstoves and was 0.08 – 1.64 mg g^{-1} (of PM) for total 17 PAH, 0.06 – 0.98 mg g^{-1} for genotoxic PAH, and 0.001 – 0.147 mg g^{-1} for BaP alone.

Another work was carried out by Olsson and Kjällstrand[146] (2004) to determine the compounds emitted from the burning of softwood pellets collected from three different Swedish manufacturers in laboratory scale. The emissions were sampled on Tenax cartridges and assessed by gas chromatography and mass spectroscopy. But, they observed no large differences in the emissions from pellets from different manufacturers. The major primary semi-volatile compounds released during flaming burning were found to be 2-methoxyphenols from lignin. The methoxyphenols are of interest due to their antioxidant effects, which may counteract health hazards of aromatic hydrocarbons. They also observed that glowing combustion released the carcinogenic benzene as the predominant aromatic compound. However, the benzene emissions were lower than from flaming burning. To relate the results from the laboratory burnings to emissions from pellet burners and pellet stoves, they determined chimney emissions for different burning equipments and they found that the pellet burner emitted benzene as the major aromatic compound, whereas the stove and boiler emitted phenolic antioxidants together with benzene.

Guo[79] *et al.*, (2003) carried out a work with an aim of low VOCs emission house to reduce the level of VOCs in domestic housing. In the study, before application, the construction materials used in the house were tested in an environmental chamber and low VOC emission materials were than selected. Design of the house was made with following major criteria, viz., maximizing the ventilation rate and avoiding the use of high VOC emission materials in the house. From the study, they observed that by improving building design and proper construction materials selection, the risk of personal exposure to VOCs in the house was significantly reduced. Furthermore, they also combined the results of this study with three traditional ways in improvement of IAQ. The results obtained from the study confirmed that the most effective strategy for controlling IAQ was pollution prevention and the next most important was the design of ventilation rates to handle uncontrollable sources.

Bruce[42] *et al.* (2004) made an interesting observation to assess the impact of improved stoves, house ventilation, and child location on levels of IAP and child exposure in a rural Guatemala population reliant on wood fuel. Their results shows that the 24-hour kitchen CO concentration was lowest for homes with self-purchased *Planchas*: mean (95% CI) CO of 3.09 ppm (1.87 – 4.30) *vs* 12.4 ppm (10.2 – 14.5) for open fires. The same ranking was found for child CO exposure, but with proportionately smaller differentials ($p < 0.0001$). The 24-hour $PM_{2.5}$ in the sub-sample showed similar differences ($n = 24$, $p < 0.05$). They have made a concluding remark from the multivariate analysis that stove/fuel type was the most important determinant of kitchen CO, with some effect of kitchen volume and eaves. They further revealed that stove/fuel type is also the key determinant of child CO, with some effect of child position during cooking.

Zhang and Zhao[228] (2007) made an investigation and simulated the indoor particle pollution from coal combustion for some typical home in Xuanwei, China by computational fluid dynamics (CFD) method. Benzo[a]pyrene, one of the important pollutants from incomplete combustion, was used as a criterion for its strong carcinogenicity in risk assessment. Mechanical exhaust fan was installed in order to reduce the concentration of indoor suspended particles. Based on the simulation results, an engineering-oriented method was demonstrated to be effective in assessing indoor particle pollution by coal combustion and its health effect. Results indicated that the indoor particle pollution was rather serious due to poor ventilation. Women, who spent more time indoors than men, had higher risk for lung cancer.

Naumova[137] *et al.*, (2003) did a work on gas/particle distribution of PAHs in coupled outdoor/indoor atmospheres. Their main objective was to evaluate the hypothesis that outdoor air pollution contributed strongly to IAP. During the study, concentration of

PAHs, $PM_{2.5}$, and organic and elemental carbon (OC and EC) were measured in 48h integrated samples collected in the indoor and outdoor air in Los Angeles. The measured partition coefficients of PAHs, in the individual samples were correlated with the compounds sub-cooled liquid vapour pressure. Value of the measured partition coefficients were varied by about two orders of magnitude for any given value of vapour pressure. These variations in gas/particle partitioning of PAHs were found higher than the estimated systematic and random error of the measured partition coefficients and are related to the aerosol characteristics and sample conditions. From the study, they concluded that both EC and OC are important predictors of gas/particle partitioning of PAHs, with EC being a better predictor. Because EC is highly correlated with (and is a good tracer of) primary combustion-generated OC. The result also suggests that PAHs more readily sorb on combustion-generated aerosol containing EC.

Earlier, Naumova[138] *et al.*, (2002) carried out a study on the indoor and outdoor air concentration of 30 PAHs in 55 non-smoking residences of three urban areas in the US viz., Los Angeles, CA; Houston, TX and Elizabeth, NJ. In the outdoor samples, the total PAH concentrations found were 4.2 – 64 ng m^{-3} in Los Angeles, 10 – 160 ng m^{-3} in Houston and 12 – 110 ng m^{-3} in Elizabeth where as indoor concentrations were 16 – 220 ng m^{-3} in Los Angeles, 21 – 310 ng m^{-3} in Huston and 22 – 350 ng m^{-3} in Elizabeth. The PAH profile of low molecular weight PAHs (3 – 4 rings) in the outdoor samples from the three cities were not significantly different. In contrast, the profiles of 5 – 7 ring PAHs in these cities were significantly different, which suggested different dominated PAH sources. The signatures of 5 – 7 ring PAHs in the indoor samples in each city were similar to the outdoor profiles, which suggested that indoor concentrations of 5 -7 ring PAHs were dominated by outdoor sources. Indoor-to-outdoor ratios of the PAH concentrations showed that indoor sources had a significant effect on indoor concentrations of 3 – ring PAH and a smaller effect on 4 – ring PAHs and that outdoor sources dominated the indoor concentrations of 5 – 7 ring PAHs.

Lee[102] *et al.*, (2002) made an investigation of indoor air quality at residential homes in Hong Kong. The air pollutants measured in the study included CO_2, PM_{10}, formaldehyde, VOCs and airborne bacteria. The results of the study indicated that the 8h average concentrations of CO_2 and PM_{10} in the domestic kitchens that investigated were 14% and 67% higher than those measured in the living rooms. The majority of the domestic living rooms and kitchens studied had average concentrations of airborne bacteria higher than 500 CFU m^{-3}. The mean total bacteria count recorded in kitchen was greater than that obtained in living rooms by 23%. In homes where occupants smoke, the negative impact of benzene, toluene and *m,p*-xylene on the IAQ was greatly enhanced. The use of LPG stove has more significant impact on indoor VOCs than the use of cooking stoves with natural gas as cooking fuel.

Pandit[154] *et al.*, (2001) investigating indoor VOCs and PAHs arising from kerosene stove. In the study, air samples representing indoor environments of a kitchen in which a kerosene stove was used were collected and then analyzed for VOCs viz., *n*-hexane, benzene, heptane, toluene, *p*- and *o*-xylene and *n*-decane using a cryogenic pre-concentration system and a gas chromatograph with a flame-ionization detector. Simultaneously, outdoor samples were also collected to determine indoor to outdoor (I / O) ratios for each compound. The study reveals significant indoor pollution due to use of kerosene as fuel. All the identified VOCs showed higher concentrations, compared to ambient levels. Mean benzene concentration was found to be six times higher than ambient benzene levels. TSPM concentrations were significantly higher in the indoor environments and exceed the Air Quality Standard stipulated for outdoor environments. Benzene soluble organics also showed higher indoor concentrations than outdoor. The mean concentrations of some individual PAH compounds are higher by approximately an order of magnitude in indoor cooking environments than outdoor cooking environments. Though the exposure to indoor PAHs could be two to ten times higher during a cooking period, the effective total daily exposure was only two times higher than that from ambient air.

Application of statistical data analysis is largely based on decision making process under uncertainty for probabilistic risk assessment of a decision. Poupard[164] *et al.*, (2005) carried out a statistical analysis of parameters influencing the relationship between outdoor and indoor air quality. During the study; ozone, nitrogen oxides (NO and NO_2), and PM (15 size intervals ranging from 0.3 – 20 μm) concentrations were monitored continuously indoors and outdoors for 2-week periods. The indoor relative humidity, temperature, CO_2 concentration (room occupancy), window openings and permeability of the building were also measured. Principal component analysis (PCA), a multivariate observation-based statistical method was used to determine the parameters influencing the relationship between the outdoor and indoor concentration levels. The analysis leads to distinguish between positively correlated, negatively correlated and non-correlated variables. The main conclusions aroused from the study were: the influence of room occupancy on the particle concentrations indoors changes with different particle sizes, the building air-tightness and the outdoor concentration level greatly influence the indoor / outdoor concentration ratios of ozone, and indoor ozone and particles concentrations are negatively correlated, which may be the result of complex homogeneous and / or heterogeneous processes.

CHAPTER III

MATERIALS AND METHODS

CHAPTER – III

Materials and Methods

3.1 Study Site

The site that has been selected for the present study was the Sonitpur district of Assam. It lies between 92°16' to 93°43' East longitudes and 26°30' to 27°01' North latitudes and covers an area of 5324 sq. km. According to the Census 2001, Govt. of India; the total no of population and households of Sonitpur district was 16,81,513 and 3,15,116 respectively including both rural and urban areas. Sonitpur district has subdivided into 7 sub-districts viz. Biswanath, Chariduar, Dhekiajuli, Gohpur, Helem, Na-Duar and Tezpur. For the present study, we have selected ten rural villages of Sonitpur district, namely, Napaam, Jaglouni, Bhaluk jharoni, Baruadoloni, Puthimari, Geruah, Balikhuti, Bapubheti, Pithakhowa and Baligaon.

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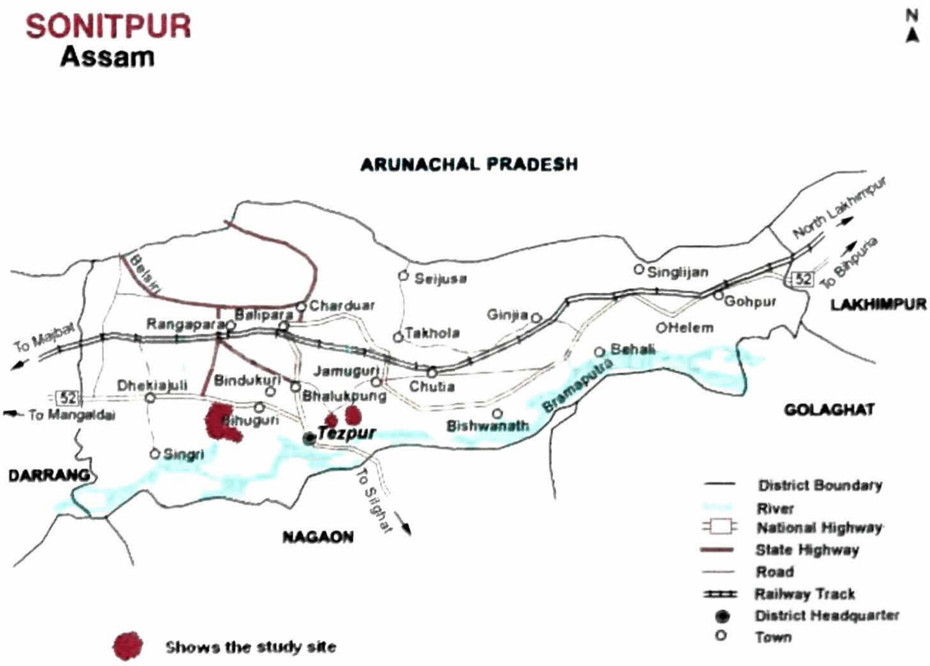


Figure: 5. Map of Sonitpur district of Assam indicating the study site.

The reason behind the selection of these ten villages was that they represent almost all the major communities of Assam living there. They represent the major household design and socio-economic status of the rural areas of the north eastern region. Furthermore, the household of these selected villages are mostly depending on solid fuel use such as firewood and dung for their cooking and heating purpose. In the figure 5, the regions of all the selected villages are shown in red coverage.

3.2 Preliminary questionnaire survey

In the first phase of the survey a questionnaire was administered to the household based on stratified random design in the study site. For this purpose, we have covered 10% of the households of each village for the survey (according to the number of households based on Census 2001). The questionnaire was primarily based on the demographic, economic, architectural, fuel use, and health aspects of the households that potentially relevant to IAP. The questionnaire format is shown in Annexure I. For the questionnaire survey, questions were asked mainly to the head of the households. For collection of additional information, sometimes group discussions were also made with the village people to know about their livelihood, fuel collection, consumption pattern, IAP related diseases particularly suffered in that area, and awareness about the IAP among them. Questionnaire format was made in the local language particularly in local language (Assamese) and for understanding about the IAP problem a leaflet was distributed among the village peoples prepared in Assamese.

3.3 Study of stove efficiency and fuel consumption analysis

After completion of preliminary baseline survey; to study the stove efficiency and fuel consumption pattern, stratified households were randomly selected, which mainly use biomass fuels (firewood and dung) for their cooking and heating purposes. After taking the consent from the selected household peoples, we carried out the study on stove efficiency and fuel consumption pattern in the households by adopting the protocol for Water Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT) prepared by Rob Bailis for the Household Energy and Health Programme, Shell Foundation (Bailis[16] *et al.*, 2004). For carrying out such analysis, we have visited the households five to six times.

3.3.1 Water boiling test (WBT)

The WBT consists of three phases (Bailis[16] *et al.*, 2004; Smith[190] *et al.*, 2007; Bailis[15] *et al.*, 2007) that immediately follow each other.

1. The first phase is the cold-start high-power test. The test begins with the stove at room temperature and a pre-weighed bundle of wood or other fuel was used to boil a measured quantity of water (2 liter) in a standard pot. As soon as the first phase was completed, the boiled water was replaced with a fresh pot of cold water to perform the second phase of the test.
2. The second phase, the hot-start high-power test, follows immediately after the first test while the stove was still hot. Again, we have used a pre-weighed bundle of fuel to boil a measured quantity of water (2 liter) in a standard pot. Repeating the test with a hot stove helps us to identify differences in performance between a stove when it was cold and when was is hot.
3. The third phase follows immediately from the second and is called the simmering phase. Here, we determined the amount of fuel required to simmer a measured amount of water at just below boiling (close as possible to 3 °C below the boiling point but should not be less than 6 °C below boiling point) for 45 minutes.

From the WBT, the output information we will get are:

- Time to boil (adjusted for starting temperature);
- Burning rate (adjusted for starting temperature);
- Specific fuel consumption (adjusted for starting temperature);
- Firepower
- Turn-down ratio (ratio of the stove's high power output to its low power output); and
- Thermal efficiency

Explanations of the calculations used in the WBT are as follows:

a) High power test (cold start)

Variables that are directly measured –

f_{ci}	Weight of fuel before test (g)
P_{ci}	Weight of pot with water before test (g)
T_{ci}	Water temperature before test (°C)
t_{ci}	Time at start of test (min)
f_{cf}	Weight of wood after test (g)
C_c	Weight of charcoal and container after test (g)
P_{cf}	Weight of pot with water after test (g)
T_{cf}	Water temperature after test (°C)
t_{cf}	Time at end of test (min)

Variables that are calculated –

f_{cm}	Wood consumed, moist (g)	$= f_{cf} - f_{ci}$
ΔC_c	Change in char during test phase (g)	$= C_c - k$ where, k is the weight of empty container.
f_{cd}	Equivalent dry wood consumed (g)	$= f_{cm} \times (1 - (1.12 \times m)) - 1.5 \times \Delta C_c$ where, m is the moisture content
W_{cv}	Water vaporized (g)	$= P_{ci} - P_{cf}$
W_{cr}	Water remaining at the end of test (g)	$= P_{cf} - P$
Δt_c	Duration of phase (min)	$= t_{cf} - t_{ci}$
h_c	Thermal efficiency	$= \dfrac{4.18 \times (P_{ci} - P) \times (T_{cf} - T_{ci}) + 2260 \times W_{cv}}{f_{cd} \times LHV}$ where, LHV is the lower heating value of fuel.
r_{cb}	Burning rate (g/min)	$= \dfrac{f_{cd}}{t_{ci} - t_{cf}}$
SC_c	Specific fuel consumption (g wood / g water)	$= \dfrac{f_{cd}}{P_{cf} - P}$

SC^{T}_{c}	Temperature corrected specific fuel consumption (g wood / g water)	=	$\frac{f_{cd} \times 75}{(P_{cf} - P) \times (T_{cf} - T_{ci})}$
FP_c	Firepower (W)	=	$\frac{f_{cd} \times LHV}{60 \times (t_{ci} - t_{cf})}$

b) High power test (hot start)

Variables that are directly measured –

f_{hi}	Weight of fuel before test (g)
P_{hi}	Weight of pot with water before test (g)
T_{hi}	Water temperature before test (°C)
t_{hi}	Time at start of test (min)
f_{hf}	Weight of wood after test (g)
C_h	Weight of charcoal and container after test (g)
P_{hf}	Weight of pot with water after test (g)
T_{hf}	Water temperature after test (°C)
t_{hf}	Time at end of test (min)

Variables that are calculated –

f_{hm}	Wood consumed, moist (g)	$= f_{hf} - f_{hi}$
ΔC_h	Change in char during test phase (g)	$= C_h - k$
f_{hd}	Equivalent dry wood consumed (g)	$= f_{hm} \times (1 - (1.12 \times m)) - 1.5 \times \Delta C_h$
W_{hv}	Water vaporized (g)	$= P_{hi} - P_{hf}$
W_{hr}	Water remaining at the end of test (g)	$= P_{hf} - P$
Δt_h	Duration of phase (min)	$= t_{hf} - t_{hi}$
h_h	Thermal efficiency	$= \frac{4.18 \times (P_{hi} - P) \times (T_{hf} - T_{hi}) + 2260 \times W_{hv}}{f_{hd} \times LHV}$

r_{hb}	Burning rate (g/min)	=	$\frac{f_{hd}}{t_{hi} - t_{hf}}$
SC_h	Specific fuel consumption (g wood / g water)	=	$\frac{f_{hd}}{P_{hf} - P}$
$SC^T{}_h$	Temperature corrected specific fuel consumption (g wood / g water)	=	$\frac{f_{hd} \times 75}{(P_{hf} - P) \times (T_{hf} - T_{hi})}$
FP_h	Firepower (W)	=	$\frac{f_{hd} \times LHV}{60 \times (t_{hi} - t_{hf})}$

c) Low power test (Simmering phase)

Variables that are directly measured –

f_{si}	Weight of fuel before test (g)
P_{si}	Weight of pot with water before test (g)
T_{si}	Water temperature at boiling ($T_{si} = T_b$) (°C)
t_{si}	Time at start of test (min)
f_{sf}	Weight of wood after test (g)
C_s	Weight of charcoal and container after test (g)
P_{sf}	Weight of pot with water after test (g)
T_{sf}	Water temperature after test (°C)
t_{sf}	Time at end of test (min)

Variables that are calculated –

f_{sm}	Wood consumed, moist (g)	$= f_{sf} - f_{si}$
ΔC_s	Change in char during test phase (g)	$= C_s - k - \Delta C_c$
f_{sd}	Equivalent dry wood consumed (g)	$= f_{sm} \times (1 - (1.12 \times m)) - 1.5 \times \Delta C_s$
W_{sv}	Water vaporized (g)	$= P_{si} - P_{sf}$
W_{sr}	Water remaining at the end of test (g)	$= P_{sf} - P$

Δt_s	Duration of phase (min)	$= t_{sf} - t_{si}$
h_s	Thermal efficiency	$= \frac{4.18 \times (P_{si} - P) \times (T_{sf} - T_{si}) + 2260 \times W_{sv}}{f_{sd} \times LHV}$
r_{sb}	Burning rate (g/min)	$= \frac{f_{sd}}{t_{si} - t_{sf}}$
SC_s	Specific fuel consumption (g wood / g water)	$= \frac{f_{sd}}{P_{sf} - P}$
FP_s	Firepower (W)	$= \frac{f_{sd} \times LHV}{60 \times (t_{si} - t_{sf})}$
TDR	Turn-down ratio	$= \frac{FP_h}{FP_s}$

There is no temperature-corrected specific fuel consumption in the simmering phase, because the test starts at T_b and the change in temperature should be limited to a few degrees.

Moisture content of the fuel was determined with the help of digital moisture meter. For measurements of pot, pan, water and fuel weighing balance of 10 kg capacity have been used.

The format of data calculation sheet for WBT is shown in Annexure II.

3.3.2 Controlled cooking test (CCT)

CCT is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace (Baldwin[20], 1987, Bailis[16] *et al.*, 2004; Bailis[15] *et al*, 2007). Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day.

1. In the first phase, a cooking task was selected for the households to perform the test.
2. After deciding a cooking task, the procedure was described in as much detail as possible to the stove users and recorded in the data sheet.

3. Now, the local condition such as wind and air temperature inside the kitchen was recorded.
4. Weight of the predetermined ingredients was taken and all the preparations such as washing, peeling, cutting etc., was done as described by the cooking directions recorded in step 2.
5. Starting with a pre-weighed bundle of fuel, weight of the fuel was recorded in the data calculation form. Fuel was supplied to the stove users that roughly double the amount that they consider necessary to complete the cooking task.
6. Starting with a cold stove which is at room temperature, the cook was allowed to light the fire in a way that reflects local practice. The timer was then started and the time was recorded.
7. While the cook was performing the cooking task, we recorded some observations and comments that the cook makes; such as difficulties that they encountered, excessive heat, smoke, instability of stove etc.
8. When the task was finished, the finishing time was recorded.
9. Now, we removed the pot of food from the stove and weighed with a balance and recorded.
10. Lastly, unburned wood was removed from fire and extinguish it. By knocking out the charcoal from the ends of unburned wood and measurement was made by weighing the unburned wood from the stove with the remaining wood from the original bundle and recorded. Weight of the charcoal was also measured by placing it in a tray and recorded in the data sheet.
11. Thus, the test was now completed.

Analysis of the CCT is made as follows –

Variables that are directly measured –

f_i	Initial weight of fuelwood (wet basis) (g)
f_f	Final weight of fuelwood (wet basis) (g)
C_c	Weight of charcoal with container (g)
Pj_f	Weight of the each pot with cooked food (g)
Pj	Weight of the empty pot (g)

t_i	Start time of cooking (min)
t_f	Finish time of cooking (min)
k	Weight of the container for char

These measurements are used to calculate the following indicators of stove performance:

W_f,	Total weight of food cooked (g)	$= Pj_f - Pj$
ΔC_c	Weight of char remaining (g)	$= C_c - k$
f_d	Equivalent dry wood consumed (g)	$= (f_i - f_f)\times(1 - (1.12\times m)) - 1.5 \times \Delta C_c$
SC	Specific fuel consumption (g wood / kg food cooked)	$= \frac{f_d \times 1000}{W_f}$
Δt	Total cooking time (min)	$= t_f - t_i$

Moisture content of the fuel was determined with the help of digital moisture meter. For measurements of pot, pan, water and fuel weighing balance of 10 kg capacity have been used.

The format of data calculation sheet for CCT is shown in Annexure III.

3.3.3 Kitchen performance test (KPT)

KPT is the principal field-based procedure to demonstrate the effect of stove interventions on household fuel consumption (Bailis[16] *et al.*, 2004; Bailis[15] *et al.*, 2007; Granderson[75] *et al.*, 2005; Granderson[77] *et al.*, 2009). There are two main goals of KPT:

a. To assess qualitative aspects of stove performance through household survey and,
b. To compare the impact of improved stoves on fuel consumption in the kitchens of real households.

To meet these aims, KPT includes quantitative surveys of fuel consumption and qualitative surveys of stove performance and acceptability. The qualitative survey does not take a long time, and was conducted separately from the quantitative part of the KPT.

For qualitative survey, a questionnaire was administered to the cooks and the format is given in Annexure IV.

For quantitative survey, the steps are as follows –

1. Each participating households were asked to give an estimate of the amount of fuelwood that they used per day.
2. This estimate was increased by 50% to determine the approximate amount of fuelwood to deliver each day for the particular household.
3. Such amount of fuelwood was supplied to the participating households for three consecutively days.
4. Cooks are requested to use only the supplied fuelwood for their daily cooking practices.
5. From second to fourth day household visit were made almost at the same time of the each day and weighed the fuelwood that remained from the supplied quantity and recorded in the data sheet from which fuel consumption for the previous day was estimated.
6. With each daily visit, the number of people that ate their meals in the household and numbers of meals prepared since the last visit was recorded along with their gender and age of each person.
7. Moisture content of the fuelwood was also recorded.
8. Measurement of fuelwood consumption per day was measured till the fourth day for the households.
9. Results at the end of the test were compiled and the total and per capita daily consumption of all fuels was calculated by using data calculation sheet.
10. Once the study of all households was completed, overall analysis of KPT to compare results of household fuel and energy consumption were made.

During the KPT, some points have to be taken care of –

1. Determination of KPT, whether it will be performed a cross-sectional or paired-sample study.

2. Defining the testing period of at least three consecutive days and try to avoid weekends unless testing is to extend over an entire week. Holydays, local events like market days that may involve above average fuel consumption should be avoided.
3. Explain to family members about the purpose of the test, and arrange to measure their fuel consumption at a roughly the same time each day.
4. Stress the household members that their cooking practices should remain as close to normal as possible for the duration of the test.
5. The family has asked to define an inventory area to store the fuel during the test.
6. If the family has gone to collect or purchase solid fuel during the days of the test, they were asked to keep newly collected or purchased solid fuel separate from fuel that has already been supplied and tested for moisture content and weighed.

Moisture content of the fuel was determined with the help of digital moisture meter. For measurements of pot, pan, water and fuel we have used weighing balance.

The format of data calculation sheet for KPT is given in Annexure V.

3.4 Monitoring and exposure analysis

Among the households where questionnaire survey was carried out previously, a stratified and randomized subset of households was selected for monitoring of respirable particulates ($PM_{2.5}$), CO and CO_2. Monitoring was done for approximately 24 - hour period in the kitchen environment. The households where stove performance and fuel consumption analysis was performed also included in the monitoring purpose. At the end of each monitoring period, a time-activity questionnaire will be administered to the household members.

Before selecting the households for monitoring, consent of the family members were taken. We have explained the purpose of the study to the family members and all the queries regarding the experiment procedure and about the instruments that have to be used for monitoring were clarified. Cooks and all other members of the households were asked to do their normal routine work as they did usually as possible.

Monitoring of $PM_{2.5}$ was done with Dust trak aerosol monitor and CO and CO_2 was done with Q-trak plus IAQ monitor. Both the instrument was allowed to take reading at an interval of 5 sec (logging interval) for 24-hour duration (test length). It was done by interfacing the instruments with a computer through data analysis software named Trak Pro™ that supplied with the instruments by the manufacturer (TSI Incorporated, USA). The instruments were than placed in the kitchen one meter away and approximately 1.5 meter height from the base of the cookstove and allowed to take reading for 24-hour duration (Balakrishnan[18] *et al.*, 2004). Since, the Dust trak aerosol monitor has a suction pump and measures PM concentration through a sensor type of 90° light scattering, laser diode; it is recommended that the flow rate should be adjusted at 1.7 L/min whereas for Q-trak plus IAQ monitor no such set up should be made as it has a sensor type of non-dispersive infrared (NDIR). After taking the reading for 24-hours, both the instruments automatically shut down and then they were collected from the household and data's were collected by interfacing with a computer through Trak Pro™ software.

The model and important specifications of both the instruments are given below –

Dust Trak™ Aerosol Monitor:

Model:	8520
Sensitivity:	
Sensor type:	90° light scattering, laser diode
Range:	0.001 – 100 mg m^{-3}
Resolution:	± 0.1 % of reading or ± 0.001 mg m^{-3}, whichever is greater
Zero stability:	± 0.001 mg m^{-3} over 24-hours using 10-sec time constant
Particle size range:	0.1 – Approx. 10 μm (upper limit is dependent on flow rate)

Flow rate range:	1.4 – 2.4 L/min
Temperature coefficient:	+ 0.001 mg m^{-3} per °C
Instrument temperature range:	
Operating range:	0 °C – 50 °C
Storage range:	- 20 °C – 60 °C
Time constant:	
Range:	Adjustable from 1 – 60 sec.
Data logging:	
Data points:	> 31,000 (21 days logging every minute)
Logging interval:	Adjustable from 1 sec – 1 hour

Q-Trak™ Plus IAQ Monitor:

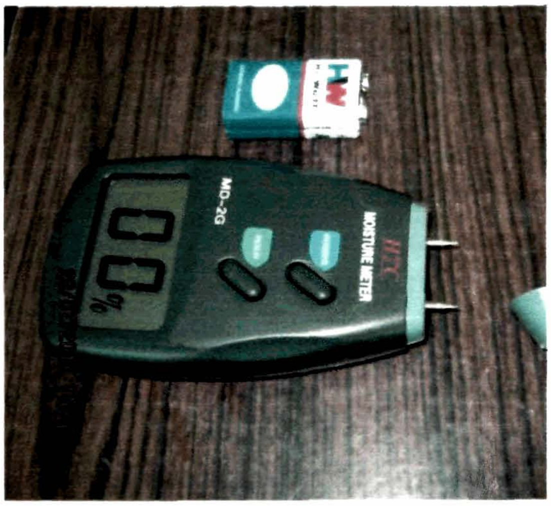
Model:	8554
CO_2:	
Sensor type:	Non-dispersive infrared (NDIR)
Range:	0 – 5000 ppm
Accuracy:	± (3 % of reading + 50 ppm) at 25°C
Resolution:	1 ppm
Temperature sensor:	
Type:	Thermistor
Range:	0 – 50 °C
Accuracy:	± 0.6 °C
Resolution:	0.1 °C
Response time:	30 sec (90 % of final value, air velocity at 2 m/sec)
Display units:	°C or °F
Humidity:	
Type:	Thin-film capacitive
Range:	5 – 95 % RH
Accuracy:	± 3 % RH (includes ± 1 % hysteresis)
Resolution:	0.1 % RH
Response time:	20 sec (for 63 % of final value)

CO sensor:

Sensor type:	Electro-chemical
Range:	0 – 500 ppm
Accuracy:	± 3 % of reading or whichever is greater
Resolution:	1 ppm
Response time:	< 60 sec to 90 % of final value.

Q-trak plus Air Quality Monitor

Dust Trak Aerosol Monitor



Digital Moisture Meter

Digital Thermometer

3.5 Intervention study

3.5.1 Selection of the cookstove design

For intervention study, we have selected a design of *Lakshmi* cookstove (Improved) which is familiar in the southern part of the India (Balakrishnan[18] *et al.*, 2004 and Dutta[60] *et al.*, 2007). We have little bit modified the design and tested in the laboratory and found the efficiency ~ 30%. The selected design is a two pot cookstove system having a chimney attached in it. In the earlier studies, this selected stove design are made with cement and plaster of paris (Balakrishnan[18] *et al.*, 2004). We have made the stove with clay, cowdung and dried rice leafs. We have selected the design and construction materials keeping in view that the costs of the stove are minimal and all the required substance is abundant in the rural areas so that people can adopt easily. During the construction of the stove, iron rods for making the grate of the stove and the asbestos chimney (5 inch diameter) were used. The schematic diagram and approximate dimension of the stove used for the intervention study is shown below.

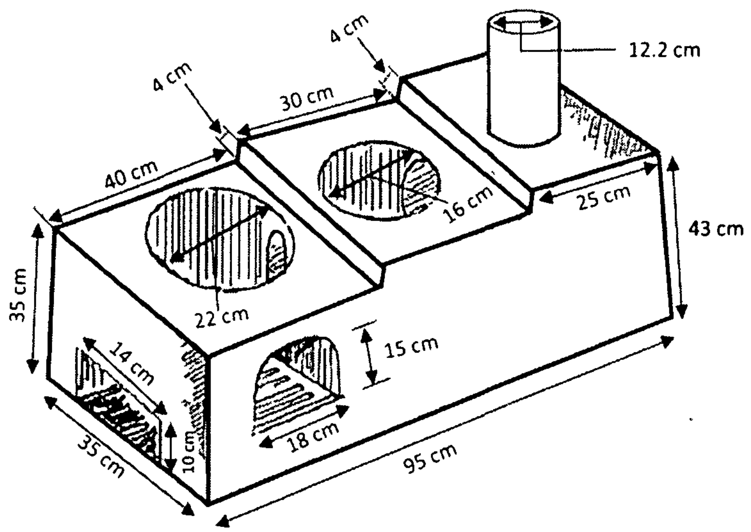


Figure: 6. Schematic diagram of improved cookstove used for the intervention study.

3.5.2 Selection of the households

To carry out the intervention study, a sub set of the previously monitored households were selected. In these purpose, we have to motivate the people about the new design of the improved cookstove and its usefulness to their life. We had trained some village persons particularly women in making the selected design of the improved cookstove and with the help of them demonstration as well as construction of the cookstove were made in the selected households. Regarding the implementation of the cookstove, it is very difficult to approach with such a newly designed cookstove among the households who are more familiar to their old ones. So, we had to visit so many times to the households to discuss and convinced them about it to get their willingness to implement the improved design.

3.5.3 Stove efficiency and fuel consumption analysis

After one month of the installation of the improved cookstove, stove efficiency and fuel consumption analysis was carried out according to the procedure descried in 3.3.1, 3.3.2 and 3.3.3. During the KPT, again a questionnaire survey was conducted with the cook to identify both strengths and weaknesses in the stove's performance as well as identify any changes in the economic status of the household regarding fuel use. The questionnaire format that was administered during this KPT observation is shown in Annexure VI.

3.5.4 Monitoring and exposure analysis

The households where the improved stove was implemented were monitored for $PM_{2.5}$, CO and CO_2 according to the same procedure as described in 3.4 and analysis were made for the change before and after implementation of the improved stoves.

3.6 Statistical analysis

To interpret the household survey data and experimental results with other parameters statistical software package such as SPSS *version 16*, Excel and Origin *version 8* was used.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER – IV

Results and Discussion

The results of the present study are presented and discussed in four parts.

Part I

In the first part, results obtained from preliminary questionnaire survey is presented and accordingly discussed.

Part II

In this part, stove performance and fuelwood consumption analysis is discussed and compared the results obtained before and after intervention study.

Part III

In the third part, emission characteristics of cookstoves before and after the intervention study are discussed relating to different kitchen orientations. Furthermore, emission parameters were also discussed in relation to different ventilation conditions and structural characteristics of the kitchen.

Part IV

In the last part, statistical analysis that carried out among the data's obtained from preliminary questionnaire survey, stove characteristics and emission measurements before and after intervention study is discussed.

PART I

Preliminary Questionnaire Survey

Baseline questionnaire survey was conducted in ten villages of Sonitpur district of Assam, namely - Napaam, Amolapam gaon, Jaglouni, Bhaluk jharoni, Baruadoloni, Puthimari, Geruah, Balikhuti, Bapubheti, and Pithakhowa. The villages were selected with the criteria that they belongs to rural areas and have a different residential communities like Assamease, Bengali, Boro, Nepali, *Adivasi* (belongs to the workers in the tea industries in origin), Bihari (belongs to the people from the state of Uttar Pradesh and Bihar in origin) basically Hindu in religion; and the Muslims that represents on the basis of population footage of Assam. The households were randomly selected for the survey and it was conducted during the month of Sptember 2007 to March 2008. A total numbers of 1268 households were surveyed in these ten villages which were around 10% of the total households considering the numbers based on Census 2001, Government of India.

4.1.1 Population profile

The study site selected for the present survey mostly dominated by the people of Hindu religion except the Napaam village, where the majority was of Muslims. Jaglouni and Bhaluk jharoni village was mostly dominated by the people of *Adivasi* and Muslim communities along with few Assamese and Bengali peoples. Napaam villages was mostly dominated by the people of Muslim in origin although few were from Assamese, Bengali and *Adivasi* people where as Amolapaam village mostly of Assamese and Nepali communities along with Bengali in origin and few peoples from Muslim and *Adivasi* also were found. Baruadoloni, Geruah, Balıkhuti, Bapubheti, and Pithakhowa are mostly dominated by Assamese people where as in Puthimari village; a combination of Bengali, Boro, Nepali, *Adivasi* and Assamese were found almost in the equal proportions.

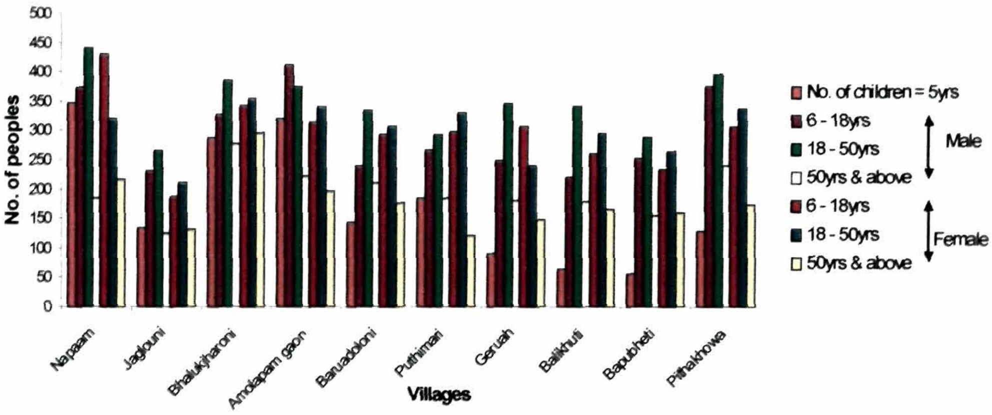


Figure: 7. Age-group wise population in the ten villages

We have collected the data of the population in terms seven age groups (Annexure I). The seven age groups were, 5 – 18 years, 18 – 50 years, 50 years and above for both male and female and children ≤ 5 years of age. In the 1268 households the total number of population were found to be 17,959. 9.82 % of population were found the children of ≤ 5 years of age and whereas percentage of male and female were found to be 46.8 % and 43.38 % respectively.

4.1.2 Household characteristics

For the survey, household characteristics were considered with the parameters of number of rooms, construction materials of roof, wall and floor of the households (i.e. the structural characteristics). We have considered four types of household design with respect to the kitchen orientation in the households (Annexure I). As we are measuring the emissions and fuel consumption patterns in the stoves that uses firewood; therefore, on the basis of kitchen orientations household design was recorded in the data sheet (Annexure I).

4.1.2.1 Roof characteristics

The roof materials were divided in to six different categories viz., a) RCC; b) GI sheet; c) asbestos/cement sheets; d) grass and bamboo; e) GI sheet and grass; and f) all other materials not stated.

It has been found that a majority of the households were having roof materials of grass and bamboos (47.48 %) followed by GI sheets (30.44 %). GI sheets along with the grass were found to be in 14.35 % of the households. It has also been observed that they normally collected the grass from the river bank of Brahmaputra for the purpose. Bamboos are collected from their own fields or from the neighbours as these materials are mostly of local abundance.

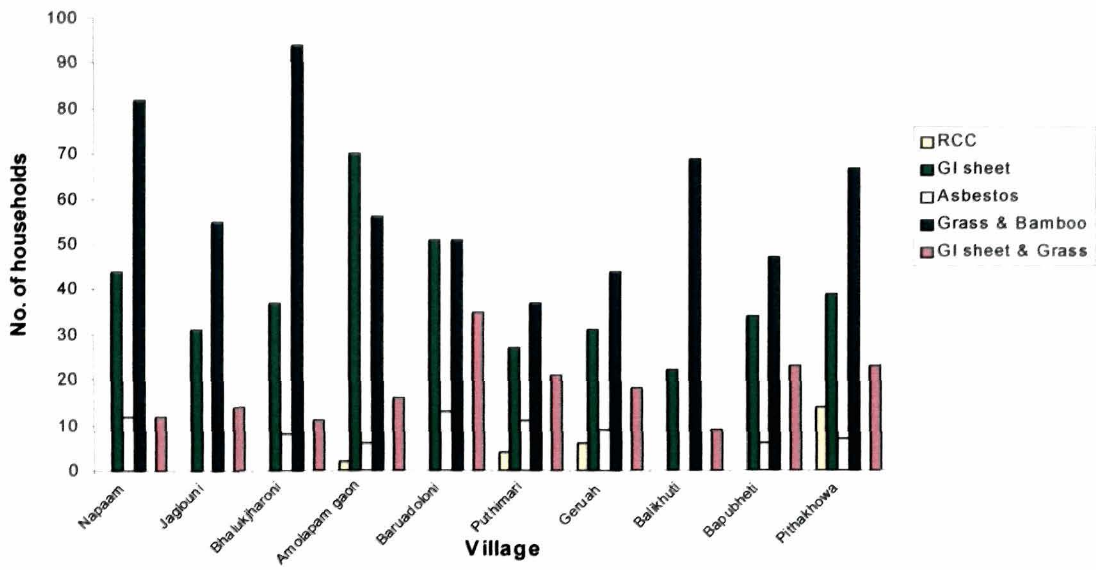


Figure: 8. Roof materials of the households in the ten villages.

4.1.2.2 Wall characteristics

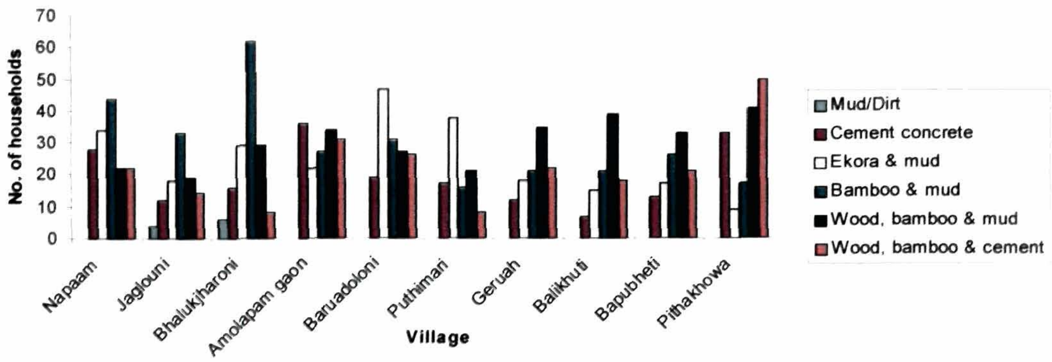


Figure: 9. Wall materials of the households in ten villages

There was a little variation in case of wall texture that has been found in the study site. The construction materials of wall was observed in the six different categories viz., mud/dirt; cement/concrete; *Ekora* and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement.

During the observation, the wall made up with wood, bamboo and mud (23.66 %) were found to be almost the same in the number of households that made by bamboo and mud (23.5 %) which are followed by *Ekora* and mud (19.48 %) next to the wood, bamboo and cement (15.77 %). Wall material of cement/concrete was mostly found in two villages Baruadoloni and Puthimari among the other villages and its contribution in the households of ten villages was found 15.22 %.

As we have said earlier that bamboos are mostly abundant in the village areas, *Ekora* was also collected by the local people from the basin of river Brahmaputra. Furthermore, wood was collected from the near by forests as well as from the home gardens. It was also observed that in the construction of wall that made up with mud, people often used cowdung as one of the ingredients.

4.1.2.3 Floor characteristics

To describe the floor characteristics, we had divided its materials in to four categories, viz., mud/dirt, cement, tiles/mosaic and brick/stone depending on the questionnaire survey..

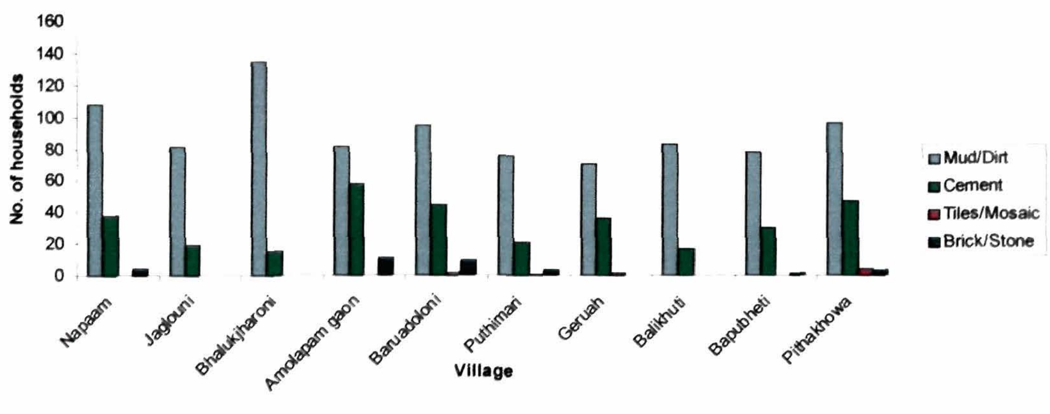


Figure: 10. Floor materials of the households in the ten villages.

In the ten villages, floor characteristics were mostly dominated by the material of mud/dirt (71.14 %). Floor materials with cement were come in the next with 25.63 %. Tiles/mosaic and brick/stone was found as a floor material in a very few households and both contributed 3.23 % of the households. Floor characteristics of the households in the ten villages are presented in Figure 10.

4.1.2.4 Number of rooms

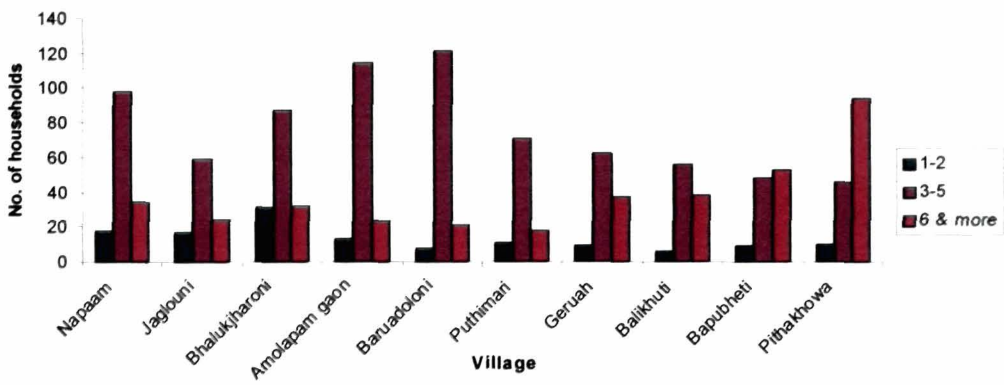


Figure: 11. Households in terms of number of rooms in the ten villages.

For the survey, we have categorized the households in to the number of rooms for the study. In this regard, we have divided the households in to three groups according to the number of rooms as 1 – 2, 3 – 5, and 6 and above. From the survey, it has been found that most of the households were having 3 – 5 numbers of rooms (60.01 %) in the ten villages followed by 6 and above (29.5 %). Except Bapubheti and Pithakhowa, households having 3 – 5 numbers of rooms were found maximum in all other villages (Figure. 11). In the rural villages of Assam, the traditional feature of the households, particularly involved in agriculture for their livelihood has often found that besides the living as well as kitchen room, they have a store room where they kept their agricultural products like rice, mustard oil, jute etc.

4.1.3 Kitchen characteristics

4.1.3.1 Kitchen type

Form the baseline survey, we have found four types of kitchens orientations among the households in the ten villages. The kitchen types were – kitchen attached with living room with partition (KAWLWP), kitchen attached with living room without partition (KAWLWOP), separate kitchen outside the living room (SKOLR), and open air kitchen (OK). Different kitchen types in terms of households in the respective villages are shown in the Figure 12.

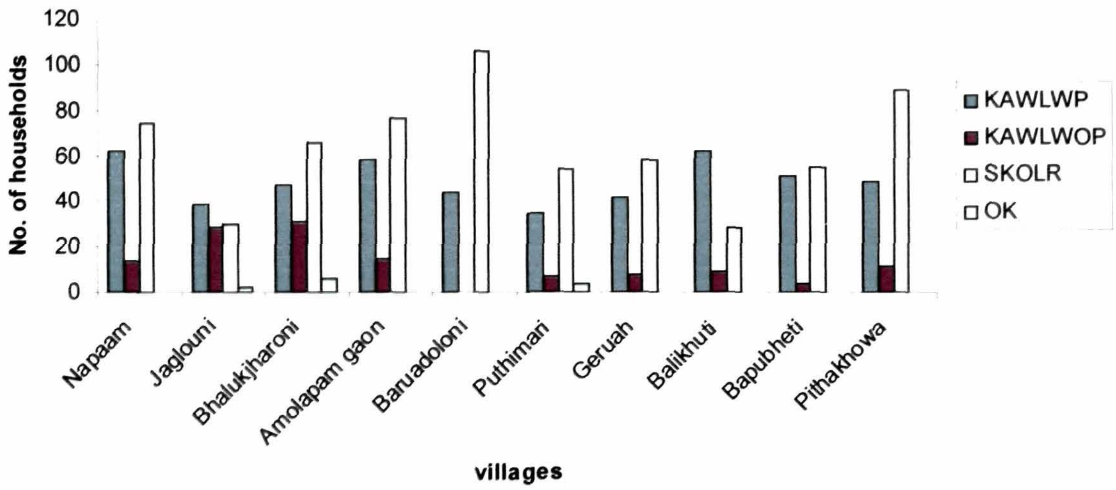


Figure: 12. Kitchen types of the households in the ten villages.

Among these four types of kitchen orientations, we have found two types of kitchen orientation in major, particularly separate kitchen outside the living room (SKOLR) and kitchen attached with living room with partition (KAWLWP) and both of them contributes almost 89 % of the total kitchens. Kitchen attached with living room without partition (KAWLWOP) was found to be only in 10.17 % and a very few was found as the open air kitchen (0.95%). Keeping in view, we have selected only three kitchen orientations except the open air kitchen for further studies (stove characteristics and emission studies).

We have also taken the data in terms of dimensions of the kitchens in the study site. During the study, we have noticed that separate kitchens outside the living room (SKOLR) and kitchens attached with living room with partition (KAWLWP) have three classes of kitchen dimensions. For these two types of kitchen orientation i.e., for SKOLR and KAWLRWP, the dimensions were found as 8ft × 8ft × 10ft, 8ft × 10ft × 10ft and 8ft × 10ft × 12ft in terms of length, breadth and height. For the kitchen attached with living room without partition (KAWLWOP), we found three different dimensions viz., 10ft × 10ft × 10ft, 8ft × 12ft × 10ft and 10ft × 12ft × 12ft. In the kitchen types, separate kitchen outside the living room (SKOLR) and attached with living room with partition (KAWLWP) are the most familiar dimensions that were found to be 8ft × 8ft × 10ft and 8ft × 10ft × 10ft. For both these kitchen types these two dimensions together accounts 77.74 % and 78.16 % of the kitchens respectively (Figure 13). In case of kitchen attached with living room without partition (KAWLWOP), familiar dimensions were observed as 10ft × 12ft × 12ft (41.86 %) and the rest i.e., 10ft × 10ft × 10ft and 8ft × 12ft × 10ft was found as 27.13 % and 31.01 % respectively (Figure 13).

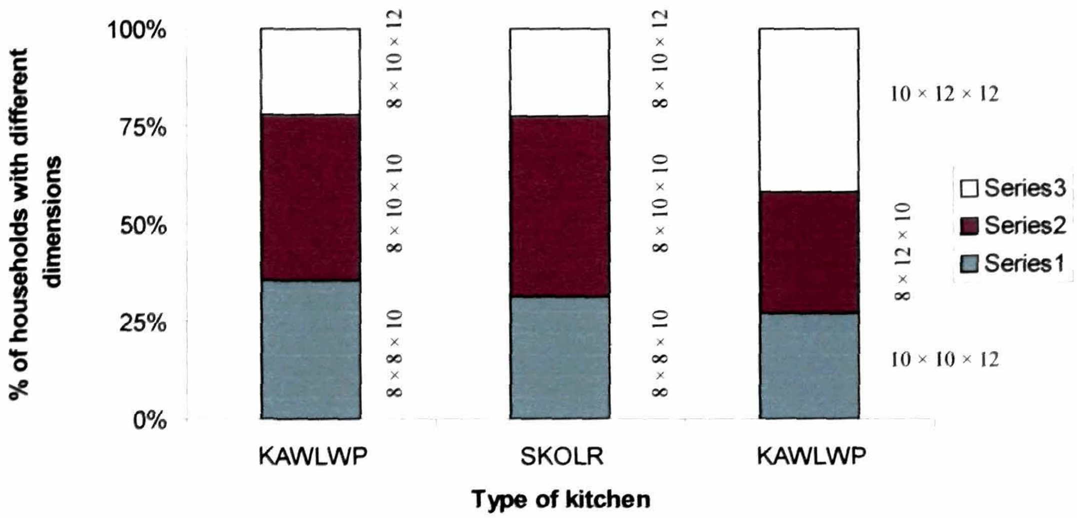


Figure: 13. Kitchen types in terms of dimensions in the households of ten villages. (The unit of the dimensions of kitchen is in ft × ft × ft)

4.1.3.2 Roof characteristics

Like roof characteristics of the households, the roof materials of the kitchens in all the villages are also dominated by bamboo and grass and were found in the 62.3 % of the kitchens. Roof materials made with GI sheets were found in the 32.26 % of the kitchens.

It was also observed that in most of the kitchens, in between wall and roof there was a gap of around 5cm to 7cm from where the smoke generated inside the kitchen from the combustion in the stove can be escape to the outside. The roof characteristics in terms of different materials in the ten villages are shown in Figure 14.

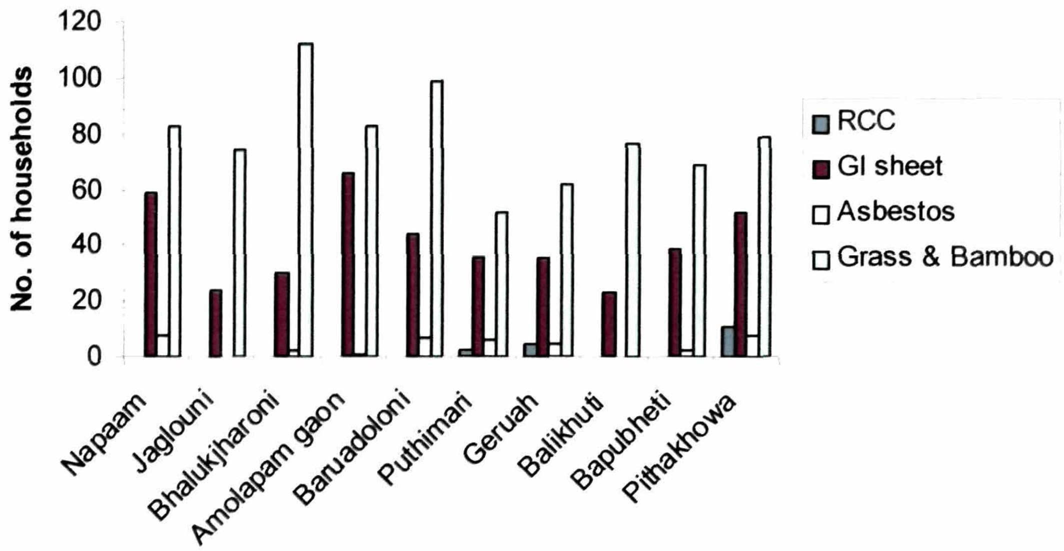


Figure: 14. Roof materials of the kitchens in the ten villages.

4.1.3.3 Wall characteristics

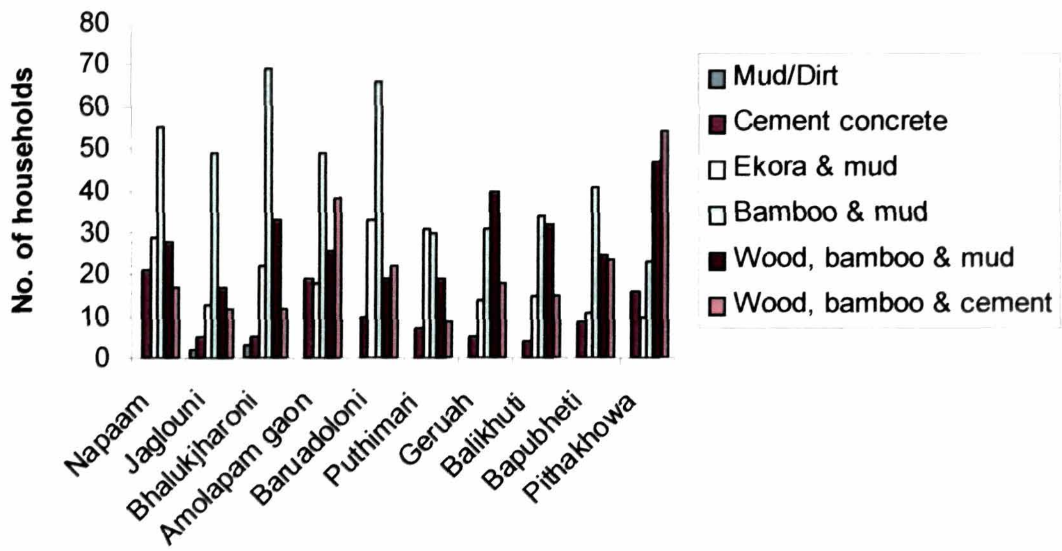


Figure: 15. Wall materials of the kitchens in the ten villages.

Unlike household wall characteristics, wall of the kitchens made with bamboo and mud have been found in most of the kitchens (35.25 %) in the ten villages followed by wood, bamboo and mud (22.56 %). Wall made with wood, bamboo and cement also played a significant contribution in the kitchen wall characteristics and was found in 17.43 % of the kitchens followed by *Ekora* and mud with 15.46 %.

Wall with cement concrete was found in a few kitchens in the study site (7.97 %). It was also observed that when the wall was made with mud with any other frame of substance like bamboo or *Ekora*, it was mixed with cowdung to prepare slurry and than pasted in the wall.

4.1.3.4 Floor characteristics

From the baseline field survey, we have found three types of floors depending on the materials in concern i.e., mud/dirt, cement and brick/stone. Figure 16 describes the numbers of households in the ten villages according to the three types of floor materials. Like in the household characteristics, floor material with mud/dirt was found in most of the kitchens (81.78 %). Floor material with cement was found in 16.56 % of the kitchens.

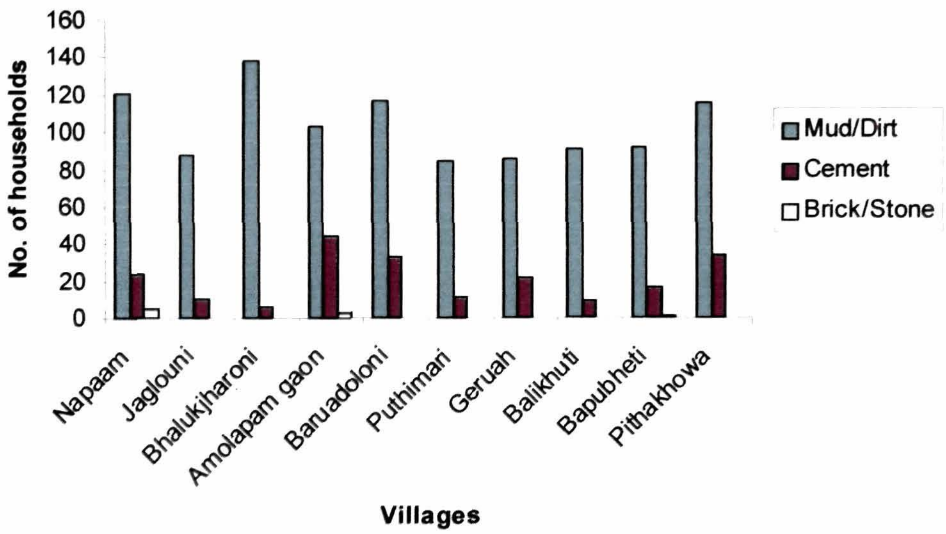


Figure: 16. Floor materials of the kitchens in the ten villages.

4.1.3.5 Ventilation condition

During the survey, we have observed that in some kitchens there were two to three small openings in the wall with size of A 4 sheet. In some other kitchens, windows of 1m × 1m and 1m × 1½m dimensions were found. For our study we have considered the A 4 sheet size openings as moderate ventilation and the windows with 1m × 1m and 1m × 1½m dimensions were considered as good ventilation source. The kitchens with no such type of ventilations were considered as poorly ventilated kitchen for this study. It was observed that, kitchens with electronic exhaust system were not found in any one of the households surveyed.

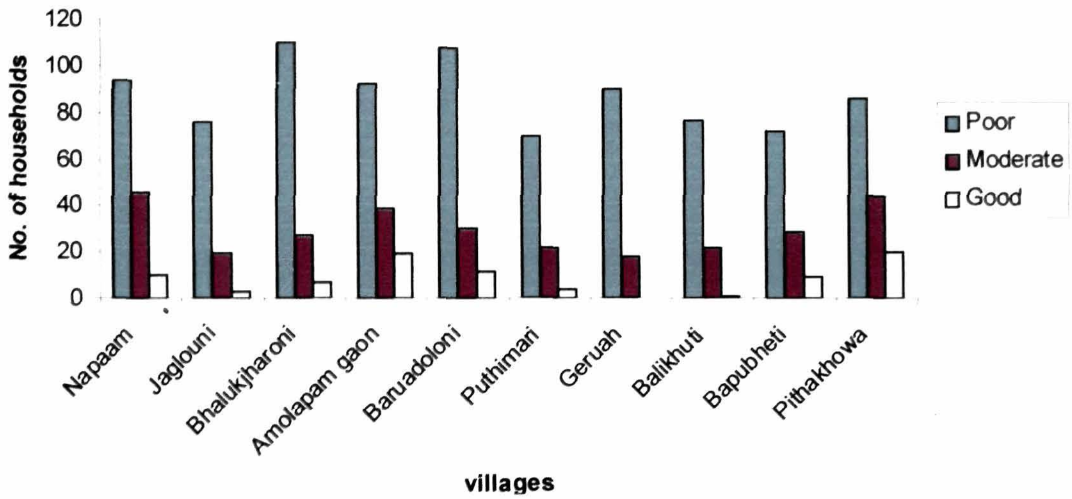


Figure: 17. Ventilation conditions of the kitchens in the ten villages.

Figure 17 represents the number of households to their kitchen ventilation condition in the respective villages that surveyed in our study. It has been found that 69.66 % of the kitchens of the study site were found poorly ventilated. Moderately ventilated kitchens were found in the 23.57 % of the households and 6.77 % of the kitchens were found good/adequate ventilation.

4.1.4 Stove characteristics

In the study site, we have found six types cooking stoves viz., traditional biomass stove, improved cookstoves with or without chimney, kerosene stove, biogas stove and LPG. It has been found that in most of the households traditional biomass cookstove (made with mud) were used (75 %). Even in the villages like Jaglouni and Bhalukjharoni 91% to

96% households uses traditional mud-based cookstoves. It was found quite encouraging that cleaner fuels like LPG and biogas were found to be used in so many households and its being increasing day by day. LPG was found to be used in 16.17 % of the households. Although households using biogas were found quite less (2.6 %), it was observed that people are interested to adopt biogas technology through different schemes of the government. Figure 18 represents the types of stoves used in the households of ten villages.

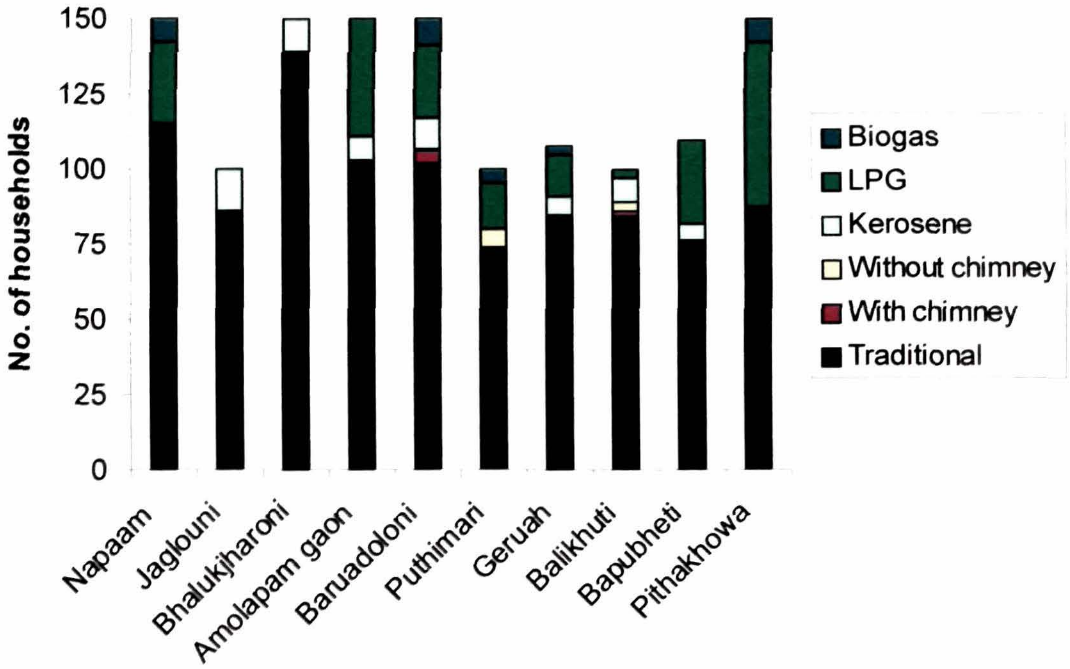


Figure: 18. Types of cookstoves used in the ten villages.

We have also found two designs of improved stoves in the study site particularly Balikhuti and Puthimari village. One of the improved stoves was found to be of two pots single fuel bed system having no chimney and the other type was found to be of two pots single fuel bed system with chimney. In both the system no grate was used in the fuel bed. Both the designs were implemented to the households by Khadi Village Industries development Corporation (KVIC), an organization of Govt. of Assam, under improved stove programme, Govt. of India.

4.1.5 Fuel use pattern

During the field survey, to collect the data relating to the fuel use by the households, we have selected three different activities of the households i.e., cooking, space heating and lighting. According to the each category, data's were collected from the households.

4.1.5.1 Fuel used in cooking

There are seven types of fuels used by the people of the households in the study site for cooking purpose. The fuel types are mainly – wood, dung cakes (cowdung), *guitha*, kerosene, LPG and crop residues. *Guitha* is a kind of processed fuel. It is made up with a small bundle of jute or bamboo stick that was covered with a paste of dung. It is than dried in sunlight and used for cooking. Figure 19 represents the different types of fuels that mainly used for cooking purpose by the households in the respective villages.

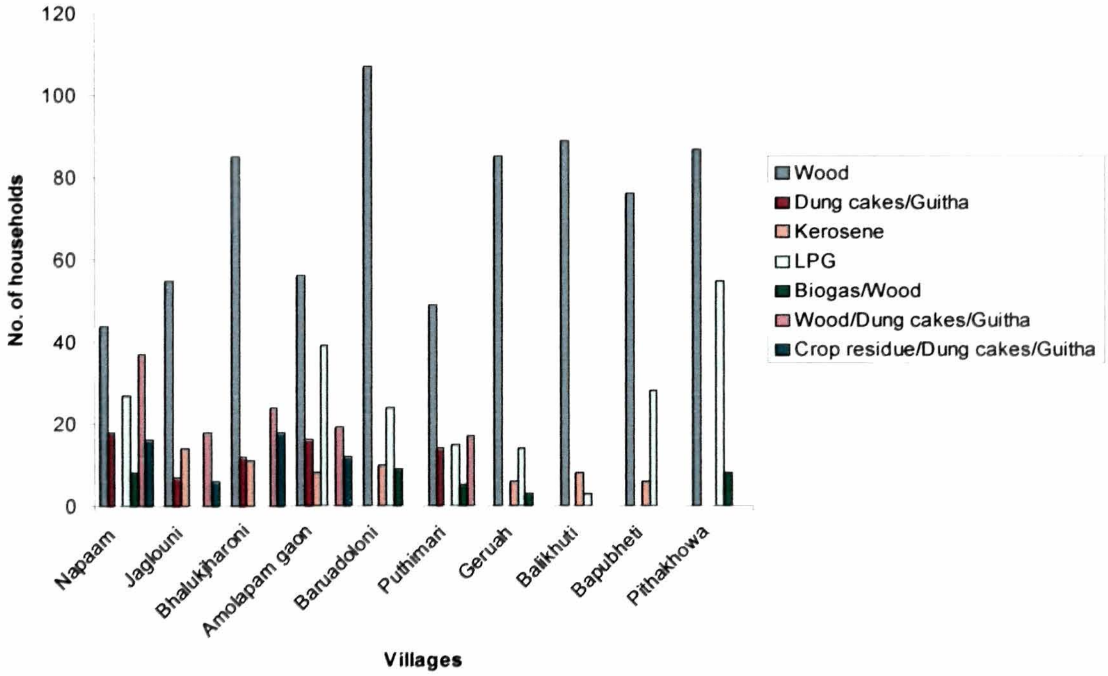


Figure: 19. Types of fuel used in the cooking purpose in the ten villages

It has been found that, majority of the households in all the ten villages were found using firewood for their cooking activities (57.81 %). Cleaner fuel like LPG were used by 16.17 % of the households. In terms of use in LPG, Pithakhowa and Amolapaam village were found significantly higher. Although the popularity about biogas was gaining among the villagers through different schemes and incentives given by the government and its nodal agencies, a very few numbers of households (2.6 %) were found using biogas for their cooking purpose. Although they are using biogas for their cooking needs, but they also uses mud stoves simultaneously for the same purpose. Dung cakes and *Guitha* also plays a role for the cooking needs in so many peoples (5.28 %) specially found in Napaam, Jaglouni, Bhalukjharoni and in Puthimari villages. However, it is found a common practice among the households of Muslim, Bengali and *Bihari* peoples. Besides these, some peoples are found using dung cakes and *Guitha* along with crop residues (4.1 %) as their main fuel source for their cooking needs. A few households were also found kerosene as their major cooking fuel (4.97%) where as 9.07 % of the households were found using wood along with dung cakes and *Guitha* for this purpose.

4.1.5.2 Fuel used in space heating

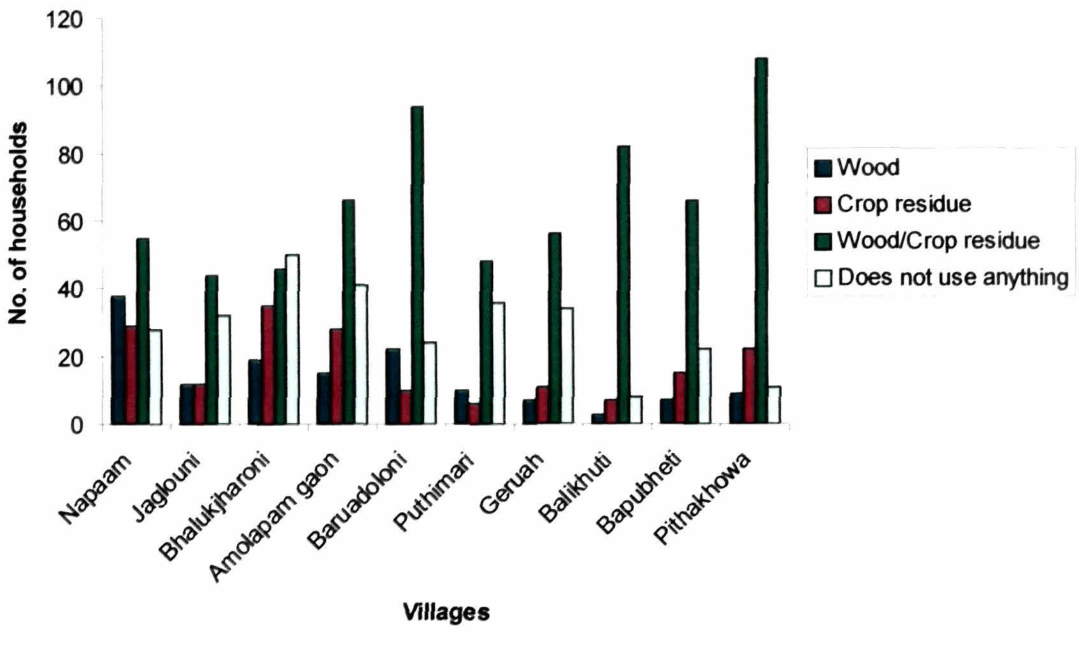


Figure: 20. Types of fuel used in space heating in the ten villages

Most of the people of the study site were found dependent on cultivation like rice, jute, mustard oil, sugar cane, vegetables etc. It has been found that around 52.44 % of the households were using wood and crop residues together for the purpose of space heating. On the other hand, 13.8 % of the households were found using only crop residues for space heating and 11.2 % were using wood (twigs and branches). It is also important to note that 22.56 % of households were not using anything for this purpose. Such people were found to be the daily labours. Males of those households were found either carrying *rickshaws* or working in the field for cultivation and construction jobs as daily labours; whether female were often found working in cultivation and constructions jobs as daily labours. Although, child labour is prohibited in our country, but some children less than 13 years of age were also found working in the field along with their parents for their survival.

Figure 20 represents the types of fuel used for space heating purpose in the respective villages.

4.1.5.3 Fuel used in lighting

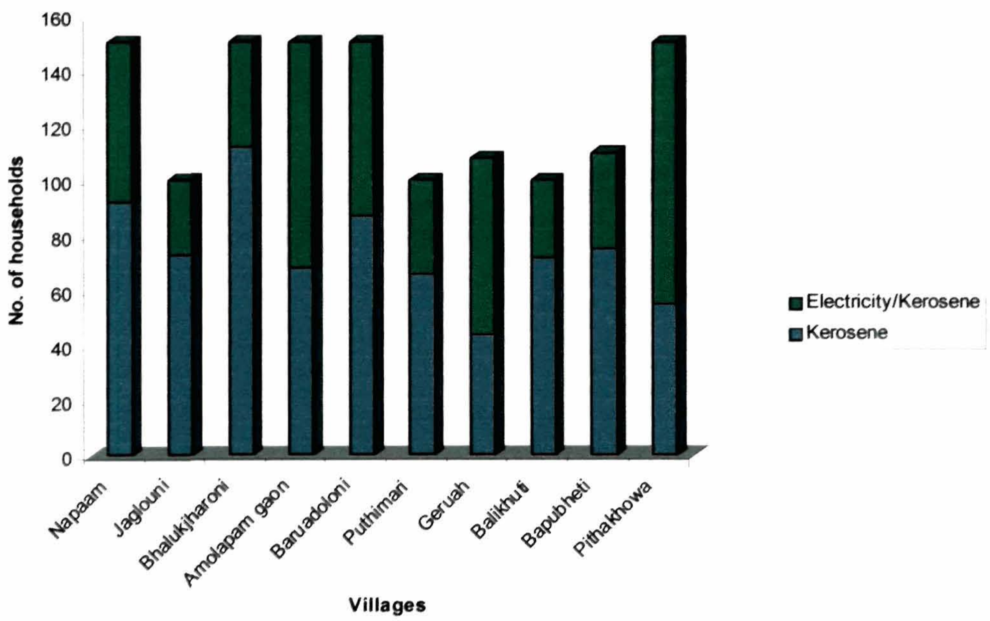


Figure: 21. Types of energy source used for lighting in the ten villages

People in the study area were found only two types energy sources for lighting purpose. A portion of the households uses electricity and kerosene together whereas the rests uses kerosene alone in the lanterns for the lighting purpose. Although all the villages that surveyed for the present study were grid connected but only 41.32 % of the households were found using electricity along with kerosene for their lighting purpose. Rest of the households (52.68 %) were found using kerosene alone for their lighting purpose. In some villages like Jaglouni, Bhalukjharoni village, it has been found that it was the economic status of the people, who does not permit them in using the electricity for the lighting purpose. Now a days, under *Griha Jyoti Asoni*, a scheme of Govt. of Assam, grid connection to the households living below poverty line is going on with a nominal charge.

4.1.5.4 Fuelwood collection and time

Although the cooking activity has been done by the female of the households (in most of the households), it has been found that for fuel collection both male and female were involved. Fuel was collected by purchasing or by collecting it from home gardens and from the near by forests.

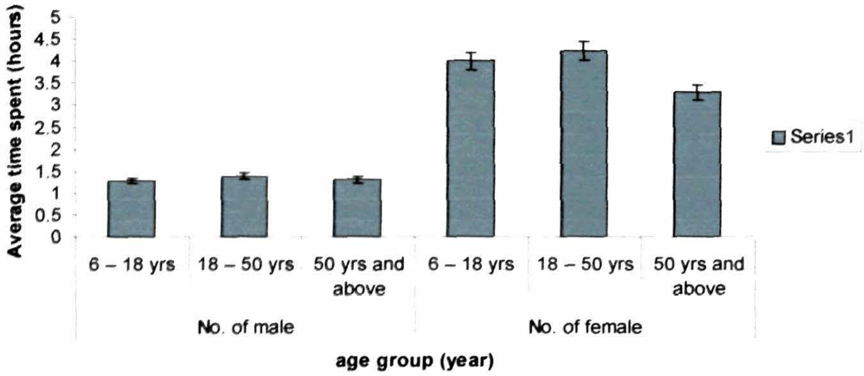


Figure: 22. Time spent (in hours) by different age groups of peoples (in weekly average) in the ten villages for fuelwood collection.

It has been found that for fuelwood/dung collection purpose weekly average time spent by the women (around 4 hour) was found more than the male (one and a half hour). Among the three age groups of woman (6 – 18yrs, 18 – 50yrs and 50yrs and above), they spend a weekly average time ranging from 3½ hours to 4½ hours. In case of male, they spend less time in fuel collection at a rate of one hour to 1½ hours. This is because of the fact that females are mainly responsible for the cooking activities in the households and the males were mostly involved in other works like, cultivation, jobs etc.

4.1.6 Income

During the baseline survey, income of the households from various sources were collected through filling in the questionnaires by a personal visit (Although the complex information that have been collected from the households are wide ranging and they cover various aspects of the household and village economy, but at present we are concerned with income only). For collecting data regarding income of the households, we have divided the income source into four major sectors – primary sector, secondary sector, tertiary sector and property. The primary sector included six types of income source viz., agriculture, labour, animal husbandry, fishery, orchard and plantation. Secondary sector included income source from mill/factory, cottage industries and construction, whereas tertiary sector constituted with trade and commerce along with service source. Lastly, incomes generated from the property have been included in the fourth sector. Figure 23, shows the percentage contribution of these four sectors corresponding to the ten villages.

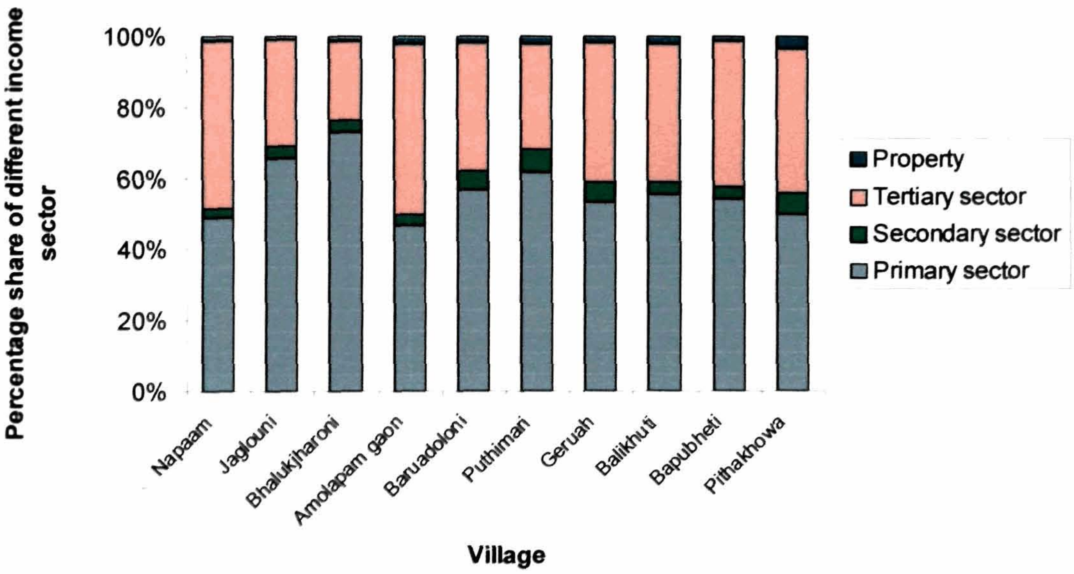


Figure: 23. Percentage share of four income sectors in the ten villages.

Table: 3. Income of sample households from various sources and per capita income per year for ten villages.

	Napaam	Jaglouni	Bhalukjharoni	Amolapam gaon	Baruadoloni	Puthimari	Geruah	Balikhuti	Bapubheti	Pithakhowa
Primary Sector (%)	**48.98**	**65.42**	**72.87**	**46.8**	**56.8**	**61.4**	**53.23**	**55.56**	**54.07**	**49.94**
Agriculture	7296794	5033114	7469996	7333850	7311200	4957689	5125446	4693032	5286088	7011194
Labour	1284870	1487643	3089870	1446016	763673	835188	816799	912636	768961	2121034
Animal husbandry	575586	251069	445265	782789	549000	589106	238522	262153	216745	463976
Fishery	727413	283919	482370	297776	309692	238625	195532	166602	292674	682462
Orchard	729679	333194	433459	291008	786548	692262	662869	480206	588110	1283913
Plantation	484942	286266	369368	406058	274500	318167	342528	291554	312002	697192
Secondary Sector (%)	**2.49**	**3.75**	**3.56**	**2.82**	**5.21**	**6.74**	**5.65**	**3.48**	**3.73**	**5.9**
Mill/Factory	231141	143133	222633	160167	239308	278396	171958	0	140815	508164
Cottage industry	0	145479	188900	128585	302654	265968	379971	278078	230550	567082
Construction	333114	151345	188900	347405	374798	293310	231588	148227	143576	373145
Tertiary Sector (%)	**47.11**	**30.12**	**22.45**	**48.14**	**36.32**	**29.47**	**39.36**	**38.75**	**40.97**	**40.49**
Trade and Commerce	1695032	757900	1327362	1558810	834058	718362	587984	499806	454198	2074391
Service	8980495	2775839	2459077	9300973	5556864	2944288	4870284	4247127	5201875	7865500
Property (%)	**1.42**	**0.71**	**1.12**	**2.24**	**1.67**	**2.39**	**1.76**	**2.21**	**1.23**	**3.67**
	321784	83299	188900	505316	293856	297039	244069	270728	169806	900948
Total Income/year	22660850	11732200	16866100	22558750	17596150	12428400	13867550	12250150	13805400	24549000
PCI/year	9780	9088	7410	10306	10284	7389	8855	7996	9708	12442

It has been found that (figure 23); percentage share in primary income sector dominates among all the four income sources, followed by the tertiary income sector. Secondary income source and the property contribute very low portion of the income. In the primary income sector, Bhalukjharoni and Jaglouni village contributes higher percentage of income with 72.87% and 65.42% respectively followed by Puthimari village with 61.4%. In case of tertiary income sector, maximum contribution was coming from Amolapam gaon and Napaam village with 48.14% and 47.11% respectively along with Bapubheti with 40.97%. We have also estimated the per capita income per year for the villages and is represented in the figure 24.

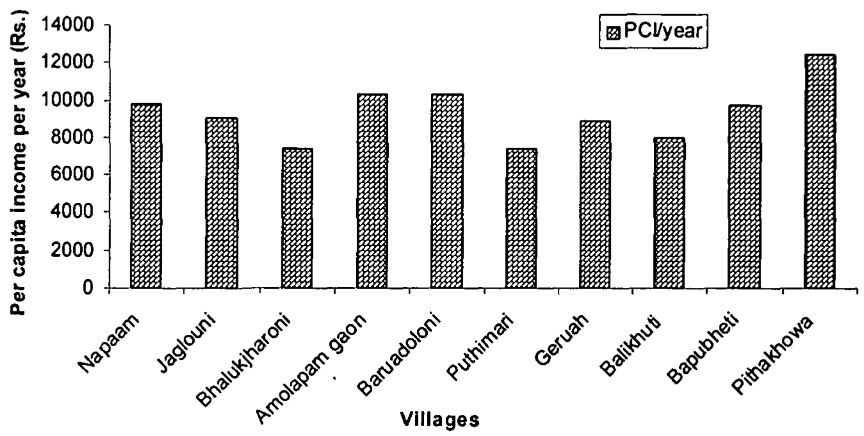


Figure: 24. Per capita income per year with respect to ten villages in Rupees.

From the survey, it has been found that the infrastructure facilities of most of the villages are very poor. Although the state income, however, has grown at a much lower rate than the national average, leading to a low per capita income of Rs 21,684, compared to India's per capita income of Rs 33,299 (Bhandari and Kale[31], 2009); the villages that have been taken for this study were found even less per capita income per year than the state average. The highest per capita income per year was estimated for Pithakhowa village of Rs. 12442 and the lowest per capita were found for the village Puthimari and Bhalukjharoni with Rs. 7389 and Rs. 7410 respectively. The present study is highly synoptic and based on a small sample size of 1268 households selected from ten villages. Therefore, our results are necessarily indicative and not conclusive. Nevertheless, they indicate the extent of poverty in the rural areas of Assam. The prime reasons of poverty are excessive dependence on primary sector, disguised unemployment, poor development of marketing facilities, connectivity and power supply, poor agricultural productivity, absence of any significant manufacturing activities, hourglass shaped occupational distribution and so on (Mishra[124], 2004).

4.1.6.1 Household income and fuel use

The energy ladder hypothesis is one of the most common approaches used in studying the household energy use patterns. The concept of energy ladder hypothesis states that people with low incomes generally use traditional fuels as their main cooking fuel and people with higher incomes tend to use modern fuels. The choice of a fuel by households depends on own price, the prices of the related fuels, appliances used, the efficiency of the fuels and household characteristics. One of the main factors that determine the selection of a fuel and the movement towards other alternatives is the income of the households (Masera[117] *et al.*, 2000). As stated earlier, the energy ladder hypothesis explains the movement of energy consumption from traditional sources to more sophisticated sources along an imaginative ladder with the improvement in the economic (income) status of households. The energy ladder is presented in Figure 25.

The underlying assumption of the model is that households are exposed to a number of fuel choices which could be arranged in an order of increasing technological sophistication. Biomass fuels occupy the bottom of the list while electricity, that is much cleaner, lies at the top. It is assumed that energy transition occurs from the bottom to the top with increasing socioeconomic status of households either through a rise in income or a fall in price (Hosier and Dowd[84], 1987). This concept is expected to align with the cross sectional and longitudinal variations in income.

The major sources of energy consumed at the household level that found in the ten villages are firewood, kerosene, LPG, biogas, electricity and crop residue /dung / *guitha*.

Thus, the hypothetical energy ladder at the micro level for these villages will constitutes of crop residue / dung / *guitha*, firewood, kerosene, Biogas and LPG. Crop residue / dung / *guitha* occupies the bottom rung of the ladder while electricity is at the top. It is assumed that with the improvement in economic status of households, they would shift towards modern fuels.

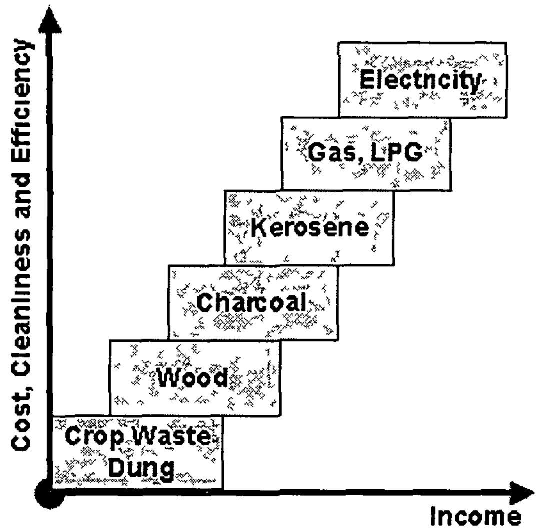


Figure: 25. Schematic diagram of the energy ladder

Now, for verifying our results, we have examined the per capita income per year of each household according to the types of fuels used for cooking and lighting purposes. For each type of fuels according to our energy ladder, we have evaluated the minimum, maximum and the arithmetic mean of per capita income per year and are represented in figure 26. Sample size and the percentage of the households are also shown in the figure 26 According to our energy ladder, for fuel types such as crop residue / dung / *guitha*, firewood, kerosene, biogas and LPG that used for cooking purpose; the mean per capita income per year for the households were found to be Rs. 5526, Rs. 7982, Rs. 7281, Rs. 10131 and Rs. 12684 respectively where as for lighting purpose (for kerosene and kerosene/electricity users) it has been estimated as Rs. 8113 and Rs. 9868 respectively.

Although our results shows the similarity with the energy ladder hypothesis but other variables such as cooking and consumption habits, dependability of supply, cost, and household preferences and tastes to explain household fuel choice, as well as to recommend policies also have to be taken care off that address issues associated with household energy use which is not included here.

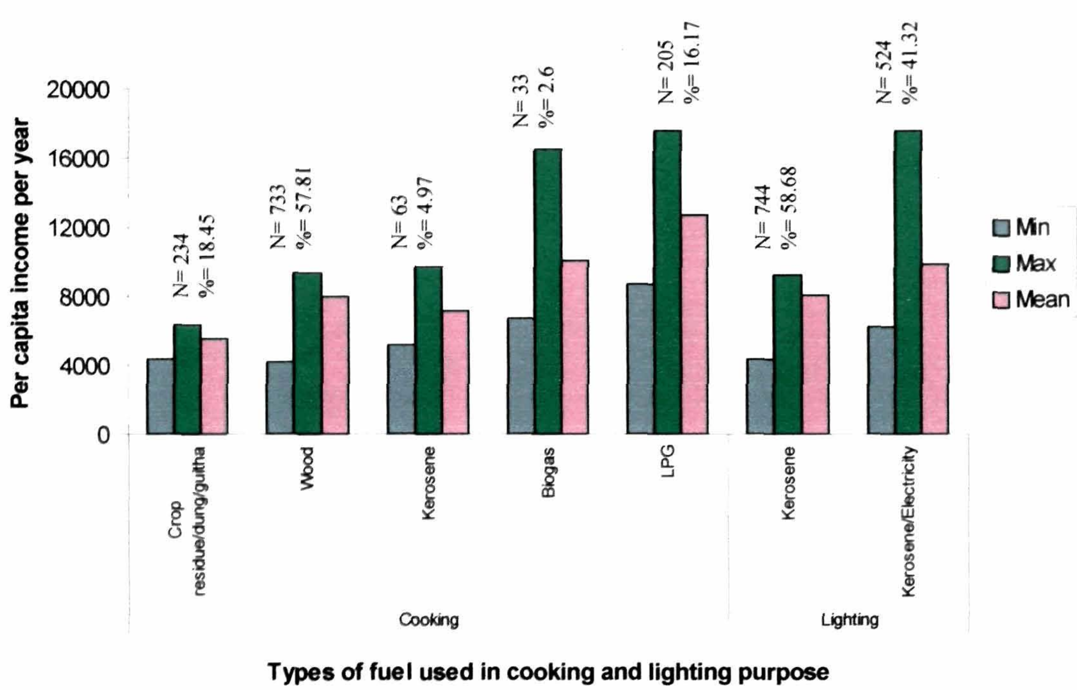


Figure: 26.Types of fuel used for cooking and lighting purpose with respect to the per capita income per year of the households.

4.1.7 IAP related disease and household condition

During the baseline survey, we are trying to collect additional information regarding the evidence of different IAP related diseases such as cough, asthma, bronchitis, cataract, tuberculosis, cancer etc. It has been found that cough, asthma and bronchitis problem is found mostly among the children ≤ 5 yrs of age and the females than male. We have found severe cough problem in a total of 611 peoples among them 367 was of children ≤ 5 yrs of age and 196 were the females. In case of asthma and bronchitis problem a total of 184 and 149 peoples were found effected among which 32 and 49 peoples are found children ≤ 5 yrs of age and 115 and 84 were the females respectively. Here, females those are involved in the cooking purpose were found mostly affected by the asthma and bronchial problem. Asthma and bronchial problem also found in a significant numbers of peoples (32 and 49 respectively) and this might be due to the habit of tobacco smoke among the males (Albalak[5], *et al.*, 1999; Bruce[43], *et al.*, 1998; Perez-Padilla[159], *et al.*, 1996; Dennis[53], *et al.*, 1996; Sandoval[179], *et al.*, 1993; Dhar and Pathania[54], 1991; Behera and Jindal[27], 1991; Pandey[151], *et al.*, 1988; Malik[112], 1985; Pandey[150], 1984; Padmavati and Arora[148], 1976). Moreover, cataract, tuberculosis and cancer were observed in significant numbers of male and females in the study site. During the study; 22, 19 and 12 male peoples were found affected with these three types of diseases respectively whereas in case of female it was found to be among 30, 15 and 4 numbers of peoples respectively. Since, most of the females were remains involved in the cooking activities in the kitchen it might be due to the cooking smoke and for male it might be due to their tobacco smoke (Mishra[127], *et al.*, 1999a; Perez-Padilla[160], *et al.*, 2001; Shalini[184], *et al.*, 1994; Rao[166], *et al.*, 1995 and Mohan[131], *et al.*, 1989). For cataract, tuberculosis and cancer no cases of children $\leq$ 5 yrs of age was found.

Regarding the ventilation condition of the kitchen and different cases of IAP related diseases as stated above, we have found that 82.6% of female peoples come from inadequate/poor kitchen ventilation whereas 17.4% were from moderate ventilation condition. If we see the scenario for the children $\leq$ 5 yrs of age; 64.3% from inadequate/poor ventilation, 22.6% were from moderate ventilation condition and 11.1% from adequate/good ventilation condition. Hence, it can be concluded that improvement of ventilation condition may enhanced the health condition of the household peoples at a great deal.

Key findings:

- *In the ten villages 9.82 % of population was found to be children of ≤ 5 years of age who are potentially vulnerable to the IAP exposure (Figure 7).*
- *It is important to note that the per capita income per year for the ten villages was found well below the national average. Hence, the result indicates that the economic condition of most of the households was found to be poor (Table 3, Figure 23).*
- *Analysis based on the survey data on household income and fuel use shows the similarity with the energy ladder hypothesis that improvement in the economic (income) status of the household makes the movement of energy consumption from traditional sources to more sophisticated sources (Figure 26).*
- *Baseline data showed that 57.81% of the rural households used firewood as their preliminary fuel source and 75% of the households used traditional cookstoves for their cooking purposes (Figure 18 and 19).*
- *Survey result shows the presence of four types of kitchens viz. kitchen attached with living room survey with partition (KAWLWP), kitchen attached with living room without partition (KAWLWOP), separate kitchen outside the living room (SKOLR), and open air kitchen (OK) among which three types of kitchen contributes more than 99% of the households except open air kitchen (Figure 12).*
- *It has been found that 69.66 % of the kitchens in the study site were poorly ventilated. Moderately ventilated kitchens were found in the 23.57 % of the households and 6.77 % of the kitchens were found good ventilation (Figure 17).*
- *Cough, asthma and bronchitis problem is found mostly among the children ≤ 5 yrs of age and the females than male whereas cataract, tuberculosis and cancer were observed in significant numbers of male and females.*
- *Regarding the ventilation condition of the kitchen and different cases of IAP related diseases as per questionnaire survey; 82.6% of female peoples come from inadequate/poor kitchen ventilation, 17.4% were from moderate ventilation condition whereas in case of the children ≤ 5 yrs of age; 64.3% from inadequate/poor ventilation, 22.6% were from moderate ventilation condition and 11.1% from adequate/good ventilation condition.*

PART II

Stove Performance and Fuel Consumption Analysis

4.2.1 Sample size selection

During the study, both stove performance and fuel consumption analysis was carried out before and after installation of the improved cookstoves (ICS) in the selected households. The households were selected randomly based on the baseline survey data to conduct these tests. In this chapter, the results of stove performance and fuel consumption analysis will be discussed on the basis of before and after intervention (without control) study. Before and after (without control) study design have several advantages – as it requires smallest sample size of all design and reduces selection bias because the same households are used for intervention studies (Bailis[15] *et al.*, 2007). For before and after study design, we have considered the sample size as per the table 4 shown below.

Table: 4. Sample size needed in each group for statistical significance for before and after study design

COV	0.1	0.3	0.5	0.7	1
delta					
0.1	8	71	196	385	785
0.2	2	18	49	96	196
0.3	1	8	22	43	87
0.4	1	4	12	24	49
0.5	1	3	8	15	31
0.6	1	2	5	11	22
0.7	1	1	4	8	16
0.8	1	1	3	6	12
0.9	1	1	2	5	10

Delta = detectable difference in means (percentage value)
COV = coefficient of variation (SD/mean)
Source: http://ceihd.org

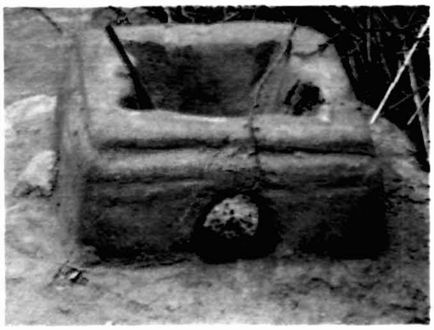
Notes*

1. 2-tail test; power = 0.80; p-value = 0.05
2. COV = SD(ICSi - TCSi)/AVE(TCSi)

The sample size depends not only on statistical rules and natural variations, but also on a choice of how small a difference the investigators would like to detect. We have considered the sample size of COV = 0.7 and delta =0.4 for carrying out our study on biomass cookstoves. It is highly recommended for the study that COV should have 0.7 and hence depending on the variation of kitchen type and stove design from the preliminary baseline survey, delta of 0.4 have been selected. It is mandatory for the study that tests should be performed always more than the sample size so that it can be adjusted during intervention study. This is because of the fact that during the study some households might switch over into other fuel source or some households might not be involved in between our study. Hence, households were selected so carefully that all the tests could be performed in the same households according to our research plan, so that actual variations in the households would come out after intervention study. All the tests such as water boiling test (WBT), controlled cooking test (CCT), kitchen performance test (KPT) and monitoring for CO, CO_2 and $PM_{2.5}$ before and after installation of ICS were conducted during the months from May, 2008 to November, 2008 in the selected households.

4.2.2 Water Boiling Test (WBT)

During the preliminary survey, we have noticed two types of major traditional biomass cookstoves apart from a few improved designs (with/without chimney) in the study site.



(Stove type A)

(Stove type B)

So, we have selected 27 households each having traditional cookstoves for the study and accordingly tests were performed. For intervention study, with the consent of such households improved stoves were constructed in all the 54 households as per the design shown in chapter 3 (Figure 6). The phase data (high power cold start, high power hot start and simmering phase) of WBT tests for both before and after intervention study were then computed and analyzed. The details of the results are shown below.

4.2.2.1 High power cold start

In high power cold start, 2 L of water was allowed to boil in a standard pot with the stove at room temperature by using a pre-weighed bundle of wood according to the procedure 3.3.1. From this test, we have found the results of five major parameters such as time to boil, burning rate, specific fuel consumption, fire power and the thermal efficiency of the stove.

Time to boil

Time to boil is an important parameter of stove characteristics. It has been found that for stove type A, average time needed to boil 2 L of water was found to be 20.7 min where as for the type B, it was observed to be 20.4 min. After installing the ICS the average time required to boil was found to be 14 min reducing the time required for the same by 31.4% for both types of stoves.

Burning rate

Burning rate is a measure of the fuelwood consumption while brining water to a boil. It has been found that in comparison to both types of traditional cookstoves (TCS) when ICS was installed burning rate was found to be increased during the high power cold phase. For the first type of TCS burning rate was found to be increased by 33% after installing the ICS where as in case of second TCS, it was found to be increased by 33.2%.

The average burning rate for the 27 stoves of type A was found to be 11.7 g/min whereas in type B it was found to be 12.2 g/min. for the two-pot improved stoves average burning rate was 15.8 g/min. The increase of burning rate is due to the fact that besides the fuel bed secondary air also comes from the bottom of the grate and hence it will help in the combustion process of the fuel. Another reason is that burn rate was found to increase with increase in fuel batch size (Bhattacharya[33] *et al.*, 2002b).

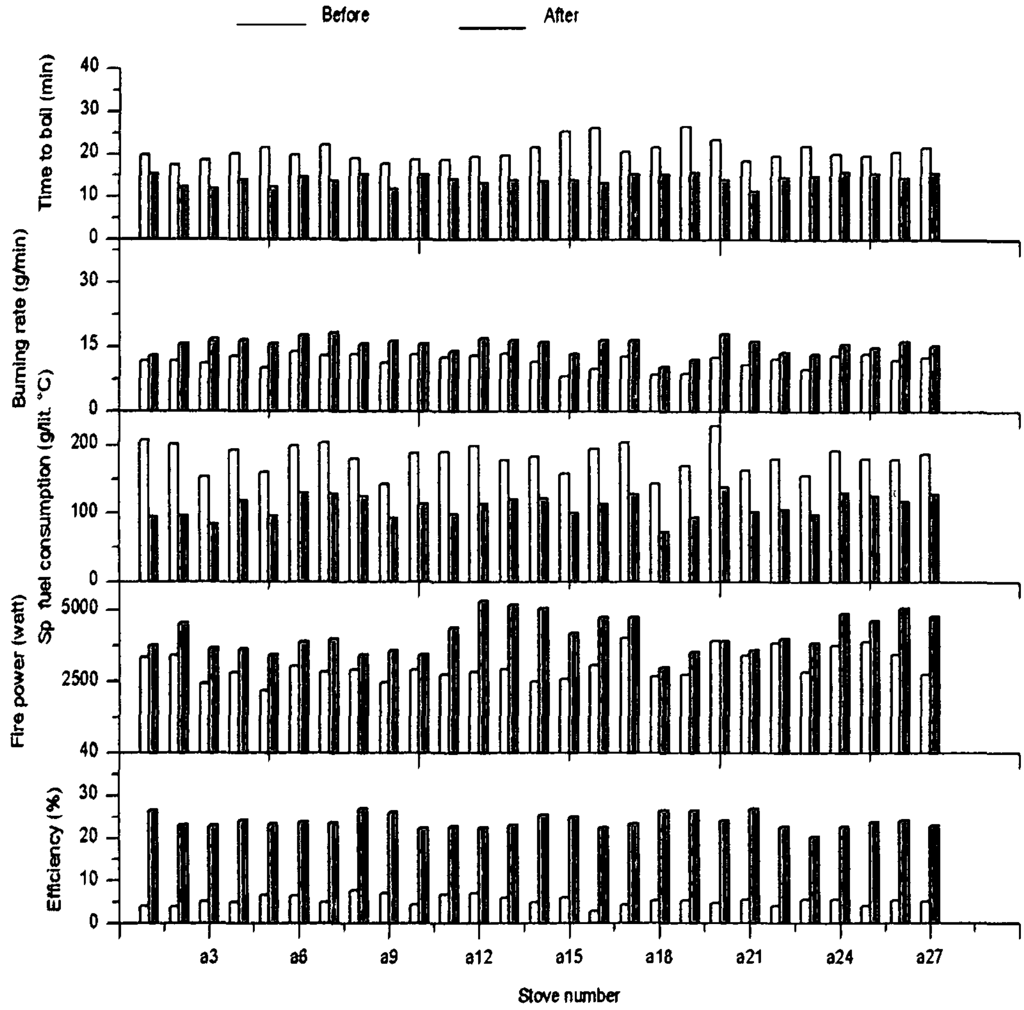


Figure: 27.Comparison of different properties of WBT before and after the intervention studies during high power cold start in 27 households having traditional cookstove type A initially.

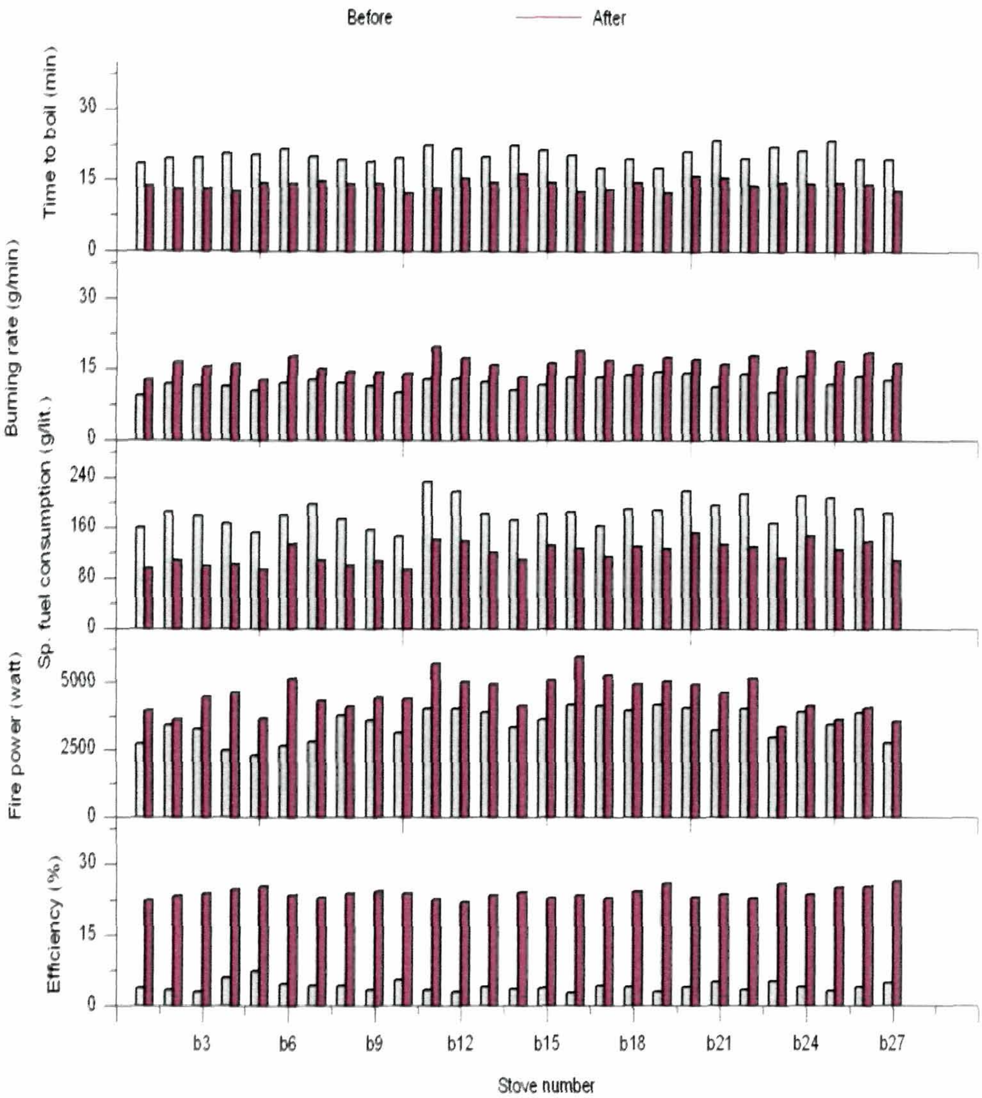


Figure: 28.Comparison of different properties of WBT before and after the intervention studies during high power cold start in 27 households having traditional cookstove type B initially.

Specific fuel consumption

Specific fuel consumption is the most useful criterion for determining how much fuel a stove is likely to consume. It is the amount of fuel required to produce a unit output. In this case, we have determined the temperature corrected specific fuel consumption which accounts for differences in initial water temperatures. It facilitates the comparison of stoves tested on different days or in different environmental conditions. This correction is a factor that normalizes the temperature change observed in test conditions to a standard temperature change of 75 °C (i.e. from 25 °C to 100 °C). The concept of specific fuel consumption with the fact that the formation of more water vapour during a cooking process is not a good practice as it consumes lots of energy and as a result additional use of fuel is unnecessarily occurs (Stove performance report, Aprovecho Research Center[11], 2005).

For stove type A, average fuel consumption (dry) has been found to be 238.9 g. After installing the two-pot ICS the fuel consumption (dry) was dropped down to 134.5 g (average) with an average reduction of fuel consumption (dry) by 43.7%. In case of stove type B, fuel consumption (dry) have found to be almost same as the previous one with 247.5 g and after installing the ICS it decreased up to 140.8 g which shows an overall reduction of 43.1 %.

In high power cold phase, it was observed that in both types of the stoves the intervention study by installation of the two-pot ICS results decrease in the specific fuel consumption considerably. It has been found that in case of stove type A, an average of 39.2 ± 6.5 % reduction was observed, whereas in B type it was found at an average of 35.6 ± 5.5%.

Fire power

Fire power is a ratio of the wood energy consumed by the stove per unit time. It tells the average power output of the stove during the high power test. Like burning rate, fire power also found increasing in case of ICS, in comparison to the TCS. The average fire powers for both the TCSs were found to be 3032.5 watt and 3468.3 watt respectively.

After installation of ICS, fire powers were found rises up with an average percentage of 39 % and 32.8 % respectively in comparison to the both types of TCSs.

Thermal efficiency

Thermal efficiency's of the stoves were calculated with the equation shown in section 3.3.1, in chapter 3. It is a ratio of the work done by heating and evaporating water to the energy consumed by burning wood. In the equation, the work done by heating water is determined by adding two quantities – firstly, the product of the mass of water in the pot, the specific heat of water (4.186 J/g °C) and change in water temperature; secondly, the product of the amount of water evaporated from the pot and the latent heat of evaporation of water (2260 J/g). The bottom of the ratio is determined by taking the product of the dry-wood equivalent consumed during the phase of the test and the LHV (lower heating value of the wood).

It has been found that thermal efficiency of both types of the TCSs increases considerably after replacing them by ICS as per the design we have considered. Initially, the average thermal efficiency's of both types were found to be 5.2 % and 4.1 % respectively, but after installation of ICS the same were increase up to 23.9 % which was the average for all the 54 households were ICS has been installed. In general, efficiency of the stoves decreases with the increase in moisture content in the fuel (Bhattacharya[33] *et al.*, 2002b). It has been found that during the tests with TCS fuel moisture content ranges from 8.7% - 16.2% and with ICS it was from 8.7% - 18.4 %.

4.2.2.2 High power hot start

In high power hot start, 2 L of water was allowed to boil in a standard pot immediately after the first phase of the test while the stove was still hot by using a pre-weighed bundle of wood as per the procedure 3.3.1. Repeating the test with a hot stove helps to identify the differences in performance between a stove when it is cold and when it is hot. From the test, we also found the results of five major parameters like high power cold start.

Time to boil

Like, high power cold start in this phase also the time to boil the 2 L of water was found to be reduced in comparison to the TCS with the ICS. Furthermore, it has also been found that it has even decreased in hot phase in comparison to the cold phase.

From the observation, it has been found that for both types of TCSs, the average time required to make the water boil was found to be 15.7 min and 15.1 min respectively in comparison to the high power cold start with 20.7 min and 20.4 min for the same. After intervention with the ICS, in high power hot phase the time that required to get boiled was found to be reduced by 38.5 % and 33.7 % respectively for both types of TCSs.

Burning rate

In this phase, burning rate has been found increasing in comparison to the cold phase. It has been found that for stove TCS A, the average burning rate was found to be 13.3 g/min in comparison to 11.7 g/min in the cold phase, where as in TCS B also it was observed to be 14.1 g/min in comparison to 16.2 g/min in the cold phase. After installation of ICS the overall burning rate was found to be 17.7 g/min, showing an average increase of 31.1% and 27.9%, in comparison to both types of TCS respectively. In high power hot start, stoves are initially in the hot condition, it enhances the evaporation of the moisture from the fuel resulting in increased burning rate.

Specific fuel consumption

Like, high power cold start in this phase also the fuel consumption was found to be reduced in comparison to the TCSs with the ICS. Furthermore, it has also been found that fuel consumption was even decreased in the hot phase in comparison to the cold phase.

It has been found that for both types of TCSs, the average fuel consumption was found to be 207.7 g and 212.1 g respectively in comparison to the high power cold start with 238.9 g and 247.5 g for the same. After intervention with the ICS, in high power hot phase the fuel wood consumption (dry) was found to be reduced by 49.9 % and 47.3 % respectively for both types of the TCSs.

It was also found that specific fuel consumption for both types of stoves was reduced in this high power hot phase in comparison to the cold phase. In this phase, the average specific fuel consumption were found to be 158.3 g/L and 157.2 g/L respectively for both types of TCSs. Intervention study shows a reduction of 45.1% and 40.2 % reduction in hot phase in comparison to the both types of TCSs.

Fire power

In high power hot phase, it has been observed that fire power also increased slightly like burning rate. In high power cold start, for both types of the TCSs the average fire power was found to be 3032.5 watt and 3468.3 watt respectively whereas in high power hot starts both are found rises up to 3474.4 watt and 4003.9 watt. In case of ICS also, it has been found increase to an overall average of 4843.9 watt in comparison to the cold start average of 4334.5 watt for the same. For both types of the TCSs a rise of 37.9% and 26.9% fire power was observed in the hot start phase after carrying out intervention study. According to Ballard-Tremeer and Jawurek[21] (1996), increase of fire power is not a good characteristics for a single pot cookstove as more energy is lost without transferring the heat to the pot, but as we had used two pot ICS, and hence such access heat was transferred to the secondary pot.

Thermal efficiency

In this hot phase, thermal efficiencies of the stoves were found increased a bit. As said earlier, efficiency of the stoves decreases with the increase in moisture content in the fuel (Bhattacharya[33] *et al.,* 2002b). Therefore, as the stoves are in hot condition during the start of this phase, moisture from the fuel evaporates rather quickly than the cold phase as a result of which burning rate also increases and hence efficiency of the stove increases. It has been found that the average efficiency of both types of TCSs was found to be 9% and 4.9% respectively. In case of ICS the overall average efficiency was found to be 28.3%.

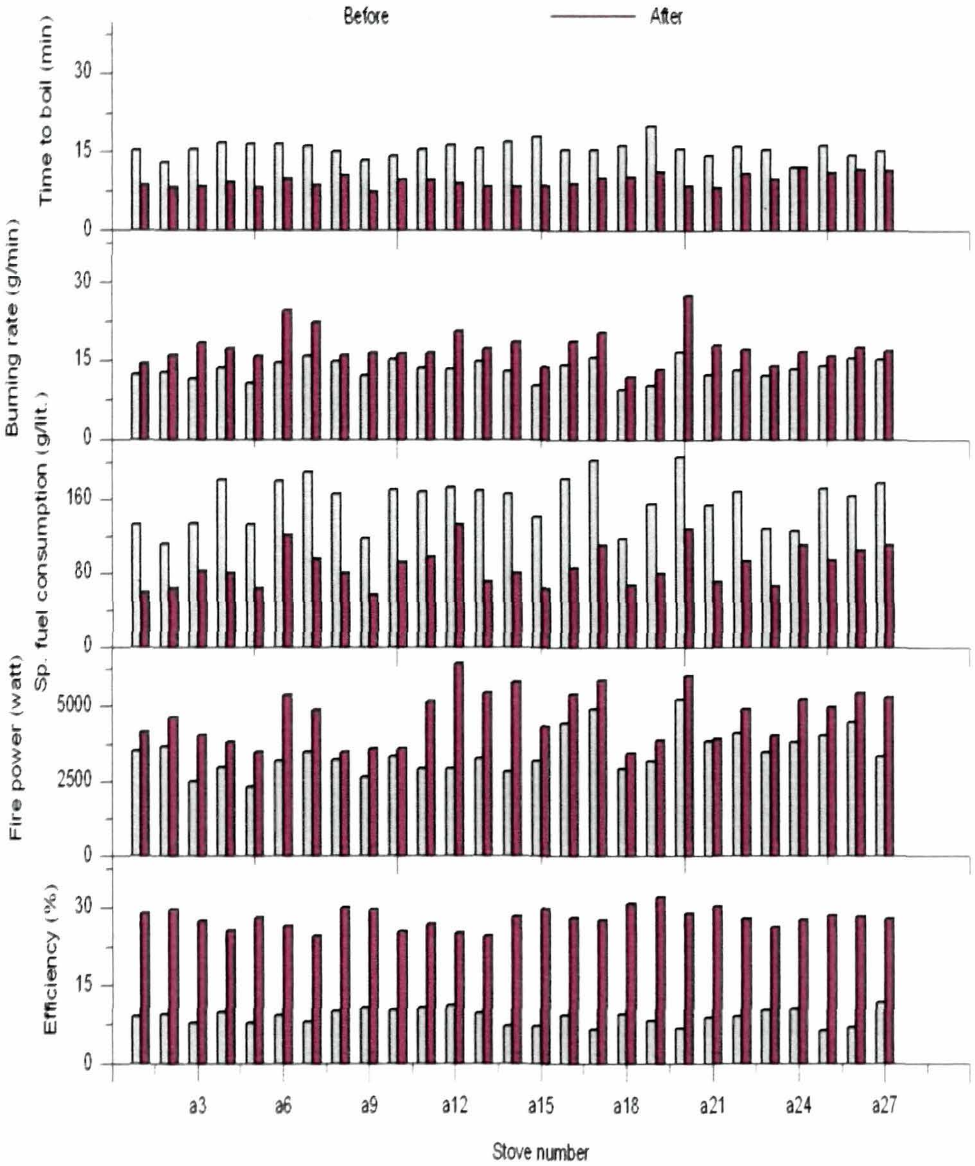


Figure: 29.Comparison of different properties of WBT before and after the intervention studies during high power hot start in 27 households having traditional cookstove type A initially.

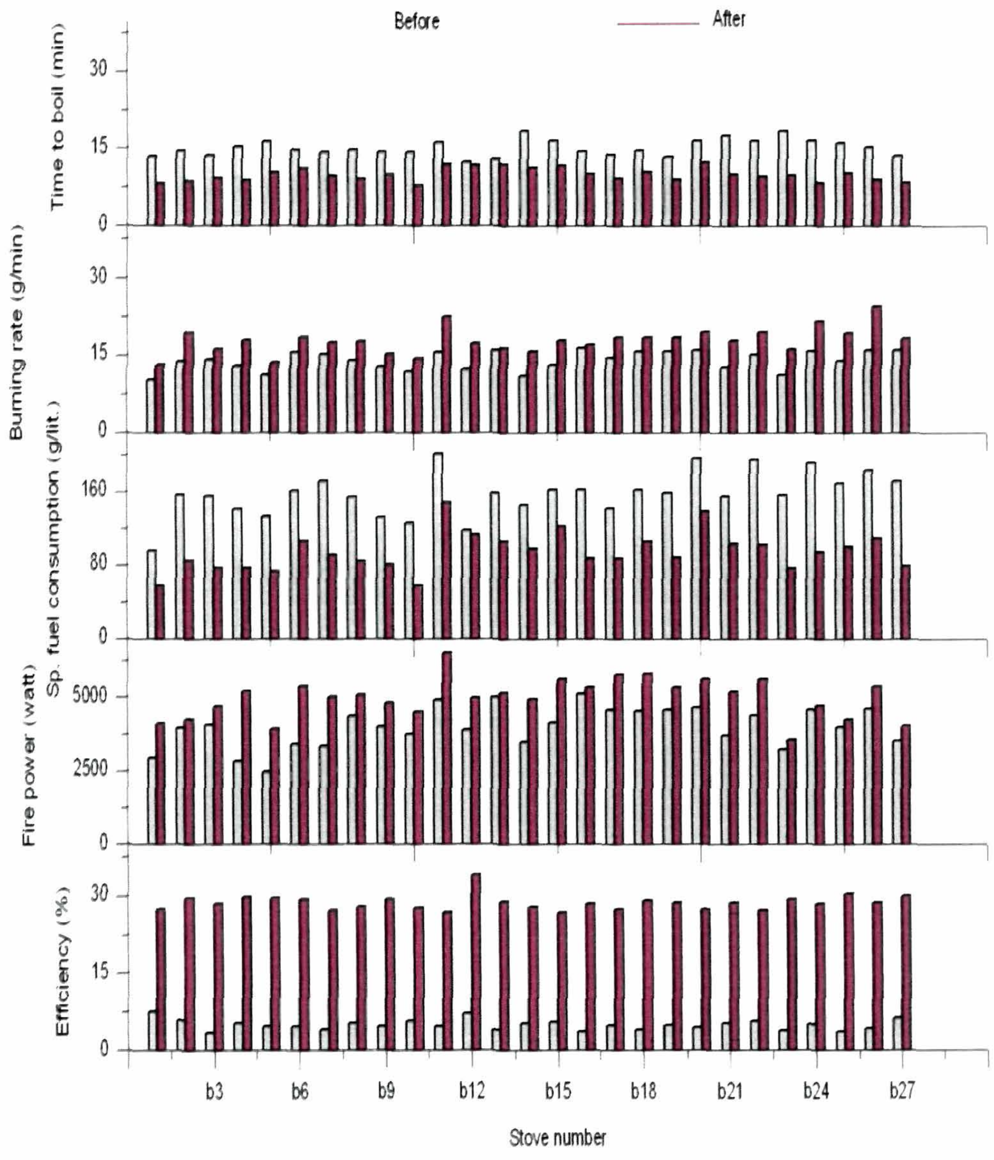


Figure: 30.Comparison of different properties of WBT before and after the intervention studies during high power hot start in 27 households having traditional cookstove type B initially.

4.2.2.3 Low power simmering

In the simmering phase that have been started immediately after the hot phase, we have to determined the amount of fuel required to simmer 2 L of water at just below boiling for 45 min as described in section 3.3.3. Basically in this test, the initial measurements are the same as in the high power test, however, the goal of the test was to maintain at a high temperature with minimal power output from the stove.

As the low power simmering phase starts immediately after the completion of high power hot start phase, there will be char remaining in the stove from the wood that used to bring the water to boil. Therefore, removing that char from the stove, weighing and relighting it disturbs the fire and may result in the water temperature dropping to far below boiling. Thus, it was recommended to assume that the char present at the start of the simmering phase was the same as the char that was measured after the high power cold start. While this was not entirely accurate, the error introduced by this assumption would be minimal if we followed an identical procedure in bringing the water to a boil.

Burning rate

It has been observed that the burning rate of all the stoves was found decreasing in comparison to the hot phase. In this phase, cookstove stores a large deal of heat and to keep the temperature of the water just below the boiling temperature for 45 min, we have to control the flame as a result of which burning rate of the fuel decreases.

During the simmering phase burning rate (average) of A and B type TCS were found to be 11.4 g/min and 12.1 g/min respectively showing a decrease from the high power hot start phase with 13.3 g/min and 14.1 g/min for the same. Similar was the case for ICS also. It reduces with a great deal from 17.7 g/min in the hot phase to the 7.9 g/min (average of burning rate in simmering phase of all the 54 ICS) in the simmering phase.

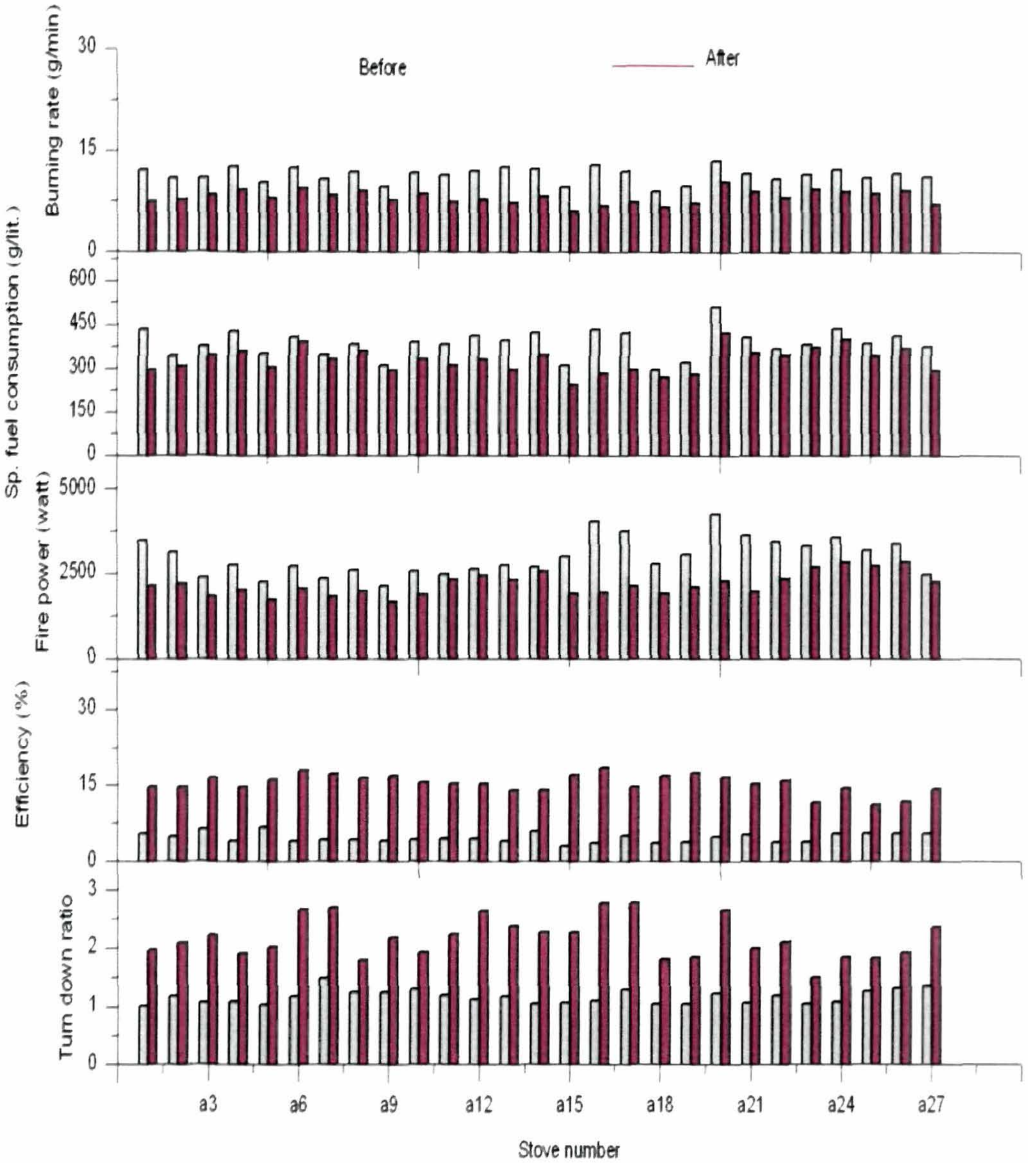


Figure: 31.Comparison of different properties of WBT before and after the intervention studies during simmering phase in 27 households having traditional cookstove type A initially.

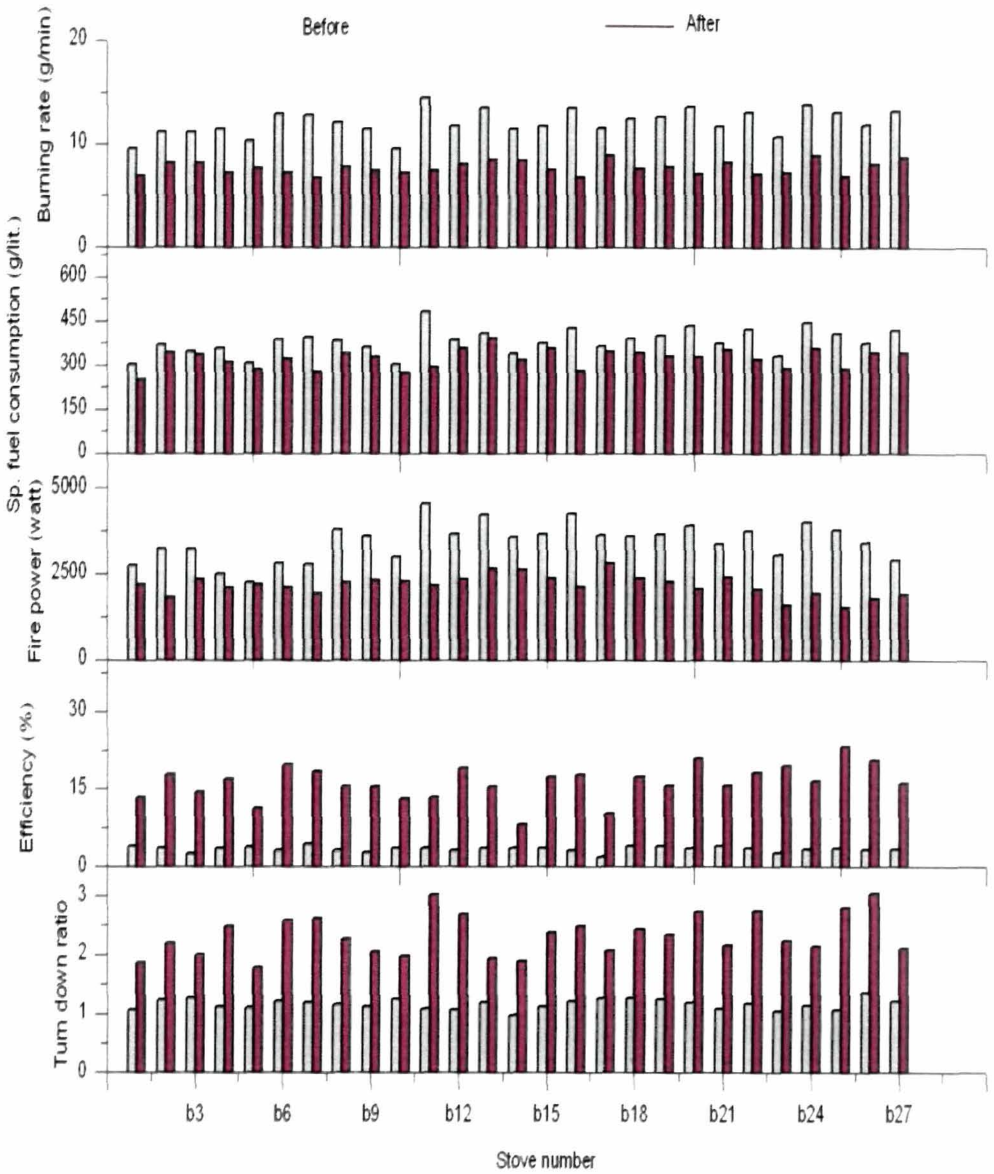


Figure: 32.Comparison of different properties WBT before and after the intervention studies during simmering phase in 27 households having traditional cookstove type B initially.

Specific fuel consumption

This is an important point to mention that in simmering phase there is no temperature corrected specific fuel consumption because the test starts at boiling temperature and the change in temperature varies within a few degrees. Hence, specific fuel consumption in the high power cold and hot start indicates the mass of fuel required to produce one liter of boiling water, whereas in simmering phase it indicated the mass of fuel required to maintain each liter of water within the 5 °C below the boiling temperature. Although both are not directly comparable but they shows some different measures of stove performance indicating two different conditions.

In this phase the specific fuel consumption (average) for both types of TCS were found to be 387.2 g/L and 381.6 g/L respectively. In case of ICS that has been installed the average specific fuel consumption were found to be 325 g/L showing an overall reduction of fuel consumption by 14.9% with both the TCSs in this simmering phase.

Fire power

Although the fire power at high power and simmering phase are not comparable but they shows a significant stove characteristics at two different conditions. In both cold and hot start during high power phase fire power was measured allowing the water to make boiled but in the simmering phase it was measured by keeping the water temperature within the 5 °C below the water temperature. During the high power it has been found that fire power was found to be more in case of hot start than the cold, but it has been observed that during simmer phase it reduces. Like burning rate, it has been found that fire power also decreases in the simmering phase in comparison to the hot phase. Average fire power for both types of TCSs was found to be 2989 watt and 3442.3 watt respectively, whereas in case of ICS it was observed to be 2168.7 watt.

In simmering phase it is also difficult to incorporate the output from additional cooking pots (as we are installed two pot ICS). In this phase multi-pot stoves appears to be at a disadvantage as lowering the power that delivered to the primary pot could not been able to deliver much heat to the secondary pot. Hence, fluctuations in temperature in the other pots were found to be more complicated to assess and finally we ignored it for the secondary pot as carried out by Food and Agriculture Organization of the United Nations (FAO[68], 1993), on Chinese fuel-saving stoves under Regional Wood Energy Development Program (RWEDP).

Table: 5. Performance characteristics of the cooking devices in water boiling test

Stove type / **Properties**	**Traditional stove type A (n = 27)**	**Traditional stove type B (n = 27)**	**ICS (n = 54)**
High power cold start:			
Efficiency (%)	5.2 (1.1)	4.1 (1.0)	23.9 (1.4)
Fire power (watt)	3032.5 (503.5)	3468.3 (583.8)	4334.5 (686.8)
Sp. fuel consumption (g/L)	181.2 (20.8)	184.8 (22.0)	114.5 (17.2)
Burning rate (g/min)	11.7 (1.6)	12.2 (1.3)	15.8 (1.9)
Time to reach boil (min)	20.7 (2.4)	20.4 (1.6)	14.0 (1.2)
High power hot start:			
Efficiency (%)	9.0 (1.5)	4.9 (1.0)	28.3 (1.7)
Fire power (watt)	3474.4 (709.0)	4003.9 (695.7)	4843.9 (805.8)
Sp. fuel consumption (g/L)	158.3 (26)	157.2 (24.6)	90.4 (21.5)
Burning rate (g/min)	13.3 (1.9)	14.1 (1.9)	17.7 (3.0)
Time to reach boil (min)	15.7 (1.5)	15.1 (1.6)	9.8 (1.3)
Simmering:			
Efficiency (%)	4.7 (0.9)	3.5 (0.5)	15.9 (2.7)
Fire power (watt)	2989.0 (563.7)	3442.3 (552.5)	2168.7 (316.5)
Sp. fuel consumption (g/L)	387.2 (47.4)	381.6 (43.6)	325.01 (38.2)
Burning rate (g/min)	11.4 (1.1)	12.1 (1.3)	7.9 (0.9)
Turn down ratio	1.2 (0.1)	1.2 (0.1)	2.3 (0.4)

Thermal efficiency

As the burning rate and fire power decreases in this simmer phase, thermal efficiency of the stoves were also found to be decreased quite an extent. For TCS type A, efficiency from the hot phase (9%) was reduced to 4.7%, whereas in case of type B stoves it reduces to 3.5%. In case of ICS, the thermal efficiency also reduces quite a great extent than the others and it reduces to 15.9%. This was because of the fact that a large amount of heat also transfer to the secondary pot.

Turn down ratio

This is also known as control efficiency and determined by the difference in fuel consumption per minute between high power (bringing water to a boil) and low power (simmering). Stoves with a higher turn down ratio are likely to use less fuel during a real-life cooking task, which involves bringing food to a boil and then cooking it at a simmer for an extended period of time. It has been observed that the turn down ratio for ICS was found to be more (2.3) in comparison to the TCS (1.2) showing less consumption of fuel in ICS (Ballard-Tremeer and Jawurek[21], 1996) than the TCS.

4.2.3 Controlled cooking test (CCT)

Controlled cooking test are conducted in real households cooking real meals, but under controlled settings in which every effort possible is made to ensure the stove is used to its best effect. It analyzes how the new stove performs compared to common or traditional cooking methods.

The CCT was chosen as the basis of this study because it provides a standardized comparison of stove performance within the real-world parameters of local fuel, food, and cooking practices. It was conducted in the kitchen under closely controlled conditions in order to simulate real cooking more closely than the WBT. In CCT, we still control certain variables such as the quantity of food prepared, the quality of fuel used and various behavioral characteristics of the cook. To control these factors, we hired a cook who is familiar to both types of the stoves. The test is repeated three times for each stove and average is reported. The cook uses an identical quantity of carefully measured ingredients for each test and is requested to cook in a similar manner throughout the tests so that the outcomes are comparable. Fuel characteristics are carefully noted and are held constant to the extent possible for all tests (Dutt and Ravindranath[59], 1993).

CCT test was carried out initially for equal number of traditional stoves {n=54 comprising of type A (n= 27) and type B (n= 27)}. Later on, all these stoves were replaced by ICS (n= 54) and repeated CCT test was performed after one month of installation

. In our case we had decided to conduct the tests by preparing rice and *dal* with a specific quantity of ingredients with the stoves. The reason behind the selection of preparing rice and *dal* was that they are the most familiar foods that preferred by all community peoples. During all the tests the ingredients for making such food was taken to be the same quantity as is shown below.

Preparation of rice:

Rice	250 gm
Water	750 ml
Pot	5 L capacities

Preparation of *dal*:

Dal	250 gm
Water	1500 ml
Onion	50 gm
Mustard oil	15 ml
Salt	10 gm
Turmeric	2 gm
Pot	5 L capacities

From CCT, we have found results of three major parameters viz, amount of food prepared, specific fuel consumption and time required to prepared the food. The summarized results showing the CCT is shown in the table 6 below.

Table: 6. Performance characteristics of the cooking devices in controlled cooking test

Stove type / **Properties**	**Traditional Type A (n = 27)**	**Traditional Type B (n = 27)**	**ICS (n = 54)**
Amount of food cooked (kg)	1.27 (0.034)	1.27 (0.043)	1.24 (0.013)
Moisture content of fuel (wt%)	12.9 (2.2)	13.6 (2.1)	12.6 (1.8)
Fuelwood (dry) consumed (kg)	3.67 (0.37)	3.32 (0.22)	2.47 (0.25)
Specific fuel consumed (kg of fuel consumed/kg of food prepared)	2.90 (0.3)	2.61 (0.18)	1.98 (0.2)
Char remaining (kg)	0.25 (0.06)	0.29 (0.05)	0.29 (0.03)
Time required (min)	28.4 (1.7)	26.8 (1.3)	17.7 (1.0)

From the CCT study we have found that for preparing almost same quantity of food (1.27 kg) in the type A and B cookstoves there is a little variation in dry fuelwood that consumed during the process (3.67 kg for type A and 3.32 kg for type B) where as in case of ICS for preparing food at an average of 1.24 kg the average fuelwood (dry) consumption is found to be 2.47 kg resulting a reduction of fuel consumption about 33.05% from type A and 24.04% for type B.

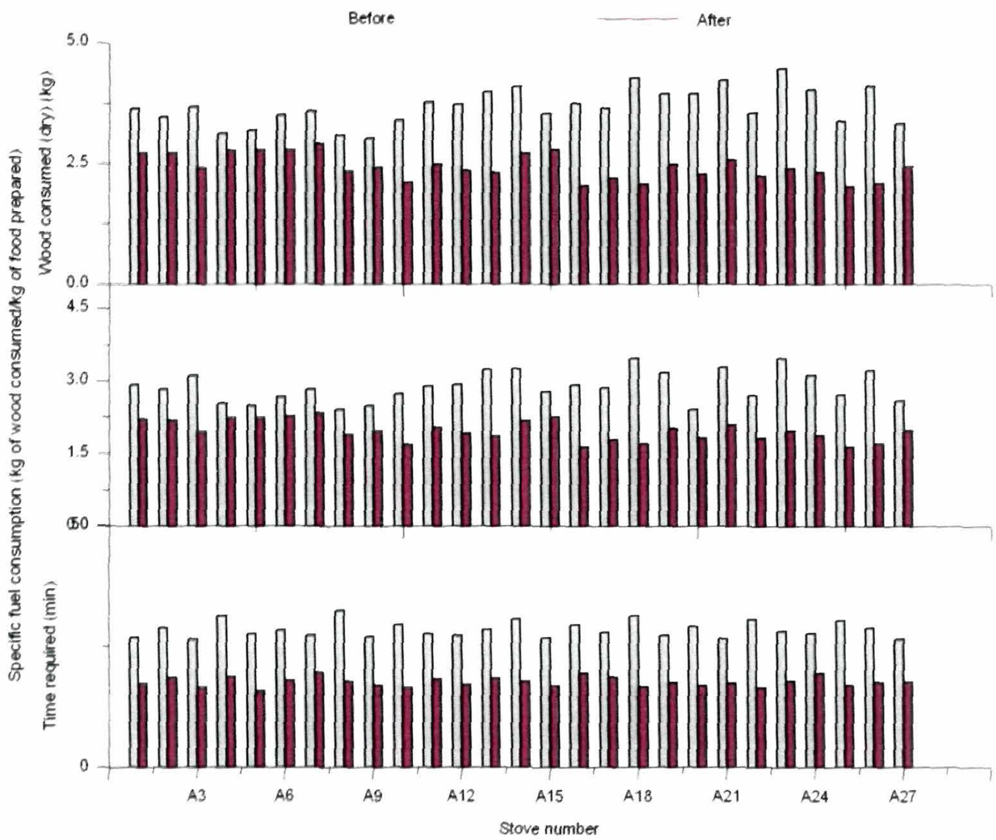


Figure: 33. Comparison of different properties of CCT before and after the intervention studies in 27 households having traditional cookstove type A initially.

In case of specific fuel consumption, there is also a little variation among the type A and type B stoves (2.90 kg for type A and 2.61 kg for type B) while ICS shows a consumption rate of 1.98 kg for per kg of food prepared showing a reduction of 31.1% and 23% reduction from type A and B stoves. We carefully represented the data by trying to make an identical condition for the tests as described by Beilis[15] *et al.* 2007; where they performed CCT in a similar manner for 12 traditional and *Patsari* stoves in Maxico. In terms of time also ICS prepares the food with less time than both type A and B stoves.

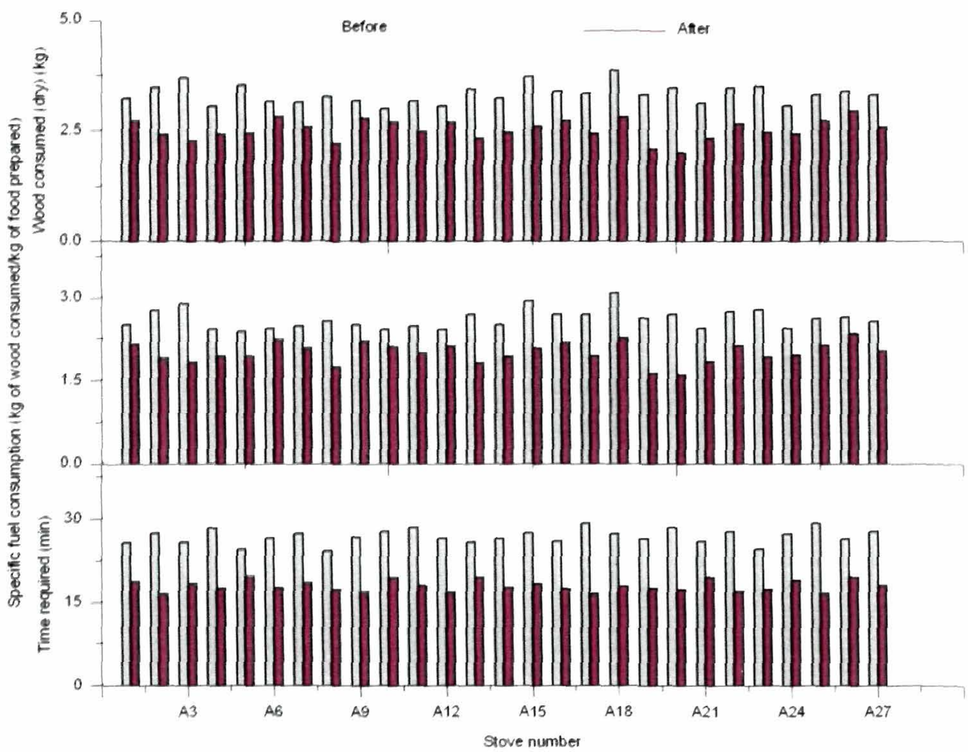


Figure: 34. Comparison of different properties of CCT before and after the intervention studies in 27 households having traditional cookstove type B initially.

Similarly, in case of time required in preparing the food that has been targeted found to be reduced by 38.23 % (type A) and 33.21% (type B) after installation of ICS. Hence, CCT result conforms that both specific fuel consumption and duration time required to prepare a food is reduced after installation of our considered ICS design with a significant manner showing faster way of cooking. The result that we have got from the CCT study shows the similarity with the works carried out by Beilis[15] *et al.*, (2007) and Bolaji and Olalusi[38] (2009).

4.2.4 Kitchen performance test

The KPT was selected over the water boiling and controlled cooking tests because it more accurately reflects the *in situ* fuel use of the stove. In the KPT, the fuel use comparison relies on consumption data from households in which normal cooking for the family is done by the usual cook over several days. The relative advantages and disadvantages of each test are related to the control of variation. There is an inevitable trade-off, of course, between efforts to reduce variability and being able to interpret the results in terms of performance of the entire population of stoves. Transitioning from the WBT to the KPT brings an improvement understanding of actual practice, but also introduces an increase in variability. Further, it also indicates that physical monitoring permits improved estimates of fuel use at the household level when compared to estimates that rely solely on survey data (McCracken and Smith[120], 1998).

The KPT conducted in this study was based primarily on the protocol that prepared by Bailis[16] *et al.*, (2004) which is already discussed in the third chapter, section 3.3.3. KPT is a study of combined physical monitoring and surveying. In this study, the most significant difference was an increase in the number of days from four to five, and the provision of uniform firewood supplies to participant households.

Our study consisted of two types of observations. Firstly, a 4-day KPT in all the 54 households that we have chosen to examine fuel use; and secondly, a single-day participant observation in those households to elicit qualitative design and usage data. Here, we have taken the same households that were studied during WBT and CCT so that actual fuel use data can be framed out. Furthermore, KPT also have been done in the same households after the two months of installing the ICS.

The wood used in the study was acquired from local timber sellers. The wood used for the study basically, bamboo (*Bambusa tulda*), *acacia* (*Acacia nilotica*) and *neem* (*Cassia fistula*) that are the most preferred wood species for cooking by the local people. After collecting the wood, it was air dried in sunlight for a week and then kept indoors. This is because of the fact that, moisture content can affects on the burn rate of wood and when moisture content is high enough it can affect the ability to ignite. Moreover, fuel moisture has a complex interaction with the two components of stove efficiency: combustion efficiency and heat transfer efficiency (Barnes[22] *et al.*, 2005). During the recruitment, each participating household were asked to give an estimate their daily fuel needs. This estimate was increased by 50% to deliver the household each day.

Although, there is no standard protocol to estimate overall moisture content from a set of meter measurements, in addition, the meter measurements are location-specific across the fuel specimen, and even though moisture content can vary significantly within a given piece of wood. However, electronic moisture meters were used in this study. For taking the moisture content in the fuelwood we have taken three readings across the wood (two in the ends and one in the middle) and average value of the three were considered.

On the first day of the study, the initial supply of wood for each household was weighed and counted, and participants were reminded to only use the wood provided to them for the study for the remainder of the KPT. The wood was stored in a designated area in each household. On days 2-4 the delivered wood and the wood remaining from the previous day was weighed and counted. In addition, a set of questions was asked in order to determine the number of meals served the previous day, and the age gender and number of people served at each meal.

On the final day, the remaining wood was weighed and counted, and questions were asked, however no wood was delivered. Participants were aware that they would be permitted to keep any wood remaining on the final day of the study thus providing some incentive to be as careful with its use as they would be with their own fuel supply. The primary tools and hardware used in the KPT were: two spring scales with 0-100 kg range and a 1 kg resolution; ropes and harnesses for wood transport.

Within a period of two months, for each of the households of the total 54 households (27 each for type A and B stoves) we have generated four fuel use data points, one per day. These data were averaged for each of the households. As the KPT included daily fuel use, the number and age of people served at each meal, and the number of meals served, fuel use can be expressed in several ways. As consistent with the protocol (Bailis[16] *et al.*, 2004), the metric reported here are kilograms of fuel per person-meal served (kg/PM). Comparisons are not significantly different using other common metrics. Person meals were scaled using an adult male as the reference, a child was weighted at 0.5 (0 – 14 yrs), an adult female at 0.8 (> 14 yrs), adult male at 1 (15 – 59 yrs) and a senior adult male at 0.8 (> 59 yrs), as suggested by (Naumoff and Kaisel[136], 2003). The summary of the results from CCT is shown in table 7.

Table: 7. Fuelwood consumption in terms of person-meal served and wood energy utilized to person-meal served in the households carrying out KPT.

Stove type / **Properties**	**Traditional Type A (n = 27)**	**Traditional Type B (n = 27)**	**ICS (n = 54)**
Moisture content of fuelwood (wt%)	13.05 (1.86)	13.45 (1.60)	12.87 (1.81)
Fuelwood (wet) consumed per day, (kg)	17.71 (1.44)	18.75 (1.68)	12.27 (1.05)
Fuelwood (dry) consumed per day, (kg)	15.40 (1.21)	16.24 (1.57)	10.69 (0.96)
Fuelwood (wet) consumed per person-meal served, kg	1.01 (0.09)	1.04 (0.16)	0.69 (0.08)
Fuelwood (dry) consumed per person-meal served, kg	0.88 (0.08)	0.90 (0.13)	0.60 (0.07)
Wood energy consumed per person-meal served, MJ	2.44 (0.71)	2.44 (0.90)	1.57 (0.60)

The results of the KPT shows that in both type of TCSs the fuelwood consumption are almost the same and has also the same in case of wood energy consumption per person-meal served. It is also found that after installation of ICS, fuelwood consumption reduced to a great extent (32%) along with the energy consumption per person-meal (35.66%). Figure 34, shows the comparison of fuel consumption and wood energy per person-meal served before and after installation of ICS.

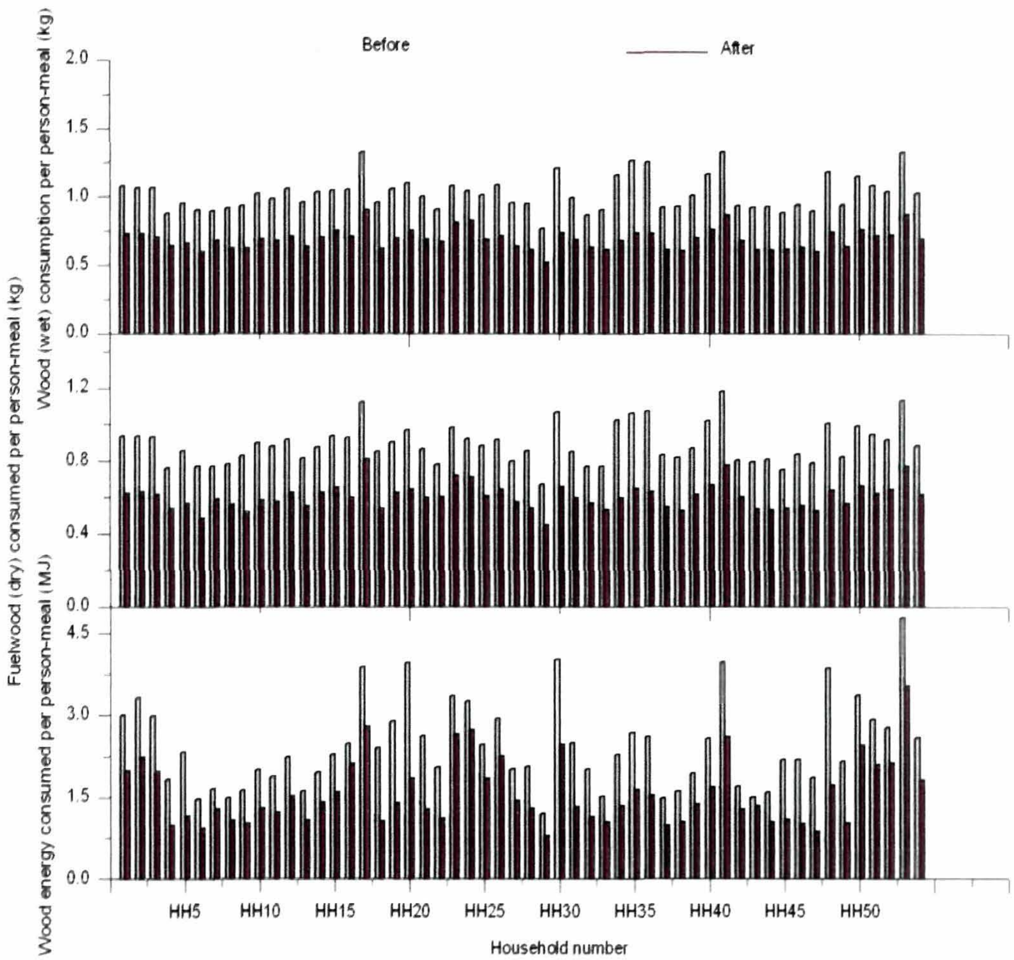


Figure: 35. Comparison of fuel consumption and wood energy per person-meal served before and after installation of ICS.

Here, in the figure household number HH1 to H27 represents the households having traditional stove type A and HH28 to HH54 represents the stove type B in black colored curve where as red colored curve represents the respective households after installation of ICS. Accordingly, blue colored curve represents the respective percentage difference among different properties.

Key findings:

- *For both type of the TCS during the cold phase efficiency was found to be 5.2% and 4.1 respectively while in case of ICS it was 23.9%. During the hot phase, efficiencies rise up in all the three types of stoves and then decreases during the simmer phase. Similar is case for fire power and burning rate also.*
- *As the efficiency of the TCSs that used by the rural household were found to be low, hence they releases high volumes of air pollutants.*
- *The result of CCT shows that there is also a little variation in specific fuel consumption, among the type A and type B stoves (2.90 kg for type A and 2.61 kg for type B) while ICS shows a consumption rate of 1.98 kg for per kg of food prepared showing a reduction of 31.1% and 23% reduction from type A and B stoves.*
- *In CCT intervention, the time required in preparing the food found to be reduced by 38.23 % (type A) and 33.21% (type B) after installation of ICS.*
- *Similarly, the result of the KPT shows that after installation of ICS, fuelwood consumption reduced to a great extent (32%) along with the energy consumption per person-meal (35.66%).*

PART III

Emission Analysis from Cookstoves in the Kitchens

4.3 Sample size

From the baseline preliminary survey, we have found two types of kitchen orientation in major, particularly separate kitchen outside the living room (SKOLR) (50.32%) and kitchen attached with living room with partition (KAWLWP) (38.56%), whereas kitchen attached with living room without partition (KAWLWOP) was found to be only in 10.17% and a very few was found as the open air kitchen (0.95%). Keeping in view, we have considered three types of kitchen orientation viz., separate kitchen outside living room, kitchen attached with living room with partition and kitchen attached with living room without partition for the emission studies.

As described in the previous chapter (Chapter IV, Part - II), we have considered the same sample size for the emission studies. Hence, we have selected 27 households, each for the three kitchen orientations (total of 81 households). The sampling procedure is described in the Chapter II. During the monitoring period all the members of the households were requested to perform their regular duties in the usual manner. After monitoring was over for a period of 24 hour, a time activity questionnaire was administered particularly to the main cook of the household.

4.3.1 Emission in kitchen before installation of ICS

The emission measurements were taken in the households during the period of May, 2008 to August, 2008. During the period of time, we have visited the households early in the morning to setup the instruments in the kitchen for 24-hour period and the very next day we collect the instruments and collected the data for further analysis.

The results representing the 24-h average concentration of CO, CO_2 and $PM_{2.5}$ for a total of 81 households with three kitchen orientations is shown in the figure 36. From the result, it has been found that in case of kitchen attached with living room with partition the 24-h average concentration of CO and $PM_{2.5}$ was found to be more in all the households as compared to the other two types, where as the concentration of the CO and $PM_{2.5}$ in the other two types of kitchens were found to be close to each other. It has also been found that the 24-haverage concentrations for CO_2 were found nearly the same to all three kitchen types.

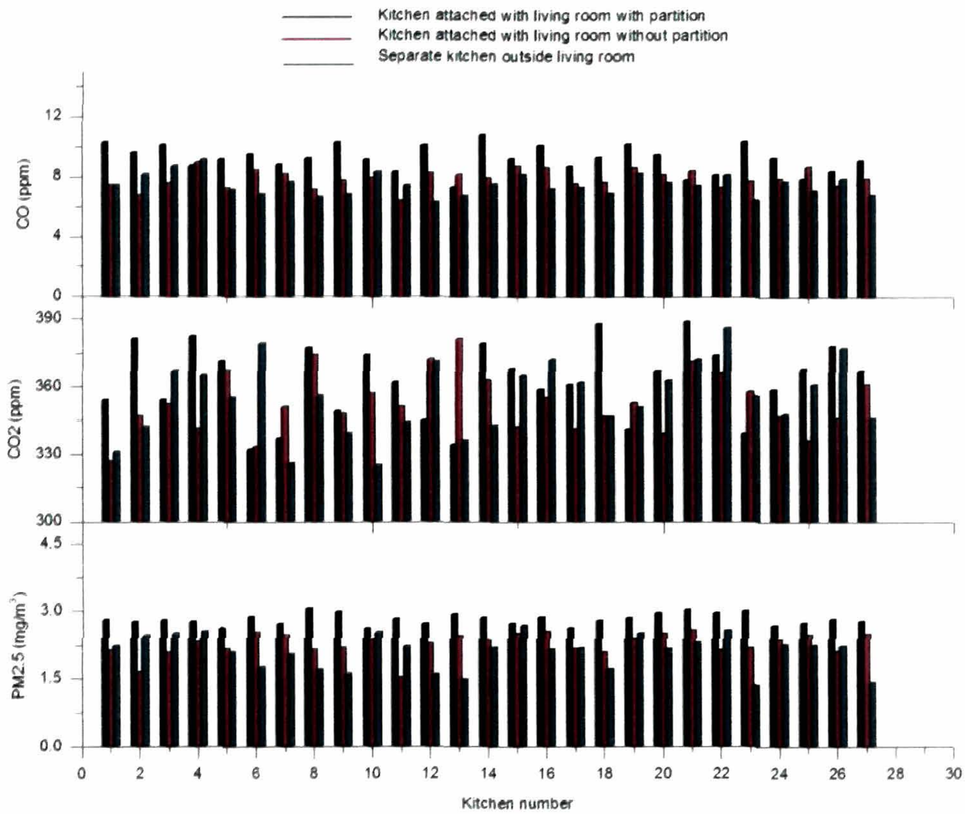


Figure: 36. Comparison of 24h average of CO, CO_2 and $PM_{2.5}$ for three different kitchen orientations (27 households for each) before installation of ICS.

The averages of CO, CO_2 and $PM_{2.5}$ for such 24-h average concentrations for 27 households of three kitchen orientations are shown in table 10. The average of 24-h average concentration of CO, CO_2 and $PM_{2.5}$ for the 27 households having kitchen with living room with partition was found to be 9.23 ppm, 362.56 ppm and 2.82 mg/m^3 respectively; whereas for kitchen attached with living room without partition and separate kitchen outside the living room, the same were found to be 7.85 ppm, 352.81 ppm, 2.26 mg/m^3 and 7.45 ppm, 355 ppm, 2.10 mg/m^3 respectively. From this observation, it can be stated that the concentration level for CO and $PM_{2.5}$ is found to be much higher than the WHO air quality guidelines (Annexure VII), which is shown in table 9.

According to exposure guidelines for residential indoor air quality, Federal-Provincial Advisory Committee on Environmental and Occupational Health, Canada; based on health considerations, the acceptable long-term exposure range for carbon dioxide in residential indoor air is ≤6300 mg/m3 (≤3500 ppm). It has been found that in all three types of kitchens 24-h average CO_2 was found to be low as compared to the guidelines level and its values found to be nearly equal to all three types of kitchens.

During the study, we have also made a calculative effort to measure the average concentration in the kitchen during cooking period and the smouldering period for the 24-h duration. It has been found that during the cooking period the average concentration for CO, CO_2 and $PM_{2.5}$ were found to much higher than the 24-h concentration level in the smouldering period showing the greater exposure, particularly to the cook and the people resides in the kitchen during the period in case of all the three types of kitchens. The comparative result of the concentrations of CO, CO_2 and $PM_{2.5}$ during cooking and smouldering period for the three types of kitchen is shown in the figure 37 below.

Here, like 24-h average concentration, concentration of CO and $PM_{2.5}$ were found to be more in kitchen attached with living room with partition in comparison to the other two types of kitchens while the concentrations of CO_2 were found nearly the same for all the three types of kitchen despite of the higher concentration than the 24-h average but still below the guidelines level. In case of smouldering period, it has been observed that although the concentration of CO and CO_2 found below the guidelines levels but the concentration of $PM_{2.5}$ were still found higher than the guidelines level. This is due to the low inside temperature and high humid condition of the kitchens (for example, we have observed that inside temperature and humidity in the kitchen having thatch and bamboo was found in the range 21 – 28 °C and 74 – 89%, for GI sheet and asbestos roof temperature and relative humidity varied from 26 – 36 °C and 67 – 75% respectively). So, there is a serious concern to all the three kitchen type households that exposed to such a high level $PM_{2.5}$ concentration for entirely 24-h period in the kitchen.

Figure: 37.Comparison of average of CO, CO_2 and $PM_{2.5}$ during the cooking and smouldering period for 24-h period in three different kitchen orientations (27 households for each) before installation of ICS.

In some of the earlier studies to determine the levels of indoor air pollutants associated with biomass combustion, concentrations of total suspended particulates (TSP) in the range of 200 – 30,000 μg/m^3 and CO concentrations between 10 to 500 ppm have been reported during the cooking period (Aggarwal[1] *et al.*, 1982; Smith[192] *et al.*, 1983; Reid[169] *et al.*, 1986; Pandey[153] *et al.*, 1990; Ellegard[63], 1996). Some 12 – 24-h determinations of respirable particulate concentrations have also been carried out, reporting 24-h means in the range of 300 – 3000 μg/m^3 (Saksena[177] *et al.*, 1992; Smith[188] *et al.*, 1994; McCracken and Smith[120], 1998). Recently, systematic, large-scale 24-h measurements of respirable particulates have been reported (Ezzati[67] *et al.*, 2000; Albalak[4] *et al.*, 2001; Parikh[155] *et al.*, 2001; Balakrishnan[17] *et al.*, 2002; Bruce[41] *et al.*, 2004).

Apart from 12 – 24h determinations, most recently, Northcross[144] *et al.* (2010) reported a 48-h concentration determination of $PM_{2.5}$ and CO carried out in the highlands of Guatemala. They estimated that 48 h mean personal $PM_{2.5}$ concentrations for mother, infants, and children in open-fire homes were 0.27 ± 0.02, 0.20 ±0.02, and 0.16 ± 0.02 mg/m^3 respectively. In chimney-stove homes, mothers and children experienced $PM_{2.5}$ personal concentrations of 0.22 ± 0.03 and 0.14 ±0.03 mg/m^3, respectively. Some other most recent 48-h determinations were reported by Dutta[60] *et al.*, (2007); Smith[190] *et al.*, (2007) and Ryhl-Svendsen[175] *et al.*, (2010).

After completing the monitoring of the concentration of CO, CO_2 and $PM_{2.5}$ for 24-h period in each of the selected households some question was administered particularly to the cook about the time activity pattern of the members of the households. The information collected from the members included the time spent in various locations and the type of activity they were involved in that particular location. The results of average durations in hour spent by household groups in the kitchen, living room and outdoor microenvironments are shown in the table 8 below.

It has been found from the result that women cooks spend the largest amount of time in the kitchen while cooking. Most importantly, it has been found that women in the age group of 19 – 50 years of age were found to be spending much time in the kitchen rather than other female cooks of other age groups. Hence, this age group of female cook has the potentiality of larger portion of exposure from the biomass combustion in the kitchen during cooking time. Moreover, children's ≤ 5 years of age also spend significant time in the kitchen as well as in the living room during the cooking and smouldering phase. Hence, they are also significantly exposed to the indoor air pollutants severely.

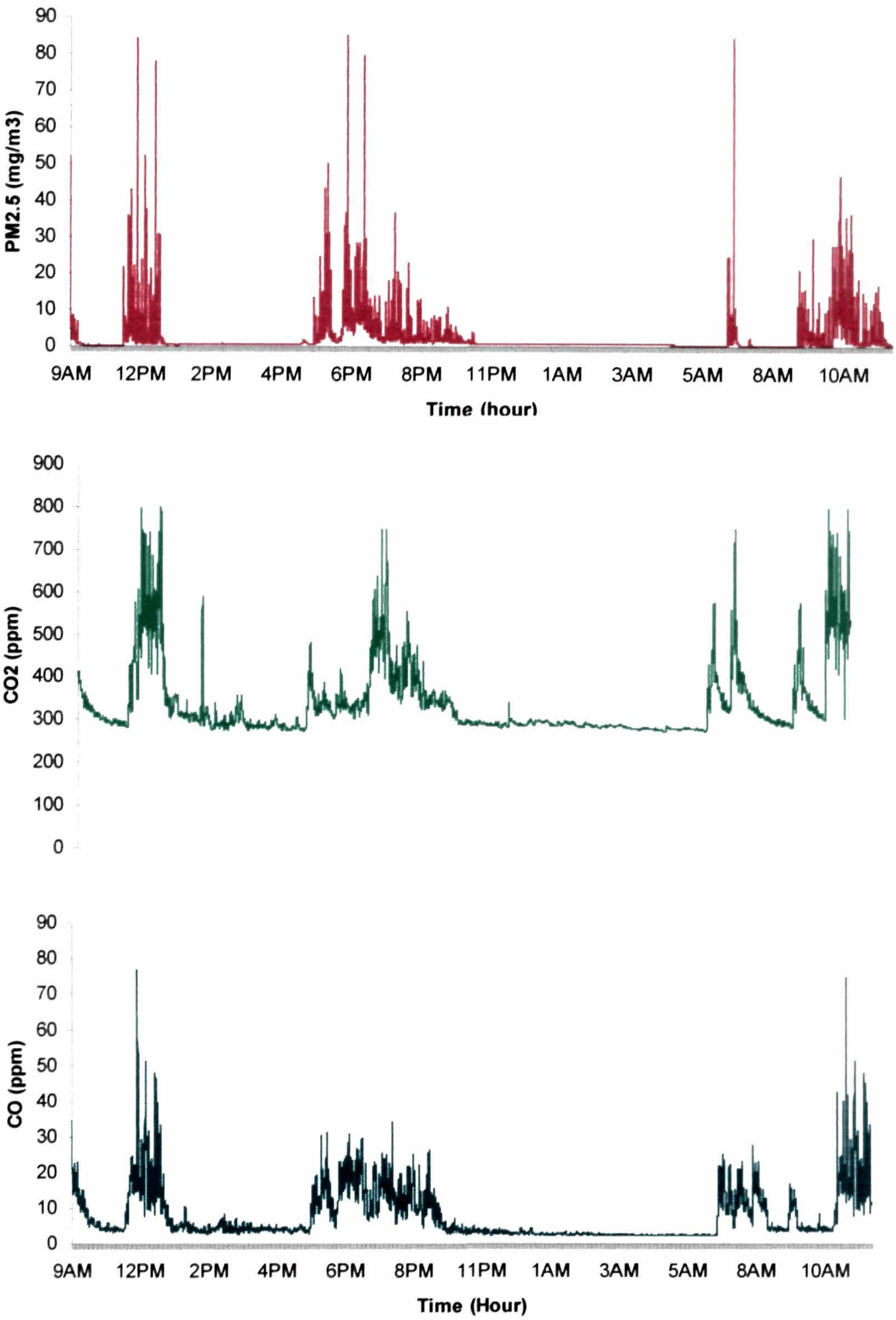


Figure 38. 24-hour concentration curve of $PM_{2.5}$, CO_2 and CO for a typical household kitchen

Table: 8. Average durations in hour spent by household groups in the kitchen, living room and outdoor microenvironments.

	Cooking period		Non-cooking period		
	Kitchen	Living	Kitchen	Living	Outdoor
Children ≤ 5 years	2.42	4.31	1.26	9.63	5.42
N	47	47	47	47	47
Std. deviation	1.2	0.7	0.3	4.6	3.9
Cooks:					
Female (6 – 18 years)	1.86	1.07	2.12	13.62	4.33
N	26	26	26	26	26
Std. deviation	1.03	0.89	1.23	3.47	2.29
Female (19 – 50 years)	2.94	0.77	3.26	13.34	3.04
N	109	109	109	109	109
Std. deviation	1.16	0.32	1.36	2.44	1.27
Female (>50 years)	1.56	2.15	3.46	12.86	3.67
N	52	52	52	52	52
Std. deviation	0.87	1.18	2.26	4.19	2.04
Non-cooks:					
Female (6 – 18 years)	1.06	3.35	0.76	12.54	6.47
N	43	43	43	43	43
Std. deviation	0.38	1.24	0.26	3.52	2.19
Female (19 – 50 years)	0.94	4.25	1.36	12.84	3.67
N	18	18	18	18	18
Std. deviation	0.24	2.18	0.47	4.26	1.08
Female (>50 years)	0.74	2.39	0.47	15:82	3.48
N	22	22	22	22	22
Std. deviation	0.32	1.05	0.15	3.66	1.24
Male (6 – 18 years)	0.67	1.16	0.82	10.43	10.62
N	86	86	86	86	86
Std. deviation	0.21	0.28	0.37	3.68	3.49
Male (19 – 50 years)	0.44	1.21	0.76	10.14	11.36
N	146	146	146	146	146
Std. deviation	0.22	0.54	0.37	3.86	4.29
Male (>50 years)	0.36	1.49	1.44	14.72	5.28
N	58	58	58	58	58
Std. deviation					

It is also found to be interesting that, other non-cook subgroups spend most of their time in the living room during the cooking period (Female 6 - 18yrs and 19 - 50yrs) and non-cooking period (all age groups of male and females). Therefore, living area concentrations found to be a very important determinant of exposures for non-cooks. This observation also made a significant remark on the exposure level to the cook as well as non-cooks having kitchen attached with living room without partition. Balakrishnan[18] *et al.*, (2004) made similar kind of 24-h monitoring study and get similar kind of results.

4.3.2 Emission after installation of ICS

During the monitoring of the three kitchen orientations with the TCS we have found that the emission level of CO and $PM_{2.5}$ were found to be almost the same in case of kitchen attached with living room without partition and the separate kitchen outside living room. Therefore for performing the intervention study, we have selected all the 27 households of kitchen attached with living room with partition and 27 households in combination of the other two types of kitchens (10 households from kitchen attached with living room without partition and 17 from the separate kitchen outside the living room). It has to be mentioned that these overall 54 households are the same households where WBT, CCT and KPT were performed after the installation of the ICS.

Monitoring for the intervention study was done after one month of the installation of ICS in the households. This monitoring was carried out during the months of September, 2008 and November, 2008. Detail results regarding the average concentration in such households with different kitchen orientations before and after installation of ICS is shown in the table 9 below alongwith WHO indoor air quality guidelines.

Table: 9.Comparison of average concentrations of the 24-h average of CO, CO_2 and $PM_{2.5}$ for different kitchen orientations before and after installation of the ICS.

	24 hour average					
	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	Percentage reduction		
				CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)
WHO Indoor air quality standard	9.00*	3500	0.025			
Before:						
Kitchen attached with living room with partition (n = 27)	9.23 (0.89)	362.56 (16.76)	2.82 (0.13)			
Kitchen attached with living room without partition (n = 27)	7.85 (0.62)	352.81 (13.36)	2.26 (0.25)			
Separate kitchen outside the living room (n = 27)	7.45 (0.70)	355 (16.32)	2.10 (0.39)			
After:						
Kitchen attached with living room with partition (n = 27)	2.75 (0.49)	284.67 (12.70)	0.78 (0.10)	70.13 (5.25)	21.33 (4.94)	70.74 (3.43)
Kitchen attached with living room without partition (n = 10)	2.30 (0.35)	280.30 (8.46)	0.62 (0.04)	71.66 (5.10)	21.16 (4.51)	74.50 (1.56)
Separate kitchen outside the living room (n = 17)	2.17 (0.30)	291.88 (11.42)	0.66 (0.10)	71.92 (3.64)	17.80 (4.72)	71.14 (4.08)

* Indoor air quality standard for CO is the 8hr average concentration as suggested by

From the results, it has been found that after installation of the ICS the average 24-h concentration of CO have been reduced by ~70 – 72%. Similarly, in case of CO_2 and $PM_{2.5}$ also the 24-h concentration was found reduced by ~18 – 21% and ~71 – 75% respectively. It is important to note that the 24-hour average concentration of CO after installation was found to be low as prescribed by the WHO guideline, but $PM_{2.5}$ concentration was still found higher than the prescribed value. In this regard we want to state that despite the decrease in 24-hour average concentration of $PM_{2.5}$ by ~71 – 75% in the entire kitchen types; outside air or humidity level also might play an important role in keeping such a higher concentration of $PM_{2.5}$ as from the October onwards to March cold season starts and similar is the case for CO_2 also.

According to a special report by Barış and Ezzati[23], 2007; an ICS dissemination program was carried out in four provinces namely, Gansu, Guizhou, Shaanxi and Inner Mongolia during 2002 – 2005. Before the intervention study, in Gansu and Inner Mongolia province brick or clay stoves were used where biomass was their fuel source. In Guizhou and Shaanxi province coal was the basic fuel source used and stove were used mainly simple metal stove (Beijing stove) and separate coal and biomass ranges, basic underground chambers stove respectively. For intervention study, they installed coal/biomass two-fuel stove where chimney extends outdoor in the Gansu households, air-circular stove in Guizhou, improved stove-bed having separate stove-bed device in Inner Mongolia and the stove with two combustion chambers for both biomass and coal having both combustion chambers with improve insulation was installed in the Shaanxi households. Their intervention study for the three provinces viz., Gansu, Guizhou and Shaanxi showed that under controlled condition the reduction of respirable particulate matter was found to be 98%, 88% and 93% respectively whereas in case of CO its found to be reduced by 88%, 66% and 75% respectively. The important point was that the concentration of the respirable particulate matter was still found higher than the WHO guidelines even after the intervention study. Similar kind of observations also found by the other researchers like Ballard-Tremeer and Juawurek[21], 1996; McCracken and Smith[120], 1998 and Bruce[41] *et al.*, 2004.

Now, the concentration level in the kitchen for CO, CO_2 and $PM_{2.5}$ will be more comparable when we consider the cooking and smouldering phase before and after intervention study which is shown in the table 10 below.

Table: 10. Comparison of average concentrations of CO, CO_2 and $PM_{2.5}$ for cooking and smouldering phase during the 24-h period in different kitchen orientations before and after installation of the ICS.

	During 24 hour period						Percentage reduction					
	Cooking period			Smouldering period			Cooking period			Smouldering period		
	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)
Before:												
Kitchen attached with living room with partition (n = 27)	23.38 (2.02)	430.89 (18.60)	5.63 (0.43)	5.40 (0.67)	240.85 (13.56)	0.82 (0.09)						
Kitchen attached with living room without partition (n = 27)	20.58 (2.28)	425.80 (21.10)	4.71 (0.34)	4.98 (0.76)	254.60 (16.43)	0.61 (0.06)						
Separate kitchen outside the living room (n = 27)	19.74 (1.92)	425.65 (13.52)	4.80 (0.23)	4.95 (0.57)	295.65 (10.78)	0.61 (0.08)						
After												
Kitchen attached with living room with partition (n = 27)	6.18 (0.98)	234.86 (18.60)	1.37 (0.26)	0.90 (0.15)	131.64 (10.15)	0.13 (0.02)	73.51 (3.88)	45.45 (2.70)	75.67 (3.62)	83.16 (3.64)	45.36 (2.63)	84.62 (2.49)
Kitchen attached with living room without partition (n = 10)	5.15 (1.03)	228.58 (16.10)	1.07 (0.13)	0.72 (0.17)	114.45 (8.56)	0.09 (0.02)	75.06 (3.45)	46.34 (2.16)	77.34 (2.23)	85.64 (2.34)	54.93 (3.66)	84.49 (3.10)
Separate kitchen outside the living room (n = 17)	5.19 (0.67)	234.99 (16.15)	1.12 (0.13)	0.79 (0.18)	133.14 (13.75)	0.09 (0.02)	73.67 (2.76)	44.82 (2.84)	76.59 (2.87)	84.07 (2.42)	55.03 (3.64)	85.18 (3.30)

As stated earlier, before the intervention it was observed that during the cooking phase the average concentration of CO, CO_2 and $PM_{2.5}$ was found to be much higher which shows the possibility of greater exposure to the people residing in the kitchen at that period. After installation of the ICS, it has been found that such concentration level decreases in a significant amount. For CO concentration it's reduced in the range by ~73% - 75% showing lower value to the WHO guidelines whereas $PM_{2.5}$ concentration is reduced by ~75% - 77% in all the three kitchen orientations showing still higher in concentration than the WHO recommendations for indoor air quality. During the smouldering phase, the scenario of reduction in the concentrations has changed a bit. In the smouldering phase, the average CO concentration was found to be reduced in the range by ~83% - 86% and $PM_{2.5}$ by ~84% – 85% in all the three kitchen orientations which was found similar to the result obtained by Ezzati[67] *et al.* (2000) when they compared the emissions of SPM and CO from traditional and improved (ceramic) biofuel stoves in Kenya under the actual conditions of household use.. During the smouldering phase, the average concentration of $PM_{2.5}$ was found to be slightly higher than the WHO guidelines for indoor air quality.

4.3.3 Structural characteristics of kitchen (in terms of roof, wall and floor) and CO, CO_2 and $PM_{2.5}$ emission

From the baseline field survey of the current work we have found a variation in the materials of roof, wall and floor in the rural households. According to the survey, we have found four types of roof materials viz., RCC, GI sheet, Asbestos, and bamboo and grass. For wall, we have found six types of materials viz., mud/dirt; cement concrete; *Ekora* and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement. In case of floor materials is concern we have got three types viz., mud/dirt, cement and brick/stone.

We have described earlier that before installation of the ICS we have monitored a total of 81 households for CO, CO_2 and $PM_{2.5}$, among which 27 households each for three different kitchen orientations except the open air kitchen.

Table: 11. Emission parameters in the three kitchen types with respect to different kitchen properties.

		24 – hour average concentration											
		Kitchen attached with living room with partition				Kitchen attached with living room without partition				Separate kitchen outside living room			
		n	CO	CO_2	$PM_{2.5}$	n	CO	CO_2	$PM_{2.5}$	n	CO	CO_2	$PM_{2.5}$
Roof	GI sheet	6	8.33 (0.45)	368.50 (18.34)	2.81 (0.16)	11	7.47 (0.53)	350.09 (10.86)	2.13 (0.31)	9	6.93 (0.52)	349.67 (16.14)	1.77 (0.35)
	Asbestos	4	8.28 (0.74)	360.25 (18.73)	2.84 (0.07)	6	7.50 (0.30)	356.67 (13.13)	2.18 (0.09)	4	7.10 (0.49)	355.00 (5.35)	1.99 (0.42)
	Grass & bamboo	17	9.77 (0.54)	361.00 (16.38)	2.82 (0.13)	10	8.47 (0.28)	353.50 (16.43)	2.45 (0.10)	14	7.89 (0.56)	358.43 (18.27)	2.34 (0.20)
Wall	*Ekora* & mud	4	9.68 (0.71)	363.75 (11.87)	2.77 (0.11)	10	7.73 (0.60)	348.00 (13.94)	2.25 (0.27)	4	7.20 (0.86)	344.75 (19.26)	1.98 (0.46)
	Bamboo & mud	6	9.22 (1.06)	361.17 (21.37)	2.85 (0.18)	4	8.13 (0.41)	363.25 (15.92)	2.30 (0.15)	2	7.80 (0.42)	354.00 (15.56)	2.44 (0.35)
	Wood, bamboo & mud	11	8.84 (0.86)	367.55 (13.91)	2.82 (0.14)	9	8.01 (0.48)	353.56 (11.81)	2.37 (0.17)	14	7.61 (0.73)	359.14 (16.21)	2.19 (0.34)
	Wood, bamboo & cement	6	9.67 (0.72)	354.00 (19.66)	2.83 (0.09)	4	7.50 (1.04)	352.75 (10.72)	2.01 (0.34)	7	7.17 (0.56)	352.86 (15.60)	1.89 (0.40)
Floor	Mud/dirt	22	9.23 (0.80)	362.36 (16.53)	2.82 (0.14)	17	7.63 (0.58)	353.76 (14.39)	2.18 (0.27)	20	7.48 (0.64)	352.35 (17.47)	2.11 (0.41)
	Cement	5	9.22 (1.34)	363.40 (19.77)	2.82 (0.08)	10	8.22 (0.52)	351.20 (11.98)	2.39 (0.15)	7	7.39 (0.89)	362.57 (9.90)	2.09 (0.33)

Here, we have made an attempt whether there is a change in the 24 average level of concentration of CO, CO_2 and $PM_{2.5}$ or not depending on the materials of roof, wall and floor. Among the 81 kitchens where monitoring was carried out for CO, CO_2 and $PM_{2.5}$ we have found three types of roof materials i.e., GI sheet, asbestos and grass and bamboo. Moreover, four types of wall materials were found viz., *Ekora* and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement whereas in case floor two types were found i.e., mud/dirt and cement.

From the analysis, it has been found that for all the three kinds of roof materials 24-hour average concentration of CO and $PM_{2.5}$ was more in the kitchen attached with living room with partition than the other two types. In case of other two types of kitchen orientations, average concentration of CO and $PM_{2.5}$ were found to be little bit more in the kitchen attached with living room without partition in comparison to the separate kitchen outside the living room for all the three types of building materials. Moreover, the roof having made up with grass and bamboo, the 24-hour average concentration of CO was found to be more in all kitchen orientations in comparison to the GI sheet and asbestos roof. This is because of the fact that kitchen having roof materials with grass (thatch) and bamboo are having high humidity (21 – 28 °C and 74 – 89%) and low inside air temperature in comparison to the GI sheet and Asbestos (26 – 36 °C and 67 – 75%) was observed. It has also to be mentioned that the dimension of the kitchen attached with living room with partition was normally found smaller than the kitchen attached with living room without partition as described earlier (Results and discussion, Part I). Hence, combined effect of inadequate ventilation, high indoor humidity and less air exchange between indoor and outdoor results higher $PM_{2.5}$ concentration in the kitchen attached with living room with partition than the other two types. Like roof materials, for all the four kinds of wall materials 24-hour average concentration of CO and $PM_{2.5}$ was more in the kitchen attached with living room with partition than the other two types. In case of other two types of kitchen orientations, 24-hour average concentration of CO and $PM_{2.5}$ were found almost similar to each other for all the four types of building materials. In case of floor materials also, 24-hour average concentration of CO and $PM_{2.5}$ was found to be more in the kitchen attached with living room with partition than the other two types while in between building materials no difference was observed.

Relating to the structural characteristics it was also observed that regarding the various dimensions of the kitchen in all the three types that found from the baseline field survey, no emission level difference was observed.

4.3.4 Emission from the stove and the kitchen ventilation condition

In the chapter 4, part I; we have stated that during the baseline survey we have found two types of ventilations in the rural kitchens. First one was the A4 sheet size small windows and the second one was with the dimensions of 1m × 1m and 1m × 1½m by breadth and height. In our study, we have considered the kitchen without having such ventilation as poorly ventilated kitchen, kitchens having small windows with A4 size as moderately ventilated and the ventilation of the kitchens were considered to be good/adequate; which are having the windows with dimensions of 1m × 1m and 1m × 1½m.

In table 12, the average 24-hour concentration of CO, CO_2 and $PM_{2.5}$ in terms of poor, moderate and good ventilation condition in the three kitchen orientations before and after the intervention study is shown. Among the 81 households, where monitoring was done before the intervention study, 40 kitchens were found to be poorly ventilated, 27 was found to be moderately ventilated and 14 kitchen were having good ventilation condition. Intervention study was carried out in 54 selected households which were previously monitored, among which 35 kitchens were poorly ventilated, 14 are moderately ventilated and only 5 kitchens were having good/adequate ventilation. It needs to be mentioned that these 54 kitchens are the same where ICS was installed. Based on the above observations, it has been found that the concentration of CO and $PM_{2.5}$ was found to be more in the kitchen attached with living room with partition in all the three types of ventilation conditions in comparison to the other two type's viz., kitchen attached with living room without partition and the separate kitchen outside the living room.

The result also clearly indicates that an improvement in the ventilation condition reduces the pollutants level in the indoors considerably. From poor ventilation to the good ventilation condition, the result shows around 20% reduction in the concentration of CO whereas 30% - 37% in case of $PM_{2.5}$ was observed. This result shows the similarity with the work carried out by Still and MacCarty[197] (2006), who states that increasing amounts of ventilation significantly reduced the levels of CO and particulate matter.

Table: 12. Average 24-hour concentration of CO, CO_2 and $PM_{2.5}$ in terms of poor, moderate and good ventilation condition in the three kitchen orientations before and after the intervention study.

	Kitchen attached with living room with partition			**Kitchen attached with living room without partition**			**Separate kitchen outside the living room**		
	24 hour average								
	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)	CO (ppm)	CO_2 (ppm)	$PM_{2.5}$ (mg/m^3)
Before:									
Poor (n =40)	9.73 (0.55)	361.33 (15.96)	2.82 (0.13)	8.29 (0.34)	353.47 (14.24)	2.43 (0.09)	8.37 (0.39)	357.29 (19.81)	2.54 (0.08)
Moderate (n = 27)	8.58 (0.22)	364 (17.76)	2.75 (0.08)	7.44 (0.20)	352.60 (13.99)	2.14 (0.04)	7.43 (0.24)	354.50 (16.35)	2.19 (0.07)
Good (n = 14)	7.78 (0.34)	366.25 (23.24)	2.00 (0.18)	6.55 (0.21)	349 (2.83)	1.58 (0.08)	6.68 (0.20)	353.75 (15.04)	1.58 (0.14)
After:									
Poor (n =35)	2.89 (0.38)	291.44 (11.28)	0.81 (0.08)	2.30 (0.35)	280.30 (8.46)	0.62 (0.04)	2.33 (0.31)	293.43 (13.84)	0.69 (0.09)
Moderate (n = 14)	2.82 (0.48)	284.40 (5.77)	0.78 (0.09)	—	—	—	2.10 (0.22)	288.44 (7.14)	0.66 (0.08)
Good (n = 5)	2.00 (0.26)	267 (4.32)	0.63 (0.04)	—	—	—	1.7	262	0.44

Key findings:

- *The concentration of 24-hour average CO and $PM_{2.5}$ was found to be more in the kitchen attached with living room with partition in comparison to the other two types.*
- *The 24-h concentration level was found much higher in concentration than the WHO air quality guidelines global update 2005.*
- *The 24-hour concentration of CO_2 was found almost similar in all the three types of the kitchens and was found much below the exposure guidelines for residential indoor air quality, Federal-Provincial Advisory Committee on Environmental and Occupational Health, Canada.*
- *During the cooking period the average concentration for CO, CO_2 and $PM_{2.5}$ were found much higher than the smouldering period showing the greater exposure particularly to the cook and the people resides in the kitchen during the cooking period in case of all the three types of kitchens.*
- *Time activity table shows that children ≤ 5 years of age and the woman in the age-group 19 – 50 years has the highest potential to the exposure of indoor smoke as they have spend most of their times in the kitchen or in the living room.*
- *The intervention study shows a significant reduction in the 24-hour average concentration in CO and $PM_{2.5}$ (~70 % - 72% and ~71 – 75% respectively) although concentration of CO_2 decreases to a little extent.*
- *After installation of the ICS, the 24-hour average concentration of CO was found low as prescribed by the WHO guideline, but $PM_{2.5}$ concentration was still found higher than the prescribed value.*
- *For the cooking period, the reduction in the concentration of CO and $PM_{2.5}$ was found to be ~73% – 75% and ~75% - 77% respectively although the concentration of $PM_{2.5}$ was found still higher than the WHO guidelines; whereas in case of smouldering period it was found to be reduced by 83% - 86% for CO and 84% - 85% for $PM_{2.5}$.*
- *For all the three types of roof materials viz., GI sheet; asbestos; and grass and bamboo; CO and $PM_{2.5}$ concentration was found to be more in the kitchen*

attached with living room with partition than the other two types that have been studied whereas it was found to be lowest in separate kitchen outside living room.

- *Among the three roof materials, concentration of CO and $PM_{2.5}$ was found to be highest in grass and bamboo for all the three kitchen types.*
- *Considering all the four types wall materials viz., Ekora and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement; CO and $PM_{2.5}$ concentration was found to be more in the kitchen attached with living room with partition than the other two types whereas the CO and $PM_{2.5}$ concentration was found to be lowest in separate kitchen outside living room except for wall material bamboo and mud.*
- *Similarly, a floor material with mud/dirt and cement shows the same trend like roof and wall materials.*
- *Hence, the kitchen in the living room with partition shows the highest 24-hour average concentration of CO and $PM_{2.5}$ whereas separate kitchen outside the living room is the lowest.*
- *Considering the building materials, kitchen having roof material with grass and bamboo; and the wall material with Ekora and mud have the highest concentration of CO and $PM_{2.5}$ concentration whereas kitchens having roof materials with GI sheet and wall materials with wood, bamboo and cement have the lowest CO and $PM_{2.5}$ concentration.*
- *From poor ventilation to the good ventilation condition (based on our study) emission level of CO was reduced by 20% whereas the $PM_{2.5}$ concentration was reduced by 30% – 37%.*

PART IV

Statistical Analysis and Experimental findings

From the previous three parts of results and discussions we have got several important variables which are responsible for the indoor air quality of a household and design. The major variables are the emission levels, stove types, types of fuel used, ventilation and the kitchen types such as kitchen orientation etc. In this chapter we will discuss the results of the statistical analysis of such experimental variables.

4.4.1 Stove performance tests

4.4.1.1 Water boiling test (WBT)

As described earlier, WBT includes a high-power (fast-boil) phase and a low-power (simmer) phase. Furthermore, high-power phase also have two sub-phases namely- cold start and hot start which signifies that the test were performed at the cold and hot condition respectively. Each phase yields a number of stove performance indicators including time to boil a fixed quantity of water, fuel consumption per unit of boiled water, burning rate, fire power and the efficiency. Table 13 shows the relative changes in stove performance between the improved cookstove and the two types of traditional cookstoves that have been considered for the current studies.

In high power hot start when the data of different properties such as specific fuel consumption, burning rate, firepower and efficiency of the two types of TCS was pooled with the similar variable data of the ICS, it gives statistically highly significant result ($p = 0.01$), whereas during the cold and simmer phase it was also found significant at $p = 0.05$ except few variables (Table 13). It was found that although in the cold phase the time to boil, specific fuel consumption was reduced whereas burning rate, fire power and efficiency was increased in case of ICS in comparison to the TCS considerably; but during the hot phase such changes were found to be more. In the simmer phase also, again specific fuel consumption was found reduced along with the burning rate and fire power but turn down ratio was found to be increased considerably.

Table: 13. Percentage changes in performance of improved stove relative to traditional stove for selected indicators.

			Traditional stove A and Improved stove A (n = 27)					Traditional stove B and Improved stove B (n = 27)				
			% difference	Mean	St. Dev.	t	Sig. (2-tailed)	% difference	Mean	St. Dev.	t	Sig. (2-tailed)
High power test	Cold start	Time	-31.38	6.60	2.41	14.25	**	-31.36	6.43	1.31	25.43	**
		Burning rate	33.04	3.71	1.53	12.63	**	33.23	3.99	1.24	16.73	**
		Sp. fuel consumption	-39.16	71.1	15.34	24.08	**	-35.61	65.8	13.14	26.05	**
		Fire power	39.05	1110	698.78	8.24	***	32.78	1060	588.53	9.36	***
		Efficiency	376.62	18.7	1.83	52.91	***	513.42	19.8	1.20	85.99	***
	Hot start	Time	-38.53	6.13	1.96	16.27	***	-33.69	5.18	1.82	14.82	***
		Burning rate	31.76	4.20	2.48	8.79	***	27.94	3.84	1.86	10.71	***
		Sp. fuel consumption	-45.06	71.3	19.45	19.06	***	-40:15	63.4	19.19	17.16	***
		Fire power	37.88	1220	827.86	7.64	***	26.93	992	594.55	8.67	***
		Efficiency	221.37	18.9	2.68	36.70	***	504.10	23.7	1.65	74.68	***
Low power test	Simmering	Burning rate	-28.96	3.32	1.02	16.90	**	-35.52	4.36	1.40	16.16	**
		Sp. fuel consumption	-14.90	59.2	38.47	7.99	**	-14.91	59.6	45.77	6.77	**
		Fire power	-25.82	817	532.89	7.96	**	-35.66	1280	574.25	11.56	**
		Efficiency	244.80	10.7	2.33	23.80	**	383.11	12.9	3.27	20.50	**
		TDR	87.22	1.01	0.34	15.45	***	101.70	1.17	0.33	18.22	***

Notes:
Cases in which ICS is significant relative to TCS at p = 0.01 are shown as *** and p = 0.05 as **, where p refers to the probability that the observed difference occurred by chance. By convention, p = 0.05 indicates that a finding is statistically significant.

"-ve" sign in the % difference indicates reduction in ICS than TCS and vice versa.

4.4.1.2 Controlled cooking test (CCT) and Kitchen performance test (KPT)

Earlier we have analyzed the results of the 54 households where CCT and KPT were performed before and after the installation of the improved stoves. The results were shown in the table 6, table 7, figure 33, figure 34, figure 35 and in figure 36. From CCT, we have got two main indicators viz., time to prepare a fixed amount of food and specific fuel consumption, whereas in KPT we have considered three parameters as the indicator viz., wet wood consumed per capita per day, dry wood consumed per capita per day and energy consumed per capita per day.

For doing the analysis, we have performed the 2-tailed pair test for the evaluation of the significant differences of the study i.e. between the results of before and after installation of the improved cookstoves.

From the statistical analysis of the CCT, it has been found that for both the indicator such as time to prepare a fixed amount of food and specific fuel consumption the results shows highly significance when compared to the both types of traditional cookstoves to the improved stoves at 95% confidence interval. The results are shown in the table 14 below.

Similarly, in KPT also all the three parameters viz., wet wood consumed per capita per day, dry wood consumed per capita per day and energy consumed per capita per day were found to be statistically significant were compared to the mean difference of the result before and after the installation of the improved cookstoves at 95% confidence interval. The results were summarized in the table 14 below.

4.4.2 Kitchen orientation and CO, CO_2, $PM_{2.5}$ emission

As we have stated earlier that we have considered three kitchen orientations for the emission studies viz., kitchen attached with living room with partition, kitchen attached with living room without partition and separate kitchen outside the living room. For representing the data we have performed Wilcoxon signed rank test for evaluation of significant difference among the emission parameters depending on the kitchen orientations.

Table: 14. Percentage changes in performance of improved stove relative to traditional stove for selected indicators during CCT and KPT.

		Traditional stove A and Improved stove (n = 27)					Traditional stove B and Improved stove (n = 27)				
		% difference	Mean	St. Dev.	t	Sig. (2-tailed)	% difference	Mean	St. Dev.	t	Sig. (2-tailed)
CCT	Time	38.23	10.9	1.96	28.98	0.000	33.21	8.95	1.92	24.23	0.000
	Sp. fuel consumption	28.43	0.92	0.41	11.83	0.000	22.99	0.61	0.26	12.25	0.000
KPT	Wet wood consumed per capita/day	31.10	0.32	0.05	35.20	0.000	34.08	0.36	0.09	21.80	0.000
	Dry wood consumed per capita/day	31.19	0.28	0.04	32.37	0.000	33.37	0.30	0.07	22.20	0.000
	Energy consumption per capita/day	34.57	0.84	0.40	10.93	0.000	36.75	0.90	0.41	11.36	0.000

Dutta[60] *et al.*, 2007, also carried out similar kind of analysis for the comparison of TCS with some different types of stoves like *Lakshmi*, *Bhagyalaxmi* stoves. The results of our analysis were summarized in the table 15 below.

In our study for intervention study, 54 households have been participated among which 27 households were having kitchen attached with living room with partition, 10 households were having kitchen attached with living room without partition and 17 households have their kitchen separated outside the living room.

From the statistical analysis it has been seen that emission data of improved cook stove showed a significant reduction in mean by 70.79% ($p < 0.000$) in $PM_{2.5}$, 70.21% in CO ($p < 0.000$) and 21.49% in CO_2 ($p < 0.000$) when all the households having kitchen attached with living room with partition were pooled together (table 15). Similarly, in case of separate kitchen outside the living room improved cookstoves also showed significant reduction in mean 71.18% ($p < 0.000$) in $PM_{2.5}$, 72.01% in CO ($p < 0.000$) and 17.98% in CO_2 ($p < 0.000$) and finally when all the households having kitchen attached with living room without partition were pooled together here also improved cookstoves showed a significant reduction of 74.49% ($p < 0.004$) in $PM_{2.5}$, 71.85% in CO ($p < 0.005$) and 21.35% for CO_2 ($p < 0.004$) in mean.

We have also made a comparative statistical analysis of emission level and the three kitchen orientation that have been measured before the intervention study with the motive that whether there was any significant difference between the emission level of CO, CO_2 and $PM_{2.5}$ when considered with two different kitchen orientations. The summary of the results are shown in the table 16 below.

From the result it has been found interesting that when we pooled the data of kitchen attached with living room with partition with kitchen attached with living room without partition and similarly kitchen attached with living room with partition with separated kitchen outside the living room particularly for $PM_{2.5}$ and CO they showed a highly significant results ($p < 0.000$) at 95% confidence level.

Most interestingly, it has been found that when the emissions of CO, $PM_{2.5}$ and CO_2 for kitchen attached with living room with partition is pooled with other two types the t-values found to be more. This is because of the fact that emission level in the kitchen attached with living room with partition has higher value than the others two. We have already stated earlier that the dimension of the kitchen attached with living room without partition has found to be more than the kitchen attached with living room with partition. Besides these, ventilation condition in kitchen attached with living room without partition has more adequate than the kitchen attached with living room with partition. Hence, circulation of air or the air exchange ratio between indoor and outdoor is more prominent in kitchen attached with living room without partition. Similar is the case with separate kitchen outside the living room too.

Table: 15. Comparison of ICS with the TCS with respect to the emission parameters of three kitchen types.

Kitchen type	Pollutants	Before				After				t	p-value (Wilcoxon rank test)	Mean percentage change
		N	Mean	St. Dev.	Maximum	N	Mean	St. Dev.	Maximum			
Kitchen with partition	$PM_{2.5}$ (mg/m^3)	27	2.67	0.32	3.06	27	0.78	0.09	0.94	-4.54	0.000	70.79
	CO (ppm)	27	9.23	0.89	10.80	27	2.75	0.49	3.80	-4.54	0.000	70.21
	CO_2 (ppm)	27	363	16.76	389.00	27	285	12.70	389.00	-4.54	0.000	21.49
Kitchen without partition	$PM_{2.5}$ (mg/m^3)	10	2.43	0.10	2.58	10	0.62	0.04	0.67	-2.80	0.004	74.49
	CO (ppm)	10	8.17	0.58	8.70	10	2.30	0.35	2.90	-2.81	0.005	71.85
	CO_2 (ppm)	10	356	15.42	381.00	10	280	8.46	292.00	-2.81	0.004	21.35
Separate kitchen outside	$PM_{2.5}$ (mg/m^3)	17	2.29	0.3	2.69	17	0.66	0.10	0.84	-3.62	0.000	71.18
	CO (ppm)	17	7.75	0.64	9.10	17	2.17	0.30	2.70	-3.63	0.000	72.01
	CO_2 (ppm)	17	356	15.74	386.00	17	292	11.42	313.00	-3.62	0.000	17.98

Table: 16. Comparison of kitchen orientations in terms of emission level of $PM_{2.5}$, CO and CO_2.

Pollutants	**Kitchen type**	**N**	**Mean**	**St. Dev.**	**t**	**p-value (Wilcoxon rank test)**
$PM_{2.5}$ (mg/m^3)	KAWLWP - KAWLWOP	27	0.56	0.27	10.67	0.000
	KAWLWP – SKOLR	27	0.72	0.45	8.38	0.000
	KAWLWOP - SKOLR	27	0.16	0.48	1.72	0.098
CO (ppm)	KAWLWP - KAWLWOP	27	1.38	1.09	6.58	0.000
	KAWLWP – SKOLR	27	1.78	1.17	7.92	0.000
	KAWLWOP - SKOLR	27	0.39	0.89	2.33	0.028
CO_2 (ppm)	KAWLWP - KAWLWOP	27	9.74	21.04	2.41	0.024
	KAWLWP – SKOLR	27	7.56	21.58	1.82	0.080
	KAWLWOP - SKOLR	27	2.19	21.08	0.54	0.595

Note: KAWLWP – Kitchen attached with living room with partition,
KAWLWOP – Kitchen attached with living room with partition.
SKOLR – Separate kitchen outside the living room.

4.4.3 Kitchen characteristics and CO, CO_2, $PM_{2.5}$ emission

As described in the previous chapter (Chapter IV, Part III), during the field survey we have found a variation in the kitchen characteristics in terms of different building materials of roof, wall and floor. We have pooled the emission data of CO, CO_2 and $PM_{2.5}$ for two kitchen orientations together according to the building materials of roof, wall and floor of the kitchen and than analyzed the significant differences.

Table: 17. Comparison of roof materials and 24-hour average concentration of CO, CO_2 and $PM_{2.5}$.

			N	Mean	St. Dev	t	p- value
GI sheet	CO	KAWLWP - KAWLWOP	6	1.07	0.85	3.06	0.028
		KAWLWP – SKOLR	6	1.33	0.40	8.10	0.000
		KAWLWOP - SKOLR	9	0.50	0.94	1.59	0.151
	CO_2	KAWLWP - KAWLWOP	6	19.8	22.36	2.17	0.082
		KAWLWP – SKOLR	6	15.5	27.68	1.37	0.229
		KAWLWOP - SKOLR	9	0.33	14.44	-0.069	0.946
	$PM_{2.5}$	KAWLWP - KAWLWOP	6	0.83	0.36	5.68	0.002
		KAWLWP – SKOLR	6	0.92	0.45	5.08	0.004
		KAWLWOP - SKOLR	9	0.33	0.56	1.76	0.117
Asbestos	CO	KAWLWP - KAWLWOP	4	0.80	0.45	3.52	0.039
		KAWLWP – SKOLR	4	1.17	0.59	3.98	0.028
		KAWLWOP - SKOLR	4	0.37	0.19	1.94	0.147
	CO_2	KAWLWP - KAWLWOP	4	2.75	28.92	-0.19	0.861
		KAWLWP – SKOLR	4	5.25	21.28	0.49	0.656
		KAWLWOP - SKOLR	4	8.00	8.48	1.89	0.156
	$PM_{2.5}$	KAWLWP - KAWLWOP	4	0.63	0.16	7.99	0.004
		KAWLWP – SKOLR	4	0.85	0.49	3.49	0.004
		KAWLWOP - SKOLR	4	0.22	0.37	1.17	0.325
Grass and bamboo	CO	KAWLWP - KAWLWOP	10	1.34	0.57	7.46	0.000
		KAWLWP – SKOLR	14	1.89	0.71	10.04	0.000
		KAWLWOP - SKOLR	10	0.53	0.63	2.66	0.026
	CO_2	KAWLWP - KAWLWOP	10	8.10	30.65	0.84	0.425
		KAWLWP – SKOLR	14	3.86	23.61	0.61	0.551
		KAWLWOP - SKOLR	10	1.50	27.18	0.17	0.865
	$PM_{2.5}$	KAWLWP - KAWLWOP	10	0.36	0.13	8.47	0.000
		KAWLWP – SKOLR	14	0.46	0.23	7.63	0.000
		KAWLWOP - SKOLR	10	0.09	0.24	1.16	0.275

Table: 18. Comparison of wall materials and 24-hour average concentration of CO, CO_2 and $PM_{2.5}$.

			N	Mean	St. Dev	t	p- value
Ekora and mud	CO	KAWLWP - KAWLWOP	4	1.85	0.85	4.35	0.022
		KAWLWP – SKOLR	4	2.47	0.91	5.44	0.012
		KAWLWOP - SKOLR	4	0.63	1.01	1.23	0.306
	CO_2	KAWLWP - KAWLWOP	4	12.2	19.45	1.26	0.297
		KAWLWP – SKOLR	4	19.0	27.34	1.39	0.259
		KAWLWOP - SKOLR	4	6.75	25.55	0.53	0.634
	$PM_{2.5}$	KAWLWP - KAWLWOP	4	0.45	0.21	4.33	0.023
		KAWLWP – SKOLR	4	0.78	0.43	3.64	0.036
		KAWLWOP - SKOLR	4	0.34	0.49	1.37	0.264
Bamboo and mud	CO	KAWLWP - KAWLWOP	4	1.07	1.55	1.39	0.258
		KAWLWP – SKOLR	2	1.90	1.27	2.11	0.282
		KAWLWOP - SKOLR	2	0.30	0.28	1.50	0.374
	CO_2	KAWLWP - KAWLWOP	4	12.7	30.18	-0.85	0.460
		KAWLWP – SKOLR	2	7.50	2.12	5.00	0.126
		KAWLWOP - SKOLR	2	4.00	11.31	-0.50	0.705
	$PM_{2.5}$	KAWLWP - KAWLWOP	4	0.51	0.28	3.66	0.035
		KAWLWP – SKOLR	2	0.35	0.62	0.79	0.572
		KAWLWOP - SKOLR	2	0.21	0.15	-1.95	0.301
Wood, bamboo and mud	CO	KAWLWP - KAWLWOP	9	0.86	0.95	2.70	0.027
		KAWLWP – SKOLR	11	1.16	1.08	3.59	0.005
		KAWLWOP - SKOLR	9	0.36	0.78	1.36	0.211
	CO_2	KAWLWP - KAWLWOP	9	14.2	21.66	1.97	0.084
		KAWLWP – SKOLR	11	9.91	19.11	1.72	0.116
		KAWLWOP - SKOLR	9	8.78	19.78	-1.33	0.220
	$PM_{2.5}$	KAWLWP - KAWLWOP	9	0.47	0.11	12.42	0.000
		KAWLWP – SKOLR	11	0.61	0.30	6.69	0.000
		KAWLWOP - SKOLR	9	0.19	0.10	1.98	0.083
Wood, bamboo and cement	CO	KAWLWP - KAWLWOP	3	2.20	1.65	2.31	0.148
		KAWLWP – SKOLR	6	2.40	1.19	4.94	0.004
		KAWLWOP - SKOLR	3	0.77	0.59	2.27	0.152
	CO_2	KAWLWP - KAWLWOP	3	11.0	25.21	0.87	0.447
		KAWLWP – SKOLR	6	1.67	18.60	0.22	0.835
		KAWLWOP - SKOLR	3	7.75	13.38	-1.16	0.330
	$PM_{2.5}$	KAWLWP - KAWLWOP	3	0.84	0.43	3.88	0.030
		KAWLWP – SKOLR	6	0.91	0.45	4.91	0.004
		KAWLWOP - SKOLR	3	0.01	0.58	-0.04	0.968

Table: 19. Comparison of floor materials and 24-hour average concentration of CO, CO_2 and $PM_{2.5}$.

			N	Mean	St. Dev	t	p- value
Mud/dirt	CO	KAWLWP - KAWLWOP	17	1.66	0.94	7.34	0.000
		KAWLWP – SKOLR	20	1.81	1.14	7.08	0.000
		KAWLWOP - SKOLR	17	0.07	0.86	0.34	0.741
	CO_2	KAWLWP - KAWLWOP	17	8.65	24.99	1.43	0.173
		KAWLWP – SKOLR	20	9.00	20.64	1.95	0.066
		KAWLWOP - SKOLR	17	1.00	21.49	0.19	0.850
	$PM_{2.5}$	KAWLWP - KAWLWOP	17	0.64	0.29	9.26	0.000
		KAWLWP – SKOLR	20	0.72	0.49	6.61	0.000
		KAWLWOP - SKOLR	17	0.001	0.48	0.01	0.992
Cement	CO	KAWLWP - KAWLWOP	5	0.78	1.33	1.31	0.259
		KAWLWP – SKOLR	5	1.88	1.05	3.99	0.016
		KAWLWOP - SKOLR	7	0.89	1.01	2.32	0.060
	CO_2	KAWLWP - KAWLWOP	5	16.6	14.98	2.48	0.068
		KAWLWP – SKOLR	5	3.40	26.88	0.28	0.791
		KAWLWOP - SKOLR	7	9.57	13.62	-1.86	0.112
	$PM_{2.5}$	KAWLWP - KAWLWOP	5	0.38	0.10	8.39	0.001
		KAWLWP – SKOLR	5	0.79	0.41	4.29	0.013
		KAWLWOP - SKOLR	7	0.33	0.41	2.10	0.080

In case of roof, results showed that (Table 11) the 24-hour average concentration of CO and $PM_{2.5}$ was found to be more in the kitchen attached with living room with partition than the other two types for all the three roof types i.e., for GI sheet; asbestos; and grass and bamboo. In case of CO_2, no such variation was found for all the types of the kitchen. Hence, when we pooled the data emission of kitchen attached with living room with partition with other two types for CO and $PM_{2.5}$, we have found a highly significant difference for all the three types of building roof materials (Table 17).

In case of wall, we have got four different building materials i.e., *Ekora* and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement. Here, the scenario found to be different unlike the roof building materials. It has been found that for the kitchen where the wall materials was built with wood, bamboo and mud; when the data of $PM_{2.5}$ was pooled between the kitchen attached with living room with partition with other two types it shows a highly significant difference ($p < 0.000$) (Table 18).

In case of two types floor materials namely mud/dirt and cement, for CO and $PM_{2.5}$ when data was pooled between the kitchen attached with living room with partition against the other two types of kitchen; it shows a highly significant results ($p < 0.000$) (Table 19).

4.4.4 Kitchen ventilation condition and CO, CO_2 and $PM_{2.5}$ emission

From the discussion of the previous chapter (Chapter IV, Part III), we have come into conclusion that ventilation is an important factor for the improvement of indoor air quality. The result shows around 20% reduction in the concentration of CO and 30% - 37% in case of $PM_{2.5}$ from poor ventilation to the good ventilation condition.

Table: 20. Comparison of statistical parameters with respect to the 24-hour average concentration of CO, CO_2 and $PM_{2.5}$ and ventilation conditions.

			N	Mean	St. Dev	t	p- value
Before intervention	CO	Poor - Moderate	27	1.61	0.86	9.77	0.000
		Poor - Good	14	2.81	0.81	12.94	0.000
		Moderate - Good	14	0.88	0.41	7.98	0.000
	CO_2	Poor - Moderate	27	3.67	23.74	0.80	0.429
		Poor - Good	14	5.64	19.35	1.09	0.295
		Moderate - Good	14	0.50	27.18	0.07	0.946
	$PM_{2.5}$	Poor - Moderate	27	0.41	0.32	6.67	0.000
		Poor - Good	14	1.11	0.29	14.49	0.000
		Moderate - Good	14	0.66	0.22	11.31	0.000
After intervention	CO	Poor - Moderate	14	0.51	0.57	3.33	0.005
		Poor - Good	5	0.98	0.43	5.14	0.007
		Moderate - Good	5	0.88	0.70	2.81	0.049
	CO_2	Poor - Moderate	14	3.50	15.91	0.82	0.425
		Poor - Good	5	29.8	10.89	6.12	0.004
		Moderate - Good	5	18.4	4.04	10.19	0.001
	$PM_{2.5}$	Poor - Moderate	14	0.11	0.12	3.21	0.007
		Poor - Good	5	0.25	0.12	4.89	0.008
		Moderate - Good	5	0.18	0.71	5.77	0.004

Table 20 shows the comparison of statistical indicators when the data of CO, CO_2 and $PM_{2.5}$ is pooled in between two different ventilation conditions. It has been found from the analysis that for all the combination of ventilation conditions CO and $PM_{2.5}$ emissions shows statistically highly significant difference ($p < 0.000$) whether considering the emission data before the installation of the improved cookstoves into the households. The analysis with the emission data after the intervention study also shows statistically significant results for CO and $PM_{2.5}$ (Table 20) Hence, statistical analysis of such observation proves the importance of ventilation condition for indoor air quality improvement.

Key findings:

- *In high power hot start when the data of different properties such as sp. fuel consumption, burning rate, firepower and efficiency of the two types of traditional cookstoves was pooled with the data of the improved cookstoves, it gives statistically highly significant result ($p = 0.01$), but during the cold and simmer phase it was significantly more efficient at $p = 0.05$.*
- *From the statistical analysis of the CCT, it has been found that for both the indicator such as time to prepare a fixed amount of food and specific fuel consumption the results shows highly significance when compared to the both types of traditional cookstoves to the improved stoves at 95% confidence interval.*
- *Similarly, in KPT also all the three parameters viz., wet wood consumed per capita per day, dry wood consumed per capita per day and energy consumed per capita per day were found to be statistically significant when compared to the difference in mean before and after the installation of the improved cookstoves at 95% confidence interval.*
- *Considering the kitchen orientation; statistical analysis shows significant reduction in mean for CO and $PM_{2.5}$ for all the three types of kitchens.*
- *It has been found interesting that when we pooled the data of kitchen attached with living room with partition with kitchen attached with living room without partition and similarly kitchen attached with living room with partition with separated kitchen outside the living room particularly for $PM_{2.5}$ and CO they showed a highly significant results ($p < 0.000$) at 95% confidence level.*
- *When we pooled the data considering the roof materials and the emission of kitchen attached with living room with partition with other two types for CO and*

$PM_{2.5}$, we have found a highly significant difference for all the three types of building roof materials; but for CO_2, no such variation was found for all the types of the kitchen.

- *In between kitchen attached with living room without partition and separated kitchen outside the living room no statistical difference was observed showing similar concentration level between them.*
- *For the kitchen where the wall materials was built with wood, bamboo and mud; when the data of $PM_{2.5}$ was pooled between the kitchen attached with living room with partition with other two types it shows a highly significant difference ($p < 0.000$).*
- *In case of two types floor materials namely mud/dirt and cement, for CO and $PM_{2.5}$ when data was pooled between the kitchens attached with living room with partition against the other two types of kitchen; it shows a highly significant results ($p < 0.000$).*
- *For all the combination of ventilation conditions CO and $PM_{2.5}$ emissions shows statistically significant difference before ($p < 0.000$) and after ($p < 0.005$) installation of the improved cookstoves into the households.*

CHAPTER V

SUMMARY

CHAPTER – V

Summary

The study presented here was designed to add to the foundation of knowledge which will enable the development of sustainable IAP interventions customized to the local conditions particularly in the rural areas. Because IAP exposure is a major health risk requiring public and community involvement, effective interventions must encompass both technological and behavioral elements. The results of the current study that shows the effectiveness of the interventions will contribute to a better understanding of how household energy technology interacts in reducing exposure and the socio-economic status deals with the use of fuel sources.

As discussed in the Part I of chapter IV, preliminary baseline survey was conducted in a total of 1268 numbers of households in ten rural villages of Sonitpur district of Assam to find the data related to the population, kitchen and household characteristics, income level of the households, types of cookstoves they used and the types of fuel they preferred for cooking and lighting. These findings reveal the basic background to implement our intervention study and to assess their socio-economic parameters.

From the population profile we have found that in the ten villages 9.82 % of population were found the children of ≤ 5 years of age. This gives us a significant information that such population is vulnerable to the IAP exposure as stated by most of the researchers (Misra[126], 2003a; Ezzati and Kammen[66], 2001; Robin[172], *et al.*,1996; Armstrong[12], *et al.*, 1991; Pandey[152], *et al.*, 1989; Kossove[98], 1982) that children of ≤ 5 years of age spends most of their time indoors. After analysis of the time activity data for the households peoples it also confirms that children of ≤ 5 years of age in the study area spends most of the time in indoor whether during the cooking period of non-cooking period (Table 9).

Regarding the income level of the households, it has been found that primary sector which comprises with agriculture, labour, animal husbandry, orchard and plantation dominates the most for the households followed by the tertiary sector of the income that comprises with trade and commerce along with service (Table 3). It is important to note that the per capita income per year for the ten villages was found well below the national average. Hence, the result indicates that the economic condition of most of the households was found to be poor. We have also made an analysis based on the survey data on household income and fuel use and the result found similar with the energy ladder hypothesis that improvement in the economic (income) status of the household makes the movement of energy consumption from traditional sources to more sophisticated sources.

Our study was designed for the emission level in the kitchen that occurs during the combustion of firewood. Our baseline data showed that 57.81% of the rural households used firewood as their preliminary fuel source (Figure 19) and 75% of the households used traditional cookstoves for their cooking purposes (Figure 18). Regarding the kitchen characteristics, baseline survey shows the presence of four types of kitchens viz. kitchen attached with living room with partition (KAWLWP), kitchen attached with living room without partition (KAWLWOP), separate kitchen outside the living room (SKOLR), and open air kitchen (OK) among which except open air kitchen, other three types of kitchen contributes more than 99% of the households. Therefore, we have discarded the open air kitchen from our study. Before going for emission studies we had performed WBT, KPT and CCT study with the traditional cookstoves in some selected households having such three types of kitchens. Since, we have found two types TCS as described in the Chapter IV, part II, WBT, KPT and CCT was performed for both the types. Same tests were further repeated with the ICS after installation in some selected households.

Simply introducing an ICS, however, does not guarantee that positive outcomes will be achieved. Utilizing the ICS to mitigate negative impacts of solid biomass consumption involves a dual challenge. First, there is a design problem: a technically appropriate and cost-effective stove must be developed. Second, there is the challenge of dissemination:

in order to effect positive change, the stove must be introduced into people's kitchens and adopted into their daily cooking practices. The end-result of an intervention is as much a function of user preferences and behavior as the technical design of the ICS. The stove user, however, often goes unstudied in household energy interventions (Ezzati and Kammen[65], 2002).

In our study, these points have been taken into consideration. For the construction of the ICS, we have considered wood, dung and straw of rice (dried) and for making fuel grate iron rod was used and for chimney asbestos pipe was used so that cost can be affordable for the people. After six months of the installation of ICS we have revisited the households to see the adoptability of the ICS by the households and for this a series of questions was administered particularly to the cook of the households about the suitability of the ICS and the problem that they have faced with it. During the analysis, we have found that 98% of the households have found it suitable for their use. They have mentioned some minor problems regarding the cleaning of the chimney and the high temperature of the asbestos pipe that were observed during the cooking time and regarding the flame in the secondary pot when they have to use only the primary pot during some occasions. It was also found encouraging knowing that so many other households which were not involved during our study were adopting such kind of ICS. The persons whom we had trained in constructing the ICS were mostly engaged in these jobs by getting financial assistance from those households. This shows an important point that there is a great possibility of entrepreneurship development in this area.

Stove performance testing can assist stove developers with both the design challenge and the dissemination challenge. Lab-based tests are vital during the design stage of the ICS. These inform designers about the effectiveness with which different stoves transfer the energy released from the combustion process into the cooking pot. In addition, lab testing allows designers to quickly explore the performance of different materials and assess variations in stove geometry. In contrast, field-based stove performance tests provide a kind of "reality check" for stove designers by documenting the performance of stoves in the hands of actual users in their own kitchens.

In our study, from the WBT specific fuel consumption reduces considerably in all the three phases (cold start, hot start and simmering) in case of the ICS than both type of the TCSs that have been considered during the study. For both type of the TCS during the cold phase efficiency was found to be 5.2% and 4.1 respectively while in case of ICS it was 23.9%. During the hot phase, efficiencies rise up in all the three types of stoves and then decreases during the simmer phase. Similar is case for fire power and burning rate also (Table 5, Figure 27, 28, 29, 30, 31, and 32). In the CCT, the result also shows the decrease in the fuel consumption (33.05% from type A and 24.04% for type B) and preparation time (38.23 % from type A and 33.21% from type B) during preparation of a common item (rice and *dal*) with fixed amount of ingredients under controlled condition after installation of the ICS (Table 6, Figure 33, 34). Similarly, results of the KPT shows that after installation of ICS, fuelwood consumption reduced to a great extent (32%) along with the energy consumption per person-meal (35.66%) (Table 7, Figure 35).

As discussed in the earlier chapter, it was observed that woman, particularly in the rural areas of the north eastern region cook under poorly ventilated conditions using biomass fuels, either in pits or in non-portable U-shaped stoves. These stoves burn biomass inefficiently and release high volumes of air pollutants into the indoor environments, resulting in elevated pollutant exposures. Our observation also shows the similar case in the rural households that the efficiency of such kinds of traditional stoves was found to be low (Table 5, Figure 27, 28, 29, 30, 31 and 32). The efficiencies are generally quite low and are of the order of less than 10%. The kitchens are usually blackened with smoke. The reasons for the low efficiency are not difficult to seek. The main reasons may be listed as:

a. Loss of heat through unburnt volatiles.
b. Radiation loss from the flame.
c. Cooling effect due to excess air factor.
d. Stove losses.
e. Sensible heat lost from unburnt volatiles–air mixture.
f. Incomplete combustion due to inadequate mixing of volatiles and air.

In our study, we have estimated the 24-hour average concentration of CO, CO_2 and $PM_{2.5}$ emitted from the cooking purpose in the traditional cookstoves that used from a total numbers of 81 household kitchens having three kitchen types (27 each for kitchen attached with living room with partition, kitchen attached with living room without partition and separate kitchen outside the living room). From the result, we have found that the concentration of CO and $PM_{2.5}$ was found to be more in the kitchen attached with living room with partition in comparison to the other two types which was found to be much higher in concentration than the WHO air quality guidelines global update 2005 where as concentration of CO_2 was found to be almost similar in all the three types of the kitchens and was found much below the exposure guidelines for residential indoor air quality, Federal-Provincial Advisory Committee on Environmental and Occupational Health, Canada.

We have also estimated the average concentration of CO, CO_2 and $PM_{2.5}$ during the cooking and smouldering phase within the 24-hour period of time. It has been found that during the cooking period the average concentration for CO, CO_2 and $PM_{2.5}$ were found to much higher than the 24-h concentration level in the smouldering period showing the greater exposure particularly to the cook and the people resides in the kitchen during the cooking period in case of all the three types of kitchens (Table 11, Figure 37). In this regard, table 9 suggests that children $\leq$ 5 years of age and the woman in the age-group 19 – 50 years has the highest potential to the exposure of indoor smoke as they have spend most of their times in the kitchen or in the living room. Moreover, during the cooking time the concentration level of CO and $PM_{2.5}$ was found to be so high that theses people have a severe potentiality for having so many health diseases such acute lower respiratory infection, chronic obstructive pulmonary disease, cataract, cough etc. Besides these, pregnant woman can also be affected to a great extent as so many studies reveals that biomass smoke can leads to low birth weight and adverse pregnancy outcome (Windham[214], *et al.*, 2000; Windham[213], *et al.*, 1999a; Windham[215], *et al.*, 1999b; Walsh[208], 1994; Windham[216], *et al.*, 1992; Mathai[118], *et al.*, 1992; Rubin[174], *et al.*, 1986; Martin and Bracken[115], 1986; Ritz[171], *et al.*, 2002; Ritz and Yu[170], 1999; Ha[81], *et al.*, 2001; Maisonet[111], *et al.*, 2001; Wang[209], *et al.*, 1997; Bobak and Leon[37], 1999; Bobak[36], 2000; Rogers[173], *et al.*, 2000; Chen[47], *et al.*, 2002; Maroziene and Grazuleviciene[113], 2002; Xu[223], *et al.*, 1995; Sram[195], *et al.*, 1999; Pereira[156], *et al.*, 1998; Woodruff[217], *et al.*, 1997; Loomis[107], *et al.*, 1999; Lipfert[105], *et al.*, 2000; Perera[158], *et al.*, 1999). From baseline survey also, we have found some evidence regarding IAP related diseases that cough, asthma and bronchitis problem have found mostly among the children ≤ 5 yrs of age and the females than male whereas cataract, tuberculosis and cancer were observed in significant numbers of male and females.

From the intervention study, by setting up 56 improved cookstove in the selected households we have found significant reduction in the 24-hour average concentration in CO and $PM_{2.5}$ (~70 % - 72% and ~71 – 75% respectively) although concentration of CO_2 decreases to an extent (table 10). The result also shows that the 24-hour average concentration of CO after installation was found to be low as prescribed by the WHO guideline, but $PM_{2.5}$ concentration was still found higher than the prescribed value. If we consider the average concentration of CO and $PM_{2.5}$ during the cooking and smouldering period within the 24-hour period of time the scenario has found to be changed a bit. For the cooking period, the reduction in the concentration of CO and $PM_{2.5}$ was found to be 73% – 75% and 75% - 77% respectively although the concentration of $PM_{2.5}$ was found still higher than the WHO guidelines; whereas in case of smouldering period it was found to be reduced by ~83% - 86% for CO and ~84% - 85% for $PM_{2.5}$. Hence, the results will show the basis for proper designing of a stove for which it can be disseminated for household needs.

Analysis of the 24-hour average concentration of CO, CO_2 and $PM_{2.5}$ with the kitchen characteristics (in terms of building materials of roof, wall and floor) shows some remarkable results. The significant findings from this analysis was that for all the three types of roof materials viz., GI sheet; asbestos; and grass and bamboo; CO and $PM_{2.5}$ concentration was found to be more in the kitchen attached with living room with partition than the other two types that have been studied whereas the CO and $PM_{2.5}$ concentration was found to be lowest in separate kitchen outside living room (table 12).

Among the three roof materials, concentration of CO and $PM_{2.5}$ was found to be highest in grass and bamboo for all the three kitchen types (table 12).

In case of wall materials, we have also found some important results. Like roof materials, the four types wall materials viz., *Ekora* and mud; bamboo and mud; wood, bamboo and mud; and wood, bamboo and cement that have been studied; CO and $PM_{2.5}$ concentration was found to be more in the kitchen attached with living room with partition than the other two types whereas the CO and $PM_{2.5}$ concentration was found to be lowest in separate kitchen outside living room except for wall material bamboo and mud (table 12). Similarly, a floor material with mud/dirt and cement shows the same trend.

Hence, from analysis it can be stated that the kitchen in the living room with partition shows the highest 24-hour average concentration of CO and $PM_{2.5}$ whereas separate kitchen outside the living room is the lowest. Among the three roof materials, four wall materials and two floor materials that have been studied we can be concluded that the kitchen having roof material with grass and bamboo; and the wall material with *Ekora* and mud have the highest concentration of CO and $PM_{2.5}$ concentration whereas kitchens having roof materials with GI sheet and wall materials with wood, bamboo and cement have the lowest CO and $PM_{2.5}$ concentration. Hence, the result will help in the designing of the households for the betterment of the indoor air quality.

In case of ventilation condition in concern, results of this current study shows that enhancement in the ventilation condition reduced the emission level in side the kitchen significantly. The result shows that from poor ventilation to the good ventilation condition (based on our study) emission level of CO was reduced by ~20% whereas the $PM_{2.5}$ concentration was reduced by ~30% – 37% (Table 13). Therefore, it can be concluded that the increase in the number of ventilation not only in the kitchen but also in the other rooms of the households can make better indoor air quality.

From the current study we can say that although so many workers have carried out research on the indoor air quality and stove dissemination programme, but there are few unresolved issues that has to be addressed which are as follows –

a. The problems encountered in the villages in different regions make it clear that more stove designs need to be developed to cater to cooking practices of various regions/communities. Use of portable stoves, charcoal stoves and environment-friendly charcoal production are other related issues which need to be examined.
b. Although the stoves developed remove smoke from the kitchen, it is quite likely that undesirable volatiles are sent into the atmosphere. It is perhaps important to explore clean combustion mechanisms, which improve efficiency with no adverse impact on the global environment.
c. More detailed measurements of air quality around ICS are called for to establish cleanliness of the domestic environment.
d. The dissemination of stoves in rural households is a complex process and all the ramifications of the management of such a process have not been understood. Dissemination modules which are cost-effective without affecting quality need to be developed.

Study limitations

With regards to our study design, one must distinguish between inherent limitations, based on intrinsic properties of the design, and limitations caused by incomplete or variant field application and data collection practices.

In the current study, one design limitation involved the small number of households subject to detailed post-intervention measurements of indoor air pollutants (81 for three kitchen orientation). This constraint, necessitated by the need to conserve cost and minimize household disruption, which affected the statistical power of the analysis.

Next point is regarding the concerned selection of the study groups. Factors and practical considerations such as political will, location and population size, which affect program implementation, were not used to select the study group, with implementation and control groups selected at the community versus individual level. Despite efforts to select similar villages and households, there may have been differences in environmental and socioeconomic factors even in between the same villages. These differences would mean that the study design is partially randomized and that there may have been differential secular trends in pollution level before and after the intervention study, or differential potential response to interventions.

Another practical consideration were caused by the incomplete or variant field application of the study design and data collection properties, including use of scientific measuring equipments within a compressed period of time and hence need for concentrating the tests for longer duration so that actual effect can be evaluated. For example, day-to-day fluctuations in temperature would have affected the results by increasing random variation in stove use.

Next point on the limitations of the study design involved the time span between baseline and post-intervention data. It is possible that over the time the user behaviour improves leading to better performance for both interventions and on the other hand, stove deterioration may lead to a reduction in the observed performance of new stoves.

Lastly, the study was not designed to evaluate the local environmental effects of the stove and behavioural interventions.

Important outcomes from the current study

Some important outcomes that may be drawn from the current study for carrying out such kinds of intervention study –

- Interventions designed to reduce IAP must also fulfill the purposes of energy use, itself affected by climatic, ecological and socio-cultural factors.

- Interventions must be tailored to meet local needs and conditions. They must also be affordable and sustainable.
- Provincial and community level energy infrastructure, both physical and institutional, is an important consideration for IAP intervention program. For this the study should be included extensive training program for stove workers to ensure successful stove interventions.
- Behavioural interventions alone appear ineffective in lowering IAP exposure, as changes in stove use, ventilation and other habits affecting IAP levels and exposure are insufficient. Furthermore, the knowledge of IAP health risks alone is insufficient to change fuel or stove purchasing decisions, especially if alternative stove technologies are costly, not readily available, or are perceived as such.
- It is important for rural households while continued reliance on locally available fuels, reflecting concerns of affordability and infrastructural limitations, advances in clean technologies applied to these fuels are increasingly relevant.
- IAP studies and interventions require interdisciplinary expertise and multi-sectoral/cooperation, reflecting the complex interrelationships between households energy use, IAP levels, household exposure, health and environmental effects, and other factors.
- In the rural areas particularly in the north eastern region, most of the people do not want to change their stoves with improved one because of the lake of information and belief. As they are mostly familiar with their own traditional stoves, they hesitate to adopt the new stoves (improved). Hence, motivation and carrying out the information on the IAP is necessary while implementing an intervention study among the peoples.

Recommendations and future work of research

The overall recommendations derived from the current study are –

- Proper policy and program implementation by Govt.; Govt. and non-Govt. organization; and nodal agencies for improved stove dissemination and clean technologies. In this regard, scaling up and improving the sustainability of interventions require better assessment of the supply and demand for alternative energy technologies and evaluation of the policies and programs which can optimally increase intervention coverage with a high degree of community effectiveness.

- Access to clean water and sanitation is widely recognized as a set of environmental health-exposure indicators and these are commonly cited as measure of indicators of poverty and measures of ill health. Therefore, the levels of water related hygiene could also be parallel to the indicators of household air-quality related hygiene. These potential indicators could be correspondingly defined as access to clean fuel and access to ventilated combustion technology (World Bank[218], 2002). Hence, there is a need for public intervention study like water supply and sanitation.
- There is a need for research and development support to the public sector for disseminating clean or efficient technologies.
- Subsidies which support introduction of new energy technologies may be needed to spur progression along the learning curve and help offset initial production and distribution cost before economies of scale become operational. Furthermore, the tendency of poor households to progressively discount future benefits and heavily weight present cost suggests public intervention, particularly if significant externalities are associated with this tendency; otherwise, households and communities at large would tend to underinvest in measure to reduce IAP exposure. In turn, this would discourage the development and introduction of new energy technologies.
- Beyond the technology, the public sector needs to support development of human capital related to household energy use. This applies to education generally, including sensitizing students to the IAP problem, as well as to the more specialized fields of engineering, economics, public health, environmental science and other subjects critical to research on IAP and household energy use alternatives.
- National and local area technology (for example, fuel and stove) standards are yet another requirement in addressing the IAP problem. The government of China has

begun setting energy efficiency standards for household appliances and a mandatory labeling system for energy using appliances has been introduced. The same effort also can be done in our country.

- Facilitation of private sector responses is another option for promoting the new cleaner and efficient technologies. Since alternative stoves and cleaner fuels are private goods, it could be expected that the marketplace could fairly determine their prices through competition among suppliers and distributors. Consumer choice is exercised simply by deciding whether to buy the alternative stove technologies.
- Health, like education, is a fundamental component of human capital. IAP, as a major cause of India and other developing countries, should become a more serious priority than has been the case to date.

The suggestions for the future research work and testing is suggested as –

- Better understanding of the seasonal patterns of IAP exposure and how stove and behavioural interventions may affect exposure;
- Monitoring of stove performance and user behaviour over time; particularly needed is to testing the degree to which proper stove and ventilation maintenance can contribute to reduce IAP exposure and improved IAP related health indicators (Sinton[186] *et al.*, 2004);
- Effects of alternative stoves on the amount of fuel use and their local/global environmental effects;
- Review of the supply and demand factors critical to achieving high quality technological advances in household energy use, recognizing the affordability limitations of rural households;
- Review of the respective roles of the private and public sectors in addressing the IAP problem, recognizing market imperfections and government weakness in developing countries;
- Cost-effective analysis of intervention options, including microcredit and commercial, private sector led initiatives (Easterly[61], 2006);

- Cost-benefit analysis of intervention program, welfare benefits and costs of IAP interventions should be evaluated; and
- Analysis of how gender issues and intrahousehold gender disparities influence household technology choices, and how these are affected by education and literacy levels.

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Annexure I

Preliminary baseline questionnaire survey

Conversation Format:

State	
District	
Habitation	
Household number	
Name of Respondent	
Address/Location of Household	
Pincode	
Date	M M / D D
Interviewers	1. 2.
Results	Agrees to Interview.....................1 Declines Interview......................2
Monitoring Visit	Yes No
Date	M M / D D
Time for Monitoring Visit	Morning................................1 Afternoon..............................2 Evening.................................3
Monitoring Team Names	#1. #2.

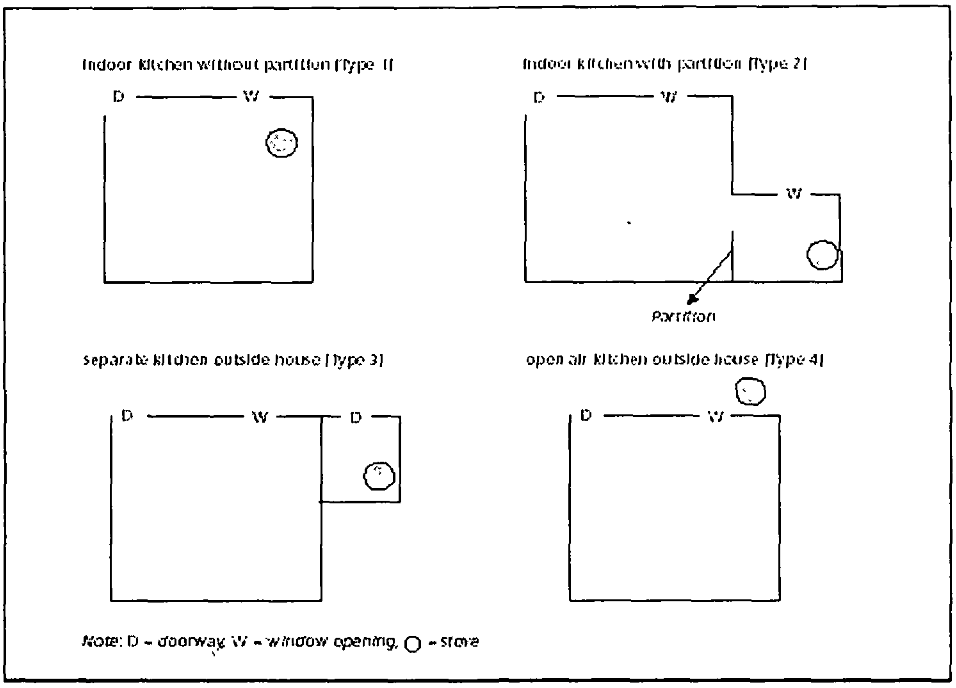
Consent for interview:

My name is ________________________________ and I am working at the Department of Energy, Tezpur University, Assam. We are conducting a survey about household energy and indoor air pollution in North-East India. We would very much appreciate your participation in this survey. This information will help people plan programs to decrease indoor air pollution in homes. It will take about 20 minutes. Participation in this survey is voluntary. You can choose not to answer any question. If you decide to participate, you may stop answering questions at anytime. All information will be kept strictly confidential and will not be shown to other persons. Do you want to ask me anything about this survey at this time?

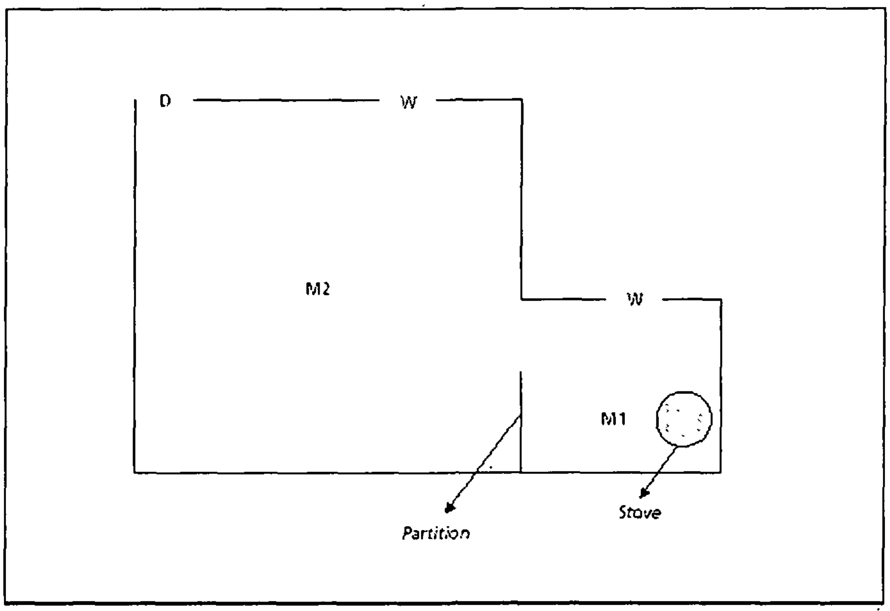
Signature of Interviewer

Date	M M / D D
Response	Respondent agrees for interview............1 Respondent declines interview...............2
Start time	______________________am / pm

Household Sketch:



Please include the following:
---------- Location of the kitchen (s)
---------- Location of the stove (s)
---------- Partition of the kitchen (if applicable)



---------- Location of all doorways, windows and major openings
Monitoring labeling to be completed by the monitoring team:

M_1, M_2 = Location of the kitchen sampler and living area sampler.

Household characteristics:

Roof Materials	Grass leaves,*Ekora* or Bamboo....1 GI sheet or Other Metal Sheets....2 Asbestos Cement Sheets....3 Brick Stone and Lime....4 Concrete RBC/RCC....5 All other Materials not stated....6
Wall Materials	Grass, Leaves, Reeds, Bamboo or Thatch....1 Mud / Dirt....2 Bamboo and mud....3 Wood, bamboo and mud....4 Wood, bamboo and cement....5 GI Sheets or Other Metal Sheets....6 Cement Concrete....7 Ekora and mud....8 Other Materials not stated....9
Floor	Mud / Dirt....1 Brick, Stone & Lime....2 Cement....3 Mosaic / Tiles....4 Other Materials not stated....5
Do you have a separate room that is used for a kitchen? Yes.....No.....	
Characteristics of the kitchen	Indoor Kitchen with Partition....1 Indoor Kitchen without Partition....2 Separate Indoor Kitchen Outside the House....3 Open Air Kitchen Outside the House....4
How many rooms are there in your household?	
Roof height (in meters)	Highest point:________ Lowest point:________ Average height:________
Wall height (in meters)	Highest point:________ Lowest point:________ Average height:________
Is there a gap between the wall and roof?	Yes No
If yes, the size of the gap in cms	cm
Number of doorways	
Number of windows / major openings	

Kitchen characteristics:

Length in meters	Longest wall:__________ Shortest wall:__________ Average length:__________
Width in meters	Longest wall:__________ Shortest wall:__________ Average length:__________
Height in meters	Highest point:__________ Lowest point:__________ Average height:__________
Number of windows / openings in kitchen	
For each window / opening in kitchen, rate size Small: less than ½ of survey page (A4 sheet) Medium: ½ to full size of survey page Large: larger than survey page	Window #1 Small Medium Large Window #2 Small Medium Large Window #3 Small Medium Large Window #4 Small Medium Large Window #5 Small Medium Large
Please rate the ventilation of the kitchen:	Poor ....1 Moderate ....2 Good 3
For households with kitchen partition: Does partition extend to the ceiling?	Yes No
If no, height of partition in cms	
For households with open air kitchen outside the house: Under any shed roof or canopy?	Yes No
If yes, what is this shed roof or canopy made of?	Grass, leaves, reeds, thatch, wood, mud, or bamboo......................................1 GI sheet/other metal sheets.................2 Asbestos cement sheets.....................3 Concrete RBC / RCC.......................4 All other materials not stated..............5
If yes, height of shed roof/canopy in cms	Highest point:__________ Lowest point:__________ Average height:__________
How many sides of the outdoor kitchen are enclosed? (i.e. by walls, make-shift partitions, etc.)	

Fuelwood use:

		Now	Winter	Summer	Monsoon
What type of fuel does your household mainly use for cooking?	Wood (logs)..................1 Wood (twigs/branches)......2 Crop residues................3 Dung cakes....................4 Charcoal......................5 Kerosene......................6 Electricity......................7 LPG...........................8 Bio-gas........................9 Other.........................10 (Specify) ________				
What type of fuel does your household mainly use for boiling / heating water?	Wood (logs)..................1 Wood (twigs/branches)......2 Crop residues................3 Dung cakes....................4 Charcoal......................5 Kerosene......................6 Electricity......................7 LPG...........................8 Bio-gas........................9 Other.........................10 (Specify)________ Not used.....................11				
What type of fuel does your household commonly use for space heating?	Wood (logs)..................1 Wood (twigs/branches)......2 Crop residues................3 Dung cakes....................4 Charcoal......................5 Kerosene......................6 Electricity......................7 LPG...........................8 Bio-gas........................9 Other.........................10 (Specify)________ Not used.....................11				
What is the main source of lighting for your household?	***Record all monitored*** Electricity...1 Kerosene...2 Gas...3 Oil...4 Other..5 (Specify) ________				

Biomass stove characteristics:

Traditional Biomass Stove

	Traditional stove #1	Traditional stove #2
	Fixed ....1 Portable 2	Fixed ....1 Portable 2
Type of stove	3 stone or brick..............1 Simple chulha................2 Modified chulha (ridged at pot hole)..........3	3 stone or brick..............1 Simple chulha................2 Modified chulha (ridged at pot hole)..........3
If stove is a modified chulha (#3 above), was this stove constructed as an improved chulha?	Yes No	Yes No
Number of pot holes		
Height of the stove in cms	cm	cm
Stove material (develop codes after the pilot)	Mud ....1 Brick ....2 Other ....3 (specify)________	Mud ....1 Brick ....2 Other ....3 (specify)________
Does the stove have a hood?	Yes No	Yes No
If yes, describe the hood:		
Is the stove ever used for space heating indoors?	Yes No	Yes No
Is the stove ever used for cooking cattle feed?	Yes No	Yes No

Improved Biomass Stoves:

Improved biomass stoves are characterized by the presence of a chimney or flue.	Traditional stove #1	Traditional stove #2
	Fixed ....1 Portable 2	Fixed ....1 Portable 2
Does the stove have a chimney (flue)?	Yes No	Yes No
If no, this is not an improved stove – record stove details in traditional stove section:		
If improved, what type?		
If improved, for how long have you had this stove?	months/years	months/years
Number of pot holes		
Describe chimney material:		
Height of chimney in cms:	cm	cm
Please rate the overall condition of the chimney:	Poorly maintained / inefficient...............1	Poorly maintained / inefficient...............1
	Moderately well maintained..............2	Moderately well maintained..............2
	Well maintained / efficient.................3	Well maintained / efficient.................3
Describe the maintenance of chimney:		
Does the stove have a controllable damper?	Yes No	Yes No
Height of the stove in cms	cm	cm
Does the stove have a hood?	Yes No	Yes No
If yes, describe the hood:	Poorly maintained 1	Poorly maintained 1
Please rate the overall condition of the stove:	Moderately well maintained..............2	Moderately well maintained..............2
	Well maintained........3	Well maintained 3
Is the stove ever used for space heating indoor?	Yes No	Yes No
Is the stove ever used for cooking cattle feed?	Yes No	Yes No

Demographic information:

Now I would like some information about the people who usually live in you're household or are staying with you that you know.

Please give me the names of the persons, who usually live in your household, starting with the head of the household.

Name	**Relationship to Head of Household***	**Sex**	**Age < 1 year give age in month**	**Involved in cooking?**	**Usually present in the kitchen during cooking?**	**What kind of work does (head) do most of the time**
Name 1	Head of Household 01	Male......1 Female...2		Yes No	Yes No	
Name 2		Male......1 Female...2		Yes No	Yes No	
Name 3		Male......1 Female...2		Yes No	Yes No	
Name 4		Male......1 Female...2		Yes No	Yes No	
Name 5		Male......1 Female...2		Yes No	Yes No	
Name 6		Male......1 Female...2		Yes No	Yes No	
Name 7		Male......1 Female...2		Yes No	Yes No	
Name 8		Male......1 Female...2		Yes No	Yes No	
Name 9		Male......1 Female...2		Yes No	Yes No	
Name 10		Male......1 Female...2		Yes No	Yes No	

O1 = Head, 02 = Wife or Husband, 03 = Son or Daughter, 04 = Son-in-law or Daughter, 05 = Grandchild, 06 = Parent, 07 = Parent-in-law, 08 = Brother or Sister, 09 = Brother-in-law or sister-in-law, 10 = Nice or Nephew, 11 = Other relative, 12 = Adopted/Foster child, 13 = Not related.

Questions for Cook:

		Fuel	How much (fuel type) do you use (per household) per day?		About what % of your total fuel use is?	Is (fuel type) collected or purchased?	If collected, approx. how much time you spend collecting (fuel type) per unit of time? (ex: 20 min per day)	If purchased, approx. how much do you spend on (fuel type) per unit of time?
For (fuel) mainly used for cooking	Fuel 1			Kg liters		Collected..........1 Purchased.........2	Time per	Rs per
What other types of fuel does your household commonly use for cooking?	Fuel 2			Kg liters		Collected..........1 Purchased.........2	Time per	Rs per
	Fuel 3			Kg liters		Collected..........1 Purchased.........2	Time per	Rs per
	Fuel 4			Kg liters		Collected..........1 Purchased.........2	Time per	Rs per
	Fuel 5			Kg liters		Collected..........1 Purchased.........2	Time per	Rs per

Does the household's cooking pattern change seasonally? If yes, describe changes and reason for change.	Yes	No
Has your household ever changes it's fuel use pattern? If yes, describe changes, when they occurred, and reasons for change.	Yes	No
Has your household ever changed its cooking area? If yes, describe changes, when they occurred, and reasons for change.	Yes	No

	Cook # 1 Name:		Cook # 2 Name:	
When do you usually cook? Fill in the following for all mentioned.				
Morning *Before Noon*	Yes	No	Yes	No
If yes, how long do you cook for in the morning?		minutes		minutes
Afternoon *Noon to 5 pm*	Yes	No	Yes	No
If yes, how long do you cook for in the afternoon?		minutes		minutes
Evening *After 5 pm*	Yes	No	Yes	No
If yes, how long do you cook for in the evening?		minutes		minutes
Other times				
Specify other times and activities (making tea, etc.)	Yes	No	Yes	No
If yes, how long do you cook for at other times?		minutes		minutes
What kind of work do you (cook) do most of the time?				
Do you (cook) earn cash for this work?	Yes	No	Yes	No
Do you (cook) smoke more than 1 cigarette every day?	Yes	No	Yes	No
If yes, how many cigarettes do you smoke every day?				
If yes, for how long have you smoked cigarettes?				
Do you (cook) smoke more than 1 bidi every day?	Yes	No	Yes	No
If yes, how many bidis do you smoke every day?				
If yes, for how long have you smoked bidis?				
How long have you (the cook) lived here?				
What was the fuel mainly used for cooking in the place you lived before this?				
How long did you live here?				
Do you (cook) suffer from tuberculosis?	Yes	No	Yes	No
Have you (cook) ever received medical treatment for tuberculosis?	Yes	No	Yes	No
Does anyone in the household suffer from blindness?	Yes	No		
If yes, who?				
Has anyone in the household ever been diagnosed with or had surgery for cataracts?	Yes	No		
Diagnosed with cataracts?	Yes	No		
If yes, who?				
Had surgery for cataracts?	Yes	No		
If yes, who?				
If there is more than one cook, who is the main cook?	Cook # 1 1 Cook # 2 2			

Ownership and assets (quantity and present market value):

			"Enter 0 in case of not owning"
I.D.	**Asset description**	**Asset amount** (For land, use decimal; for others, use numbers)	**Present market value** **(Rs.)**
1	Cultivable land		
2	Homestead land (including structure)		
3	Commercial land		
4	Other land (including pond, orchard)		
5	Business/shop structure		
6	Rickshaw/helicopter*/van/ push cart		
7	Bullock/buffalo/horse		
8	Sheep/goat		
9	Refrigerator		
10	Radio		
11	Cassette player/tape recorder		
12	Television		
13	Bicycle		
14	Motor cycle		
15	Baby taxi		
16	Bus/truck/car		
17	Country boat		
18	Motorized vessel/engine boat		
19	Land Phone		
20	Mobile Phone		
21	Tractor/power tiller		
22	Deep tube well		
23	Shallow tube well		
24	Poultry		
25	Rice/flour mill		
26	Sugarcane crusher		
27	Handloom		
28	Oil crusher / *ghani*		
29	Other, specify____________		

Cash family income (monthly):

Source	Income
Wage/ salary	
Crop sale	
Rental income	
Income for self employed/ Business income	
Remittance	
Others (please specify)	
Total	

What is the total monthly (cash) expenditure of the household?

Amount (Rs.)	

Value of household or homegrown products (monthly):

Product consumed	Market value
Rice consumed	
Vegetables consumed	
Fish	
Fruit	
Rental value of the house (when owned)	
Others (please specify)	
Total	

Consent for monitoring:

Tomorrow, some other people from our team will be measuring the air quality in several homes in your village. This will take one full day (about 24 hours, including 1 hour for setup time and collection of samplers). Measuring will involve the placement of samplers inside and outside the houses while cooking and also while cooking is not going on. Participation is voluntary. The monitors are run by batteries and are very safe. They do not cause electrical shocks or fires and will have no effect on children or others in the house, although they do make a small amount of noise. You can choose to have the monitor removed at any time. We would very much appreciate your participation in this survey.

Do you want to ask me anything about the monitoring at this time?

Signature of Interviewer :

Date	M M / D D
Response	Respondent agrees for interview............ 1 Respondent declines interview...............2
Start time	______________________am / pm

Annexure II
WBT data calculation sheet

Name(s) of Tester(s) ______________________________

Test Number	____________	Location	____________
Date	____________	Wood species	____________
Stove type/model	____________	Wind condition	____________
Air temperature	________ °C	Dry weight of Pot#3	________ g
Average dimensions of wood	________ cm×cm×cm	Dry weight of Pot#4	________ g
Dry weight of Pot#1	________ g	Weight of container for char	________ g
Dry weight of Pot#2	________ g	Local boiling point	________ °C

Wood moisture content – method used for calculation: Gravimetric, Moisture meter ____________

If using gravimetric methods, record in the "Avg MC" space If using moisture meter, use meter's averaging function and record in the "Avg MC" space Avg MC (wet) ____________

WBT Test 1		**High power test (cold start)**				**High power test (hot start)**				**Simmer test**			
		Start		Finish: when pot #1 boils		Start		Finish when pot #1 boils		Start		Finish: when pot #1 boils	
Measurements	Unites	Data	label	Data	label	Data	label	Data	label	Data	label	Data	label
Time	min	____	t_{ci}	____	t_{cf}	____	t_{hi}	____	t_{hf}	____	t_{si}	____	t_{sf}
Weight of wood	g	____	f_{ci}	____	f_{cf}	____	f_{hi}	____	f_{hf}	____	f_{si}	____	f_{sf}
Water temperature, Pot#1	°C	____	$T1_{ci}$	____	$T1_{cf}$	____	$T1_{hi}$	____	$T1_{hf}$	____	$T1_{si}$	____	$T1_{sf}$
Water temperature, Pot#2	°C	____	$T2_{ci}$	____	$T2_{cf}$	____	$T2_{hi}$	____	$T2_{hf}$				
Water temperature, Pot#3	°C	____	$T3_{ci}$	____	$T3_{cf}$	____	$T3_{hi}$	____	$T3_{hf}$	$T1_{si}$ is set equal to T_b because the tesy starts after the pot has boiled.			
Water temperature, Pot#4	°C	____	$T4_{ci}$	____	$T4_{cf}$	____	$T4_{hi}$	____	$T4_{hf}$				
Weight of Pot#1 with water	g	____	$P1_{ci}$	____	$P1_{cf}$	____	$P1_{hi}$	____	$P1_{hf}$	____	$P1_{si}$	____	$P1_{sf}$
Weight of Pot#2 with water	g	____	$P2_{ci}$	____	$P2_{cf}$	____	$P2_{hi}$	____	$P2_{hf}$				
Weight of Pot#3 with water	g	____	$P3_{ci}$	____	$P3_{cf}$	____	$P3_{hi}$	____	$P3_{hf}$	$P1_{si}$ should be the mass of water after the pot comes to boil.			
Weight of Pot#4 with water	g	____	$P4_{ci}$	____	$P4_{cf}$	____	$P4_{hi}$	____	$P4_{hf}$				
Fire-starting materials (if any) ____													
Weight of charcoal + container	g			____	C_c			____	C_h			____	C_s

WBT Test 2		High power test (cold start)				High power test (hot start)				Simmer test			
		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils	
Measurements	Unites	Data	label	Data	label	Data	label	Data	label	Data	label	Data	label
Time	min		t_{ci}		t_{cf}		t_{hi}		t_{hf}		t_{si}		t_{sf}
Weight of wood	g		f_{ci}		f_{cf}		f_{hi}		f_{hf}		f_{si}		f_{sf}
Water temperature, Pot#1	°C		$T1_{ci}$		$T1_{cf}$		$T1_{hi}$		$T1_{hf}$		$T1_{si}$		$T1_{sf}$
Water temperature, Pot#2	°C		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$				
Water temperature, Pot#3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$	$T1_{si}$ is set equal to T_b because the tesy starts after the pot has boiled.			
Water temperature, Pot#4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot#1 with water	g		$P1_{ci}$		$P1_{cf}$		$P1_{hi}$		$P1_{hf}$		$P1_{si}$		$P1_{sf}$
Weight of Pot#2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$				
Weight of Pot#3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$	$P1_{si}$ should be the mass of water after the pot comes to boil.			
Weight of Pot#4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any) ______													
Weight of charcoal + container	g				C_c				C_h				C_s

WBT Test 3		High power test (cold start)				High power test (hot start)				Simmer test			
		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils	
Measurements	Unites	Data	label	Data	label	Data	label	Data	label	Data	label	Data	label
Time	min		t_{ci}		t_{cf}		t_{hi}		t_{hf}		t_{si}		t_{sf}
Weight of wood	g		f_{ci}		f_{cf}		f_{hi}		f_{hf}		f_{si}		f_{sf}
Water temperature, Pot#1	°C		$T1_{ci}$		$T1_{cf}$		$T1_{hi}$		$T1_{hf}$		$T1_{si}$		$T1_{sf}$
Water temperature, Pot#2	°C		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$				
Water temperature, Pot#3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$	$T1_{si}$ is set equal to T_b because the tesy starts after the pot has boiled.			
Water temperature, Pot#4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot#1 with water	g		$P1_{ci}$		$P1_{cf}$		$P1_{hi}$		$P1_{hf}$		$P1_{si}$		$P1_{sf}$
Weight of Pot#2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$				
Weight of Pot#3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$	$P1_{si}$ should be the mass of water after the pot comes to boil.			
Weight of Pot#4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any) ______													
Weight of charcoal + container	g				C_c				C_h				C_s

WBT Test 4		**High power test (cold start)**				**High power test (hot start)**				**Simmer test**			
		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils		Start		Finish: when pot #1 boils	
Measurements	Unites	Data	label	Data	label	Data	label	Data	label	Data	label	Data	label
Time	min	____	t_{ci}	____	t_{cf}	____	t_{hi}	____	t_{hf}	____	t_{si}	____	t_{sf}
Weight of wood	g	____	f_{ci}	____	f_{cf}	____	f_{hi}	____	f_{hf}	____	f_{si}	____	f_{sf}
Water temperature, Pot#1	°C	____	$T1_{ci}$	____	$T1_{cf}$	____	$T1_{hi}$	____	$T1_{hf}$	____	$T1_{si}$	____	$T1_{sf}$
Water temperature, Pot#2	°C	____	$T2_{ci}$	____	$T2_{cf}$	____	$T2_{hi}$	____	$T2_{hf}$				
Water temperature, Pot#3	°C	____	$T3_{ci}$	____	$T3_{cf}$	____	$T3_{hi}$	____	$T3_{hf}$	$T1_{si}$ is set equal to T_b because the tesy starts after the pot has boiled.			
Water temperature, Pot#4	°C	____	$T4_{ci}$	____	$T4_{cf}$	____	$T4_{hi}$	____	$T4_{hf}$				
Weight of Pot#1 with water	g	____	$P1_{ci}$	____	$P1_{cf}$	____	$P1_{hi}$	____	$P1_{hf}$	____	$P1_{si}$	____	$P1_{sf}$
Weight of Pot#2 with water	g	____	$P2_{ci}$	____	$P2_{cf}$	____	$P2_{hi}$	____	$P2_{hf}$				
Weight of Pot#3 with water	g	____	$P3_{ci}$	____	$P3_{cf}$	____	$P3_{hi}$	____	$P3_{hf}$	$P1_{si}$ should be the mass of water after the pot comes to boil.			
Weight of Pot#4 with water	g	____	$P4_{ci}$	____	$P4_{cf}$	____	$P4_{hi}$	____	$P4_{hf}$				
Fire-starting materials (if any) ____													
Weight of charcoal + container	g			____	C_c			____	C_h			____	C_s

Comments:

____

____

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____

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____

Annexure II
CCT data calculation sheet

Basic test data:

Qualitative data:

Name(s) of Tester(s)	______________	Type of stove: Stove 1	______________
	______________	Type of stove: Stove 2	______________
Test number		______________	
		Location	______________
Date	______________	Wood species	______________

Quantitative testing condition:

Avg. dimensions of wood (length × width × height)	________	cm	_____	Empty weight of Pot#1	________	g	P1
Wood moisture content (wet basis)	________	%	m	Empty weight of Pot#2	________	g	P2
Local boiling point of water	________	°C	T_b	Empty weight of Pot#3	________	g	P3
				Empty weight of Pot#4	________	g	P4
				Weight of container for char	________	g	k

Other comments on test conditions: ______________________________

____

____

Cooking task:

The standardized cooking task:
Use this space to describe the standardized cooking process that forms the basis of this test. Describe each step with enough detail so that an experienced cook from the area where the test is performed could follow them easily. If more space is needed, extend the description below the space provided.

Ingredients	Name	Amounts (g)	Step	Directions
1	________	________	1	________
2	________	________	2	________
3	________	________	3	________
4	________	________	4	________
5	________	________	5	________
6	________	________	6	________
7	________	________	7	________
8	________	________	8	________
9	________	________	9	________
10	________	________	10	________
11	________	________	11	________

CCT - ___ for stove ____ :

Wind condition ________________ Air temperature ____________ °C

Measurements	Units	Initial measurements: Data	Initial measurements: Label	Final measurements: Data	Final measurements: Label
Weight of wood used for cooking	g	________	f_i	________	f_f
Weight of charcoal and container	g			________	C_c
Weight of Pot#1 with cooked food	g			________	$P1_f$
Weight of Pot#2 with cooked food	g			________	$P2_f$
Weight of Pot#3 with cooked food	g			________	$P3_f$
Weight of Pot#4 with cooked food	g			________	$P4_f$
Time	min	________	t_i	________	t_f

Calculations		*Formula*	*Calculations*		*Formula*
Total weight of food cooked	g	$W_f = \sum_{j=1}^{4} (Pj_f - Pj)$	Specific fuel consumption	g/kg	$SC = (f_d/W_f) \times 1000$
Weight of char remaining	g	$\Delta C_c = k - C_c$	Total cooking time	min	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	$f_d = (f_f - f_i) \times \{1 - (1.12 \times m)\} - 1.5 \times \Delta C_c$			

Description of the stove: ____

____

Annexure IV

KPT pre-intervention questionnaire survey

1. Date			
2. Name of Interviewer			
3. Household code			
4. Village ID			
5. Community ID			
6. List gender and age of HH members (up to 10 people):	Gender/Age	Count	
	Children 0-14		
	Women over 14		
	Men 15-59		
	Men over 59		
7. Primary income generating activities (circle one):	Farming only	If farming, list crops:	
	Wage labor only	a)	
	Farming and wage labor	b)	
	Shopkeeping	c)	
	Farming and shop-keeping		
	Other -		
8. Who is primarily responsible for cooking?	List gender and age as in question 7 above:		
9. Is cooking done indoors, outdoors, or both?			
10. Is the kitchen separate from the main house? (circle one)			Yes/No
11. What kind of stove(s) are used? What is the age and frequency of use of each stove?	Stove/fuel	Age of stove (yrs)	Frequency of use (times per day, week, or month)
	a)		
	b)		
	c)		

12. Whose job is it to obtain cooking fuel?	For each Stove/fuel from question 12, list the family members' gender and age as in question 7 above:
	a)
	b)
	c)

13. Where is cooking fuel obtained and roughly how far is the source of fuel from the household (record distance or time needed to walk to source)?	Give answers for each Stove/fuel given in question 12	
	Location	Distance from household
	a)	a)
	b)	b)
	c)	c)

14. How much is consumed and how much does the family spend on each type of fuel per month	Give answers for each Stove/fuel listed in the response to question 12	
	Monthly fuel consumption	Monthly expenditure on fuel
	a)	a)
	b)	
		b)
	c)	
		c)

Questions about the main wood burning stove

15. What kinds of pots are used for cooking (e.g. round or flat bottom, metal or ceramic, etc.)?	
16. Are pot-lids usually used for cooking?	
17. How is the fire normally controlled?	

18. Does the family perform maintenance on the improved stove?	Type of maintenance	Frequency (circle appropriate response)
	Cleaning stove of ashes	Never Daily Weekly Monthly
	Cleaning flue	Never Daily Weekly Monthly
	Repairing cracks	Never Daily Weekly Monthly
	Other task -	Never Daily Weekly Monthly

19. Is the stove used for any purpose other than cooking food for the family (circle as appropriate)?	Preparing food for livestock
	Preparing food/drink for commercial sale
	Other? ______________________

20. What does the primary cook like about the stove (list replies)?	
21. What does the primary cook dislike about the stove (list replies)?	
22. Describe condition and appearance of primary woodstove and kitchen (if possible, make a sketch or take a photo).	

23. If the family is not currently using a new stove, are they interested in using one? *If the respondent responds positively, provide information about how they can get a new stove*	
24. Is the family willing to participate in a more detailed study that involves daily measurements of fuel consumption?	
25. Is the family willing to participate in a follow-up survey to assess their satisfaction with the new stove 3-6 months from now?	
Thank the respondent for participating and, if they responded positively to questions 24 or 25, tell them that you will be in contact with them in the future.	

Annexure V

KPT data calculation sheet

Household data and results:

Name(s) of Enumerator(s) ____________ Type of stove ____________

Family name/HH code ____________ Start date of KPT ____________

Time family is to be visited ____________ Is fuel provided (yes/no) ____________

Schedule of KPT:

Day 0: Initial briefing of family, defining wood inventory area, and weighing of initial stock of wood
Day 1 and 2: Visit family at roughly the same time, weighing fuel remaining in stockpile and weigh any wood added on that day.
Day 3: Final weighing and debriefing of family. If possible, tell them the outcome of the test and present them with appropriate compensation.

Description of the location of the household:

____

____

____

____

____

____

____

____

The enumerator should fill out the following two worksheets – data will be filled here.

Daily Results	No. of adult equivalent people	Wood consumption unadjusted for moisture content: Mass of wet wood used in the past 24 hours (kg)	Wood consumption unadjusted for moisture content: Wet wood used per capita in past 24 hours (kg/person)	Wood consumption adjusted for moisture content: Mass of dry wood used in the past 24 hours (kg)	Wood consumption adjusted for moisture content: Dry wood used per capita in past 24 hours (kg/person)
Day 1	________	________	________	________	________
Day 2	________	________	________	________	________
Day 3	________	________	________	________	________

Overall results:	**Wet wood**	**Wet wood per capita**	**Dry wood**	**Dry wood per capita**
Average daily fuel use	________	________	________	________
Standard deviation	________	________	________	________
CV (SD – Avg.)	________	________	________	________

KPT daily data form: Family name / HH code: ____________________

Gender and age	Child 0– 4	Female >14 over	Male: 15–59	Male: >over 59
Adult equivalent	0.5	0.8	1.0	0.8

Day 0:
Initial stock of fuel in inventory area ____________________ kg

Day 1:	Day 2:
People present for meals during the last 24 hour period Children 0 – 14 ________ Females > over 14 ________ Males 15 – 59 ________ Males > over 59 ________ Total adult equivalent ________ *Fuel consumed between day 0 to day 1* Fuel moisture (wet basis) ________ Fuel in stock (excluding new additions not weighed during previous visit). ________ Fuel collected during past 24 hours (kept apart from previous day's weighed fuel add to stock after weighing). ________ Fuel consumed in past 24 hours ________	*People present for meals during the last 24 hour period* Children 0 – 14 ________ Females > over 14 ________ Males 15 – 59 ________ Males > over 59 ________ Total adult equivalent ________ *Fuel consumed between day 1 to day 2* Fuel moisture (wet basis) ________ Fuel in stock (excluding new additions not weighed during previous visit). ________ Fuel collected during past 24 hours (kept apart from previous day's weighed fuel add to stock after weighing). ________ Fuel consumed in past 24 hours ________
Day 3: *People present for meals during the last 24 hour period* Children 0 – 14 ________ Females > over 14 ________ Males 15 – 59 ________ Males > over 59 ________ Total adult equivalent ________ *Fuel consumed between day 2 to day 3* Fuel moisture (wet basis) ________ Fuel in stock (excluding new additions not weighed during previous visit). ________ Fuel collected during past 24 hours (kept apart from previous day's weighed fuel add to stock after weighing). ________ Fuel consumed in past 24 hours ________	

Fuel moisture:

Moisture should be read the day before from the stock of fuel that is going to be used during the next 24 hour period. For each day, randomly draw three pieces of the fuel and measure its moisture in three positions.

Family name / HH code: ______________________

Day 0:

	Instrument reading (% dry basis)		
	1	2	3
Piece 1	________	________	________
Piece 2	________	________	________
Piece 3	________	________	________

Day 1:

	Instrument reading (% dry basis)		
	1	2	3
Piece 1	________	________	________
Piece 2	________	________	________
Piece 3	________	________	________

Day 2:

	Instrument reading (% dry basis)		
	1	2	3
Piece 1	________	________	________
Piece 2	________	________	________
Piece 3	________	________	________

Annexure VI

KPT post-intervention questionnaire survey

1. Date		
2. Name of Interviewer		
3. HH Code		
4. Village ID		
5. Community ID		
6. List gender and age of HH members (up to 10 people):	Gender/Age	Count
	Children 0-14	
	Women over 14	
	Men 15-59	
	Men over 59	
Observable Information (to be recorded by the Interviewer)		
7. What Types of stoves are present in the kitchen?		
8. Does the improved stove appear as if it has been used recently?	Yes/No	
a. Is the stove warm to the touch?	Yes/No	
b. Are there ashes or embers inside?	Yes/No	
c. Is there soot around the fuel chamber?	Yes/No	
9. Where is the stove (circle appropriate answer)?	Inside main house	
	Inside separate kitchen	
	Outside	
	Other -	
10. Does it appear as if other stove(s) are also being used?	Yes/No	

What kind(s) of stove(s)?	Stoves:
11. Describe the fuel that is being used (describe kind of wood, size, moisture, etc)?	Species -
	Size -
12. What is the condition of the stove?	(circle appropriate answer)
Are there cracks in the stove?	Yes/No – if yes, where?
Is the flue/chimney attached?	Yes/No
Are there holes in the flue/chimney?	Yes/No
Is there a door?	Yes/No
Is there other noticeable damage?	Yes/No - if yes, describe:
13. Is there any evidence of repairs made to the stove (describe)?	
14. If the stove has air-holes or other control mechanisms, are they functioning (describe details)?	Yes/No
Questions to be posed to the principle user of the improved stove	
15. How long has the family been using this stove (months or years)?	
16. How often does the family use the stove (circle as appropriate)?	Every day
	Several times a week
	One time per week
	Less than weekly
	Never
a. If the respondent answers once a week or less, ask why it is not used more frequently.	Reason:
17. What kinds of pots are being used in the new stove (describe)?	

18. Does the family perform maintenance on the improved stove?	Type of maintenance	Frequency (circle appropriate response)
	Cleaning stove of ashes	Never Daily Weekly Monthly
	Cleaning flue	Never Daily Weekly Monthly
	Repairing cracks	Never Daily Weekly Monthly
	Other task -	Never Daily Weekly Monthly

19. Is the stove used for any purpose other than cooking food for the family (circle applicable response)?	Preparing food for livestock
	Preparing food/drink for commercial sale
	Other?

20. Does the family use any other kinds of stoves in addition to the improved stove?	Stove/fuel	Age of stove (yrs)	Frequency of use (times per day, week, or month)
If yes, list them here (up to two other stoves in addition to the improved stove)	a) Improved stove		

	b)		
	c)		

21. How much fuel is consumed by each stove and how much does the family spend on each type of fuel per month?	Give answers for each Stove/fuel listed in the response to question	
	Monthly fuel consumption	Monthly expenditure on fuel
	a)	a)
	b)	
		b)
	c)	
		c)

22. Is it easier or more difficult to cook with the new stove? Describe why.	<u>Easier</u> <u>Harder</u>	Why?
23. Do meals take longer to prepare using the new stove? If yes, list the meals that take longer to prepare.	<u>Yes</u> <u>No</u>	Meals:
24. Are there any cooking tasks easier to accomplish with the new stove? If yes, list these tasks.	<u>Yes</u> <u>No</u>	Tasks:
25. What does the cook like most about the stove?		
26. Is there anything that the cook would change about the new stove?		
27. What problems does the cook have with the improved stove? Review the following list and indicate Yes or No as appropriate. Also ask if the new stove is better or worse than the old stove with respect to each problem.		

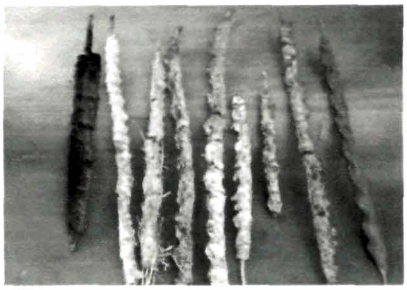
	Problem exists (Yes/No)	Better/worse than old stove:
a. The stove causes burns		
b. The pots are not stable		
c. The pots do not fit		
d. Fire turns pots black		
e. Stove makes a lot of smoke		
f. Stove takes long to get hot		
g. Stove is hard to start		
h. Fire goes out easily		
i. Hard to control temperature		
j. It is difficult to cook certain foods (list locally appropriate foods below)		
•		
•		
•		
k. Stove uses too much wood		
l. Can not fit preferred size of fuel		
m. Stove does not heat the room during cold seasons		
n. Stove does not provide light		
o. Stove breaks easily		
p. Stove needs a lot of maintenance		
q. Other problems (list)		
•		
•		
•		

Annexure VII

WHO air quality guidelines (Indoor), global update 2005

Pollutants	Standard	Averaging time
Carbon monoxide	9 ppm	8-hour
	25 ppm	1-hour
$PM_{2.5}$	25 μg/m^3 10 μg/m^3	24-hour (99 percentile) 1-year
PM_{10}	50 μg/m^3 20 μg/m^3	24-hour (99 percentile) 1-year
Ozone	100 μg/m^3	8-hour, daily maximum
Nitrogen dioxide	200 μg/m^3 40 μg/m^3	1-hour 1-year
Sulphur dioxide	500 μg/m^3 20 μg/m^3	10-minute 24-hour

People constructing roof with thatch



Guitha prepared with cowdung

Firewood stored in homes

Woman preparing food with ICS

Chimney outlet of ICS in roof

Indoor smoke released from the roof

Monitoring of CO, CO_2 and $PM_{2.5}$ with Dust trak and Air quality monitor and questionnaire survey with cook