

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF MEDICINE
DEPARTMENT OF PHYSIOLOGY**



**EFFECTS OF INDOOR AIR POLLUTION BY BIOMASS
FUELS ON RESPIRATORY FUNCTIONS IN GONDAR,
ETHIOPIA**

**A Thesis Submitted to the School of Graduate Studies, Addis Ababa
University in Partial Fulfillment of the Requirements for the Degree
of Master of sciences in Medical Physiology**

**BY
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**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

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ETHIOPIA**

By

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Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for a degree in any university and that all sources of material used for the thesis have been duly acknowledged

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List of Acronyms

ARI	Acute respiratory infection
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary diseases
DALYs	Disability-adjusted life years
IAP	Indoor air pollution
FVC	Forced vital capacity
FEV ₁	Forced expiratory volume at first second
NO ₂	Nitric oxide
NGO's	Nongovernmental organizations
OSHA	Occupational Safety and Health Administration
PM	Particulate Matter
Ppm	Part per million
PEFR	Peak expiratory flow rate
RSPs	Respirable suspended particles
SO ₂	Sulfur dioxide
WHO	World health organization

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Abstract

Poor households in Ethiopia depend heavily on wood, dung, and other biomass fuels for cooking. Inhalation of pollutants from these fuels may cause deleterious effects on health. The objective of this study was to investigate the effects of exposure to indoor air pollution from the use of biofuels on lung functions and respiratory symptoms in women.

The study was conducted at Gondar town (kebele16) 750 kilometers from Addis Ababa between June and August 2010. A total of 285 women (200 biomass fuel users, 85 non users) between ages 18 and 59 years (mean age 29.7 ± 9.14 for biomass users and 30.83 ± 11.07 for controls) were selected by multistage cluster sampling technique. All selected subjects were non-smokers and used to cook 3-4 hr/ day regularly. Those who cook in open air without kitchen and smokers were excluded from the study. A closed end respiratory symptom questionnaire was administered by a trained laboratory technician at the house where the study participants were cooking. The questionnaire included history of smoking in the family, type of cooking fuel used, and duration of cooking and respiratory symptoms experienced, frequency of the signs and symptoms, past illness, etc .

All Participants' height and weight were measured in light clothing and with their shoes removed. Height was measured to the nearest 0.1 cm using a standard meter while weight was measured to the nearest 100 g using Salter scales. Lung function tests (forced vital capacity (FVC), forced expiratory volume in the one second (FEV_1) of each woman were measured by using a Spiro Pro spirometer and peak expiratory flow rates (PEFR) by Wright peak flow meter. Each subject was instructed to sit and practice with the instrument, to place the mouthpiece in the mouth keeping the nose closed, to make a maximal inspiratory effort, and to blow out with a maximal effort. The test was repeated five times after adequate rest, and results were obtained from the spirometer. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were derived from best spirogram recorded. Three peak expiratory flow rate (PEFR) readings were recorded using Wright peak flow meter and the maximum record was used. $FEV_1\%$ ($FVC/FEV_1 \times 100$) and individual predictive values based on age, sex, body weight, standing height were calculated by using predicted formula. The Carbon monoxide (CO) level used to assess indoor air pollution from biomass fuels was measured in each kitchen while cooking by using digital CO meter Metavico/09 as per instruction on the manual and the effect of this pollution on the women's respiratory function was analyzed.

The prevalence of wheeze (OR=8.11), phlegm (OR=17.1), bronchitis (OR=2.08) and asthma (OR=7.01) were significantly higher in the exposed groups relative to the no-exposure group. The mean measured value of ventilatory capacity FVC (2.20 ± 0.89 for biomass users and 2.62 ± 0.89 for controls, $p=0.0004$); FEV_1 (1.67 ± 0.77 for biomass users and 2.24 ± 0.82 for controls, $p=0.0002$) and PEFR (181.45 ± 72.14 for biomass users and 243.52 ± 98.13 for controls, $p=0.0003$) were found to be significantly reduced in exposed group compared with controls and predicted values. Mean indoor CO level (238 ± 40 ppm) were higher than Occupational Safety and Health Administration (OSHA) exposure limit (101-200 ppm) and negatively correlated with reduction in the mean lung function parameters. It is concluded that indoor air pollution had deleterious effect on the respiratory function of women. The study recommends that better ventilated houses with windows, separate kitchens be used and that exposure level may be limited by using improved stoves rather than the usual 3-stone-fire stove and that there must be intervention that educates women about behavioral possibilities to reduce the exposure for themselves and their children to cooking fire.

Key words- Indoor air pollution, Carbon monoxide, Lung function parameters, Respiratory symptoms

1. Literature review

1.1. The Use of Biomass Fuels in the World

Biomass is defined as the group of biologic materials (living organisms, both animal and vegetable, and their derivatives) present in a specific area, collectively considered. Some of this material is used as fuel for cooking or home heating (Smith, 1987).

Close to 50% of the world population(around 3 billion people) use biomass fuels as their primary source of domestic energy for cooking, home heating, and light, ranging from near 0% in developed countries to more than 80% in China, India, and sub-Saharan Africa (World Resources Institute, 1999). In the rural areas of Latin America, approximately 30 to 75% of households use biomass fuels for cooking (Bruce, 2000).

Wood is the biomass fuel most frequently used both as unprocessed wood and as charcoal, the latter having far lower impact in indoor air pollution (WHO, 2002). In some regions, especially in sub-Saharan Africa, roughly 20% of the wood energy harvest is processed into charcoal and could reach 50% in some countries (WHO, 2002). Use of animal dung, crop residues, corncobs, and grass increases when wood is scarce or the forests are situated far away from the community (WHO, 2002).

The use of solid fuels is linked to the gross national product per capita (Barnes *et al*, 1994), and in general, in the same geographic zone, the use of solid fuels is higher in households with lower income. The global energy derived from biomass fuels has fallen from 50% in 1900 to nearly 13% in 2000, but recently it seems to be increasing, especially among the poor (Smith, 1990). The current socioeconomic situation in many developing countries suggests that the use of biomass fuels will continue in the coming decades (Bruce, 2000). In these countries, nearly 2 billion kilograms of biomass are burned every day (Smith, 1988). In rural India, nearly 90% of the primary energy is derived from biomass (wood, 56%; crop residues, 16%; dung, 21%) (Balakrishnan, 2002). The total annual average of wood production used for fuel in developing countries increased approximately 16.5% over the past decade to about 1.55 billion cubic meters (Ezzati, 2000).

Studies specific to East Africa demonstrate that air pollutants originating from biomass are indeed problematic in that region. Kumie et al, 2009, found that in one region in Ethiopia the level of NO₂ in households that used biomass fuel for cooking was twice the WHO guideline for NO₂ concentrations. A study in rural southwestern Ethiopian communities (Farris, 2002) documented the biomass fuel-related problems. These included the conditions that produced exposure such as no separate kitchen and lack of windows and elevated particulate matter concentrations. Another study in rural northern Ethiopia documented that 80% of cooking was done indoors with biomass (Edelstein et al, 2008). In this same study only 13% of the women thought the smoke exposures were of concern. In nearby Kenya, Ezzati and Kammen(2001) studied the effects of pollutants from biomass combustion on health in rural areas and found that acute respiratory infection increased with increasing exposure to particulates with a mass median aerodynamic diameter less than 10 μm.

This same study indicated that due to gender roles (including cooking), females spend more time indoors than outdoors, and thus they may have higher exposures to indoor air pollution than adult males. The exposures are likely to be higher for females in rural areas, where the “3-stone fire” is traditionally used for cooking compared to urban and semi urban areas, where ceramic wood stoves or charcoal stoves are more likely to be used for cooking.

1.2. Pollutants from Biomass Fuels

Uncontrolled exposure to indoor air pollution occurs in most poor communities. The main cause is the use of cheap or free, readily available fuels such as sticks, crop residues such as maize and sorghum stalks, animal dung, and less commonly, charcoal in open, unvented fireplaces inside the home. The typical fireplace is an earth hearth on the floor with three stones or clay props to carry a pot. Use of cleaner fuels, such as kerosene or butane, is mostly too expensive, both in terms of investment for equipment and in terms of the fuel cost itself. There are also strong traditions that regulate both the type of hearth and the use of fuels (Zhang and Smith, 2003).

As smoke, pollution from biomass fuel combustion is a complex mixture of gases and suspended particles. Among the gases, carbon dioxide, water vapor, oxides of nitrogen and carbon monoxide are the most dominant, but a large number of organic compounds occur in the smoke in proportions relating to both fuel type, conditions of combustion and temperature (Bruce et al, 1998). It also includes inorganic salts, carbon, and hydrocarbons mixtures depending on fuel and combustion conditions. The larger molecules of polycyclic hydrocarbons have been implicated in cancer causation (Bruce *et al*, 1998).

Carbon monoxide, for example, can cause acute and chronic effect on humans at various concentrations which may be manifested as headache, dizziness, vision and hearing impairment, asphyxia, cerebral congestion, edema and death (Lan *et al*.2002). There is also growing evidence of health effects of other kinds, including Tuberculosis, cataracts, several other cancers, low-birth-weight, still birth and heart disease. (Smith, 2003)

1.3. Contribution of the Use of Biomass Fuels to Air Pollution

In general, the household use of solid fuels (biomass or coal) is the main source of indoor air pollution and, in certain geographic zones and seasons, also of outdoor pollution. The pollutant emissions from burning solid fuels usually exceed considerably the health-based national standards for outdoor pollution (U.S. Environmental Protection Agency, 1997).

1.3.1. Indoor air pollution

Cooking is the most important activity contributing to indoor air pollution. However, in some regions, especially in Asia, heating is another important source (Jin *et al*, 2005). The majority of rural households in developing countries burn biomass fuels in open fireplaces or in nonairtight stoves, resulting in substantial emissions, which, in the presence of poor ventilation, produce very high levels of indoor pollution with 24-hour mean PM10 levels in the range of 300 to 3,000 mg/m³, which may reach 30,000 mg/m³ during periods of cooking (Bruce *et al*, 1998).

The mean 24-hour levels of CO in the same households are in the range of 2 to 50 ppm, and can reach 500 ppm during cooking. The measurement of indoor air pollution from biomass combustion is complex because of the temporal and spatial distribution within the household, and the characteristics of the ventilation.

In developing countries, the levels of indoor air pollution in homes using biomass fuels for cooking far exceed the health-based standards in the whole household, in both cooking and sleeping or living areas, with repeated episodes of intense emissions (Ezzati *et al*, 2000). Cooking or heating with biomass fuels in stoves or fireplaces vented to the outdoors (airtight stoves) also produces high indoor air pollution. Several important pollutants exceed substantially the total global outdoor exposures, although there is a substantial reduction in indoor concentration of pollutants compared with houses with unvented stoves.

Studies from China (Zhang *et al*, 2005) and from other developing countries (Saksena *et al*, 2007) provide data supporting the large contribution of indoor pollution to total exposure, especially for women and children. In China, it has been estimated that 80 to 90% of the total exposure to PM10 results from indoor air pollution due to solid fuel use in the rural population and this contribution is less than 60% in the urban population (Mestl *et al*, 2007). The level of exposure of a population or an individual who uses solid fuels is extremely variable (Kilabuko *et al*, 2007). Up to half of the total exposure in women who cook with solid fuel may be due to high-intensity episodes when they are close to the fire, especially when starting or stirring the fire (Kilabuko *et al*, 2007).

In addition to the strength of sources, the impact of indoor emissions on air quality depends directly on ventilation and air mixing of the space. Most housing in developed countries lies at temperate latitudes and has relatively low exchange rates of indoor with outdoor air, typically one air change per hour or less (Murray *et al*.1995).

Even low emission rates in such housing can result in indoor pollutant concentrations at levels of public health significance. Ventilation rates for houses in developing countries, which lie primarily in tropical and subtropical regions of the world and are often open to the outdoors, are

likely to be greater (Murray et al.1995). Strong sources can be readily identified in developing countries, however, including biomass (wood, crop residues, and dung) and coal burning for cooking and heating.

Indoor pollutants can be grouped by source into four principal classes: combustion products; semi-volatile and volatile organic compounds released by building materials, furnishings, and chemical products; pollutants in soil gas; and pollutants generated by biological processes (Samet et al.1991). The principal combustion pollutants include carbon monoxide, nitrogen and sulphur oxides, particles, and volatile organics. The complex mixture in indoor air produced by tobacco smoking has been referred to as environmental tobacco smoke (ETS) (Samet et al.1991). A wide variety of semi-volatile and volatile organic compounds can be found in indoor air; there are diverse sources of these compounds. The gas from the ground beneath a home may contain pollutants such as radon and termiticides that may adversely affect health. There are many biological agents in indoor environments including, for example, pollens and moulds, insects, viruses, and bacteria.

Although systematically collected data are unavailable, it is likely that the relative importance of the four types of indoor air pollution varies throughout the world with climate and level of development. For combustion sources, some generalizations can be made. After tobacco smoking, gas stoves have been the most common indoor pollution source of concern in studies in developed countries (Samet *et al.*1991). In the global context, however, gas stoves are near the upper end of a historical evolution in the quality of household fuels, sometimes called the energy ladder (Smith, 1990).On the lowest rungs are dried animal dung and scavenged twigs and grass as cooking fuels. The next rungs in the sequence are crop residues, wood, and charcoal. The first non-biomass fuel on the ladder is kerosene or coal, and bottled and piped gases and electricity are highest. In general, each successive rung on this ladder is associated with increases in the technology of the cooking system, cleanliness, efficiency, and cost.

1.7. Indoor air pollution and acute lower respiratory infection

According to the WHO Global and Regional Burden of Disease Report(2004) acute respiratory infections from indoor air pollution from burning wood, animal dung, and other biofuels are estimated to kill one million children annually in developing countries.

Pneumonia, the most common type of Acute Lower Respiratory Tract Infection (ALRI), is now the single most important cause of death worldwide among children under 5 years of age (Smith *et al*, 2000). The risk is highest in the first year of life, and especially in the first six months (Smith *et al*, 2000). A growing number of studies have reported an increased risk of ALRI associated with exposure to bio-mass smoke, although for a number of reasons to do with the methods and study design, the evidence from these studies is not reckoned to be particularly strong.

1.7.1 Studies Using indirect Exposure Indicators

The early studies with few exceptions use indirect measures for linking indoor air pollution to ARI, such as traditional house, “no window in house,” or use of biomass fuels (Smith *et al*, 2000). Most studies use small sample size in relation to exposure homogeneity, the high occurrence of the health outcome, and the potential for confounding, all of which lead to a need for a large study sample (Romieu *et al*, 2002).

One study from Nepal among 2 years old children who were followed for two different periods showed that a statistically significant for consistency and direct relationship between “hours near the fireplace” and severe pneumonia (Ezzati *et al*, 2002).

Three studies conducted on children of 5 years old from Gambia used the indirect exposure definition of “child being carried on the mother’s back during cooking” and all the three studies

reported that there was an increased risk of ARI among the exposed children (Ezzati and Kammen ,2002).

An intervention introducing improved stoves to compare the traditional one i.e. three-stone fireplace in Kenyan community reported that ARI significantly associated with using the traditional stove (Ezzati and Saleh, 2000).

Similarly a study from Turkey among a cohort of 204 infants who were followed up until their first birthday indicated that the risk of acute lower respiratory tract infection (ALRI) which were identified as reported symptoms, were significantly related to use of wood stove for heating(Viegi *et al* ,2004).

1.7.2. Studies Using direct Exposure Indicators

A few of these studies have measured exposure to smoke directly. Furthermore, people with lower exposure usually have better housing, nutrition, and less crowding. As a result, it is difficult to determine whether it is the smoke exposure itself that is responsible, or the association of smoke exposure with these factors. Nevertheless, the results are quite compelling especially as there is growing evidence of the effects of particulate pollution in urban settings, and that passive smoking (another form of biomass air pollution) increases the risk of acute chest illness in young children.

A study in Kenya measured respirable suspended particles (RSPs) and nitrogen dioxide as 24-h averages. Pollution samples were taken from a sample of houses, stratified according to building characteristics such as thatched vs. corrugated roof or external vs. internal kitchen (in total, 36 houses) (Smith, 2000). Concentrations of RSPs were consistently very high, reported as 20-times higher than those found in a study of Dutch smokers' homes.

Nitrogen dioxide concentrations were on the same levels as in smokers' homes (Wafula, 1990). Other studies exposure levels also report high or very high levels of indoor air pollution and known factors related to high levels of exposure (Smith, 2000).

1.8. Chronic Obstructive Lung Disease (COPD) and Biomass Smoke

Chronic Obstructive Lung Disease is one of the leading causes of morbidity and mortality in the industrialized and developing countries (Duflo *et al*, 2008). It is predicted that by 2020, COPD will be the third leading cause of death and the fifth leading cause of lost disability-adjusted life years (DALYs) worldwide (Briggs,2003). A large number of cross-sectional and case-control studies of people in developing countries exposed to solid fuel smoke have suggested that chronic exposures are associated with chronic airflow obstruction in adults (Rehfuess *et al*,2006). However, most of the studies only investigate the prevalence of COPD in different fuel-type groups. The study by Liu *et al* (2003) investigated the relationship between COPD and air pollutant concentrations of SO₂, NO₂, CO and particulate matter with an aerodynamic diameter of 10 µm or less (PM10). They found that air pollutant concentrations in the kitchen and adjacent living area and the SO₂ concentration in the kitchen of patients with COPD were significantly higher than for those without COPD. In these studies SO₂ was significantly associated with the prevalence of nonsmoking women with COPD.

The study by Mishra (1997) showed that elderly men and women living in households using biomass fuels have a significantly higher prevalence of asthma than those living in households using cleaner fuels; the adjusted effect was higher in women than in men.

The results of a population based case-control study of childhood asthma conducted in Shunyi county located in suburban Beijing showed an increased risk for use of coal for heating and cooking without ventilation (Briggs , 2003).

The finding of another study showed that exposure to solid fuel smoke exacerbate asthma for children between 5 and 14 years and for persons older than 15 years (Rojas *et al*, 2002).

Another study in large size group of 7058 elementary school children living in four large Chinese cities was done to assess exposure –response relations (Bruce *et al*, 2004). When lifetime exposures to coal smoke from heating were classified according to four ordinal levels (no, light, moderate and heavy exposure), monotonic and positive exposure-response relationships were observed for odds ratio estimates of phlegm, cough with phlegm and

bronchitis (Bruce *et al*, 2004). In addition, cough, wheeze and asthma were all more in the exposed groups relative to the no-exposure group (Bruce *et al*, 2004).

One survey study on respiratory illness and domestic pollution from fires in an arid high altitude region of northern India found prevalence of chronic cough with chronic phlegm rose steeply with age, and was greater among women than men. Lung function was significantly worse in those reporting chronic cough, independently of age and sex (Barnes *et al*, 2004). Carbon monoxide (CO) measurements were used to assess domestic pollution from fires. In non-smoking men and the women, levels of exhaled CO were very significantly higher in winter than in summer, in summer, as were the levels of CO measured in the houses (Barnes *et al*, 2004). Negative association was found between the winter value of CO in exhaled air and FEV1/FVC ratio in women (Barnes *et al*, 2004). During winter, fires without chimneys gave higher levels of house pollution and individual CO in exhaled air than those with chimneys (Barnes *et al*, 2004).

2. Significances of the study

Approximately one half the world's population relies on biomass fuel (wood, charcoal, crop residues, or dung) as a primary source of domestic energy (World Resources Institute, 1999). This practice results in widespread exposure to indoor air pollution (IAP), predominantly in developing countries where other sources of energy are becoming increasingly inaccessible and unaffordable (World Resources Institute, 1999). The health effects of indoor air pollution are severe affecting women and children on their mothers back. On top of indoor air pollution there are confounders such as unventilated house and domestic crowding (Larson, 2002)

The empirical base for the health effects of biomass fuels is comparatively narrow, with few empirical studies in relation to the magnitude of the global public health importance of the problem. Most existing reports consistently indicate that indoor air pollution is indeed a risk factor for respiratory disease, but studies are generally small and use indirect indicators of pollution, such as use of biomass fuel or type of stove (Smith *et al*, 2000).

Exposure assessment for indoor air pollution in developing countries is recognized as a major obstacle because of high cost and limitations in infrastructure to measure chemical pollution. Use of indirect indicators without measurement support may increase the risk of both misclassifications of exposure and of confounding by other poverty-related factors (Smith et al, 2000).

The present study uses direct exposure measurement to pollution by measuring CO level in each kitchen and measures lung function parameters during cooking. Based on the findings, the study will provides information for users about the adverse health effect of indoor air pollution and will prepare methods to improve their stove and to use separate ventilated kitchen from living room.

The study will provide information for Health bureaus and NGO's to educate the community, to work in an area of exploring qualitatively options for interventions that are culturally and economically acceptable to local communities.

3. Objectives

3.1. General Objective

- ✓ To study the effect of indoor air pollution from biomass fuels (wood, animal dung and crop product) on respiratory functions.

3.2. Specific objectives

- ✓ To measure the amount of CO from biomass fuels
- ✓ To compare lung functions at various CO exposure levels
- ✓ To compare lung functions of biomass and non-biomass fuels users
- ✓ To compare respiratory symptoms in biomass and non biomass fuel users

4. Materials and methods

4.1. Study participants

A total number of 285 women, selected by multistage cluster sampling technique, participated in this study. From 21 kebeles of the Gondar town, Kebele 16 (Chechela) area was selected randomly and all voluntary women were included in the study. The biomass user group was represented by 200 women from Gondar town (kebele 16, Chechela area). They were in the age group of 18-58 years (29.7 ± 9.14) and used to cook regularly with wood, cow dung and agricultural refuse such as, dried leaves etc. Another group of 85 women from Gondar university medical students and staffs, who do not cook, aged 18-59 years (30.8 ± 11.07), was enrolled as controls. Women in study population and control groups were selected randomly. All of them were non-smokers, and biomass users used to cook 3-4 hr/ day regularly.

4.2. Sample size

Sample size was determined by using Open EPI, Version 2 using the following formula, which compare two means,

$$n_1 = \frac{(\sigma_1^2 + \sigma_2^2 / k) (Z_{1-\alpha/2} + Z_{1-\beta})^2}{\Delta^2}$$

$$= \frac{(59.05^2 + 0^2 / 3)(1.96 + 0.8)^2}{18^2}$$

$$n_1 = 81$$

$$n_2 = \frac{(k * \sigma_1^2 + \sigma_2^2) (Z_{1-\alpha/2} + Z_{1-\beta})^2}{\Delta^2}$$

$$= \frac{(3 * 59.05^2 + 0^2)(2.76)^2}{18^2}$$

$$n_2 = 245$$

Where n_1 = sample size of control group

n_2 = sample size of biomass users

σ_1 = standard deviation of group 1

σ_2 = standard deviation of group 2

k= ratio of sample 2 to sample 1

$Z_{1-\alpha/2}$ =two –sided z value

$Z_{1-\beta}$ = power Δ^2 = mean difference

The determined sample size was $n_1=81$, control group, and exposed group, $n_2= 245$ but actual numbers of participants involved in the study were $n_1= 85$ and $n_2= 200$ because participants who cook in open air without kitchen and smokers were excluded from selected sample.

4.3. Respiratory Data Collection

A questionnaire developed on the pattern of the Medical research council (UK) Respiratory Questionnaire 1986, National Lung Institute and the British Occupational Health Research Foundation (BOHRF) with some modifications, was used for evaluation of respiratory health. The questionnaire contained questions on personal characteristic (code, sex, age, height, weight, smoking habits, etc.).

Questions on respiratory symptoms included: history of cough with or without any expectoration, amount of expectoration/day, winter exacerbations, history of any wheezing, history of chest tightness, doctor diagnosed asthma, and other systemic complaints (fever, headache, etc.). Participants' height and weight were measured with participants dressed in light clothing and with their shoes removed. Height was measured to the nearest 0.1 cm using a standard meter while weight was measured to the nearest 100 g using Salter scales.

4.4. Ethical consideration

The investigation was started after getting ethical clearance of study on human participants by Addis Ababa University Institute Research Board and Physiology department, Department Research Committee.

4.5. Pulmonary function measurement by spirometry

Lung function measurement was performed using a portable, digital Spiro pro spirometer mini-Wright peak flow meter assessments were made by a trained laboratory technician according to standard protocols. The spirometer was calibrated daily and used in ambient temperature. The lung function test of the present study was based on the operation manual of the instrument, with special reference to the official statement of the American Thoracic Society of Standardization of Spirometry.

Each subject was instructed to sit and practice with the instrument, to place the mouthpiece in the mouth keeping the nose closed, to make a maximal inspiratory effort, and to blow out with a maximal effort. The test was repeated five times after adequate rest, and results were recorded by the spirometer. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV₁) were derived from best spirogram recorded. Three peak expiratory flow rate (PEFR) were recorded using Wright peak flow meter and the maximum record was used.

FEV₁ percent, the FEV₁ expressed as a percentage of the FVC was calculated. The data were compared with individual predictive values based on age, sex, body weight, standing height and calculated by using prediction formula (Mengesha, 1985 and Mashalla, 1994).

4.6. Exposure to air pollution

Daily integrated pollution exposure was measured by using information on concentrations of carbon monoxide (Ppm) in conjunction with information on time activity patterns. The CO level was measured by using CO meter Metavico/09 and sampling protocol was based on instruction on the manual. Briefly, CO concentrations were measured in the microenvironments of exposure (kitchen) in each selected households while cooking.

The measurements were done at three levels, near the fire, far away from the fire and in the living room and the average value were taken. The households' kitchen and living room were not separate.

4.7. Statistical analysis

Analysis of data was done by SPSS 13 statistical package. Descriptive analyses were done for the variables of the present study. Individual pollution exposure was estimated by using information on the concentrations of CO in each kitchen. T-test was used to compare the mean FVC , FEV₁ and PEFR with readings in biomass users and controls .Odds ratio with 95% confidence intervals was calculated to compare the prevalence of respiratory symptoms in case and controls. Correlations between exposure indicator (CO level) and lung function were estimated using Pearson correlation coefficients and $p < 0.05$ was considered. Finally, to explore the relationship between respiratory symptoms and the exposure to pollutants, logistic-regression analysis was used. The adjusted odds ratios (ORs) and their 95% confidence intervals (CIs) were computed.

5. Results

5.1. Demographic characteristics

Descriptive characteristics of biomass fuel user and control women are compared as shown in Table 1. It is evident that they were similar with respect to age. Mean ages of the study participants were 29.7 (± 9.14) years for biomass users ($n = 200$) and 30.83(± 11.07) years for controls ($n = 85$). In case of biomass users almost 22(11%) of subjects were <20 years old, 138(60%) of subjects were in 20–39 years age group, 40(18%) of subjects in 40–59 years age. In case of control participants almost 11 (12.9 %) were <20 years old, 55 (40.6%) of subjects were in 20–39 years age group, 19 (28.5%) of subjects in 40–59 years age group and 18.2% subjects were more than 59 years old. Mean height was 159 cms (± 5.65) for control subjects and 159 cms (± 7.63) for exposed subjects. Similarly mean weight was 53.88 kg (± 8.15) and 56.33 kg (± 10.05) for control and exposed groups, respectively.

Table 1. Demographic characteristics of study population

Variable	Control (n=85) Mean \pm SD	Biomass user (n=200) Mean \pm SD
Age (year)	30.83 \pm 11.07	29.7 \pm 9.14
Range 18-58 years		
Height (cm)	159 \pm 5.65	159 \pm 7.63
Weight (kg)	53.88 \pm 8.15	56.33 \pm 10.05

5.2. Air Pollutant Concentrations

Table 2 presents the results of the air sampling. Carbon monoxide concentrations exceeded the Occupational Safety and Health Administration (OSHA) standard at most kitchens. The carbon monoxide levels in most households (146) was at OSHA exposure limit (101-200 ppm). No

household was found at normal background level (CO<10ppm). The numbers of households with CO level at OSHA standard for living areas (11-50ppm) were only 2 and at OSHA standard for enclosed space for 8-hour average (51-100ppm) were 35 households.

Table 2.CO concentration and frequency (n) of households

Co level (ppm)	Frequency (n)	OSHA standard
0-10	0	normal background level
11-50	2	standard for living areas
51-100	35	enclosed space 8-hour average
101-200	146	exposure limit
>200	17	mild headache, fatigue, nausea, dizziness

*U.S. Department of Labor, OSHA Regulation 1917.24

5.3. Respiratory symptoms and diseases

Respiratory symptom and illness data are summarized in Table 3. Biomass users had higher prevalence of breathlessness (61.5% in user vs. 45.1% in control; OR=1.88), wheezing (49% in users vs. 10.6% in controls; OR=8.11), cough (41.5% in users vs. 14.1 in control; OR=4.31), and phlegm (39.5 in users vs. 3.5 in control).

Table 3. Prevalence of respiratory symptoms in biomass users and controls, Frequency (%)

Variables	Controls	Biomass users	OR	CI (95%)
Breathlessness	39(45.1)	123(61.5)	1.88	1.12-3.147
Wheezing	9(10.6)	98(49)	8.11	3.85-17.08
Cough	12(14.1)	83(41.5)	4.31	2.20-8.45
Phlegm	3(3.5)	79(39.5)	17.8	5.44-58.45

- OR: odds ratio
- CI: confidence interval

The biomass users exhibited increased prevalence of respiratory diseases; bronchitis (25.5% in users vs. 14.1% in control; OR= 2.08), pneumonia (7.5% in users vs. 5.9% in control; OR=1.29), pleurisy (2.5% in users vs. 1.2% in control; OR=0.70), asthma (14.5% in users vs. 2.4% in control; OR =7.03) and hay fever (47.5% in users vs. 28.2% in controls; OR=2.30).

Table 4. Prevalence of respiratory disease in biomass users and controls

Disease	Controls N (%)	Biomass users N (%)	OR	CI (95%)
Bronchitis	12(14.1)	51(25.5)	2.08	1.04-4.14
Pneumonia	5(5.9)	15(7.5)	1.29	0.456-3.69
Pleurisy	1(1.2)	5(2.5)	0.70	0.16-3.00
Asthma	2(2.4)	29(14.5)	7.03	1.64-30.20
Hay fever	24(28.2)	95(47.5)	2.30	1.33-3.97

- OR: odds ratio
- CI: confidence interval

5.4. Changes in lung function

Table 5 Shows pulmonary function tests of the study subjects. There were statistically significant differences between the study groups in all lung-functions (FVC, FEV₁, and PEFr) result ($p < 0.01$). As shown on table 5 biomass fuels users had lower lung function than controls (PEFR = 181.45 ± 72.14 and 243.52 ± 98.13 ; FVC = 2.2 ± 0.89 and 2.626 ± 0.89 ; FEV₁ = 1.67 ± 0.77 and 2.24 ± 0.82 ; FEV₁/FVC% = 76.3 ± 17.2 and 85.4 ± 12.2 , respectively).

Table 5. Lung function data observed and predicted value of biomass users and control, mean \pm SD

Group	number	Observed			Predicted		
		FVC (l/s)	FEV ₁ (l/s)	PEFR(l/min)	FVC(l/s)	FEV ₁ (l/s)	PEFR(l/min)
Biomass users	200	2.20 ± 0.89	1.67 ± 0.77	181.45 ± 72.14	3.22 ± 0.30	2.61 ± 0.25	310 ± 28
Controls	85	2.62 ± 0.89	2.24 ± 0.82	243.52 ± 98.13	3.18 ± 0.26	2.58 ± 0.25	306 ± 34

t=5.9, p=0.0003(PEFR)

t= 3.6, p=0.0004 (FVC)

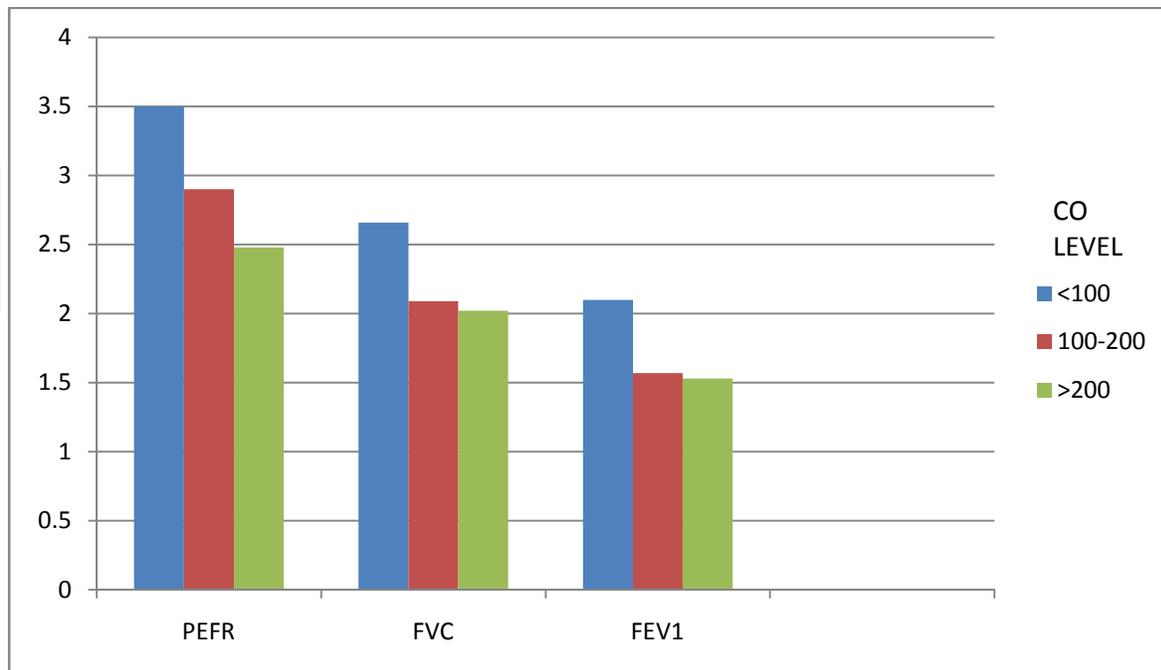
t= 5.6, p=0.0002(FEV₁)

- PEF: peak expiratory flow
- FEV₁: forced expiratory volume in one second
- FVC: forced vital capacity

5.5. Carbon monoxide levels and lung functions

Carbon monoxide was found negatively correlated with lung volumes. At CO level greater than 100, the mean \pm SD of, PEFR= 212 ± 13.58 ; FVC= 2.66 ± 0.155 ; FEV₁= 2.10 ± 0.118 . At CO level 101-200, the mean \pm SD of PEFR, FVC, FEV₁ decreased to 176 ± 5.42 ; 2.09 ± 0.69 ; 1.57 ± 0.06 , respectively. At CO level >200 the lung volumes further decreased to PEFR= 149 ± 24.1 ; FVC= 2.02 ± 0.252 and FEV₁= 1.53 ± 0.29 . Also the Pearson correlation (r) shows the CO level was negatively correlated with mean reduction in lung volumes.

Fig 1. Correlation between lung volumes and CO category



$r = -0.219, p=0.0002$ (PEFR) $r = -0.249, p=0.0003$ (FVC) $r = -0.228, p=0.001$ (FEV1)

- PEF: peak expiratory flow
- FEV1: forced expiratory volume in one second
- FVC: forced vital capacity
- CO :carbon monoxide

Multiple regressions were used to test the association between indoor air-pollutant concentrations and lung-function variability among study subjects. The results of pulmonary-function tests regressed on indoor air-pollution data are presented in Table 6. We found statistically significant ($p<0.01$) relationships between air-pollution level and pulmonary-function tests in the biomass user groups. CO exposure was associated with statistically significant decrease in all three measures of pulmonary functions

Table 6. Regression Coefficient and 95% Confidence Interval of Pulmonary Function Tests on Indoor Air Pollutants pollutant

Pulmonary function	Biomass users
Pollutant †	regression coefficient (CI)
PEFR	
CO	-0.386 (-.626 – -0.145)*
FVC	
CO	-0.005 (-0.008 – -0.002) **
FEV1	
CO	-0.004 (-0.007 – -0.002) **
FEV1/FVC (%)	
CO	-0.118 (-0.180 – -.055) **

* p< 0.05

**p<0.01

- PEF: peak expiratory flow
- FEV₁: forced expiratory volume in one second
- FVC: forced vital capacity

5.6. Relation between lung disease symptoms and lung volumes

Correlation between lung volumes and respiratory symptoms were found statistically insignificant ($p > 0.05$). Statistically significant difference was observed only between PEFR of participants who respond “yes” and “no” to cough and phlegm (PEFR, NO=207.47±92.9, YES=184.9±65.9; $t=2.1$, $p=0.03$)

Table 7. Correlation between the lung volumes and respiratory symptoms (mean±SD)

Variables	Presence/absence	PEFR	FVC	FEV ₁
Breathlessness	NO	203.66 ± 8.53	2.27±0.078	1.83±0.073
	YES	197.16 ± 6.12 (t=0.63,p=0.52)	2.36±0.074 (t=0.76,p=0.44)	1.85±0.066 (t=0.26,p=0.78)
Wheezing	NO	203.65±91.15	2.29±0.82	1.85±0.78
	YES	193.83±75.0 (t=-0.94,p=0.34)	2.37±1.04 (t=0.67,p=0.50)	1.82±0.90 (t=-0.33,p=0.74)
Cough	NO	207.47±92.9	2.38±0.86	1.91±0.75
	YES	184.9±65.9 (t=-2.1,p=0.03)*	2.21±0.99 (t=-1.49,p=0.13)	1.71±0.85 (t=-1.94,p=0.05)
Phlegm	NO	206.95±90.44	2.36±0.86	1.88±0.80
	YES	182.68±69.17 (t=2.18,p=0.03)*	2.24 ±1.01 (t=-0.99,p=0.32)	1.74±0.88 (t=1.29,p=0.1)

*P<0.05

Correlation between lung volumes and respiratory disease were found to be statistically significant (Table 9. below).

Table 9.Relation between the lung volumes and respiratory diseases (mean±SD)

Variables	Presence/ absence	PEFR (mean±SE)	FVC(mean±SE)	FEV ₁ (mean±SE)
Bronchitis	NO	206.94±88.95	2.4118 ±0.90	1.91± 0.84
	YES	175.39±66.86 (t=2.6,p=0.009)*	2.0276±0.89 (t=2.987,p=0.003)*	1.60± 0.73 (t= 2.64,p=0.009)*
Pneumonia	NO	201.85±86	2.34±0.92	1.74±0.74
	YES	175.00±69 (t=1.35,p=0.01)*	2.13±0.68 (t=0.97,p=0.03)*	1.85±0.83 (t=0.782, p=0.049)*
Pleurisy	NO	226.2±114	2.54±1.2	2.18±1.1
	YES	199.2±84.6 (t=0.88,p=0.037)*	2.3±0.90 (t=0.69, 0.048)*	1.83±0.82 (t=1.17,p=0.024)*
Asthma	NO	203±88	2.32±0.92	1.97±0.8
	YES	174±54 (t=1.78,p=0.045)*	2.03±0.82 (t=0.316,p=0.03)	1.81±0.71 (t=0.22,p=0.08)
Hay fever	NO	208±93	2.39±0.87	1.95±0.8
	YES	187±71 (t=2.01,p=0.045)*	2.2±0.9 (t=1.474,p=0.035)*	1.69±0.8 (t=2.563,p=0.011)*

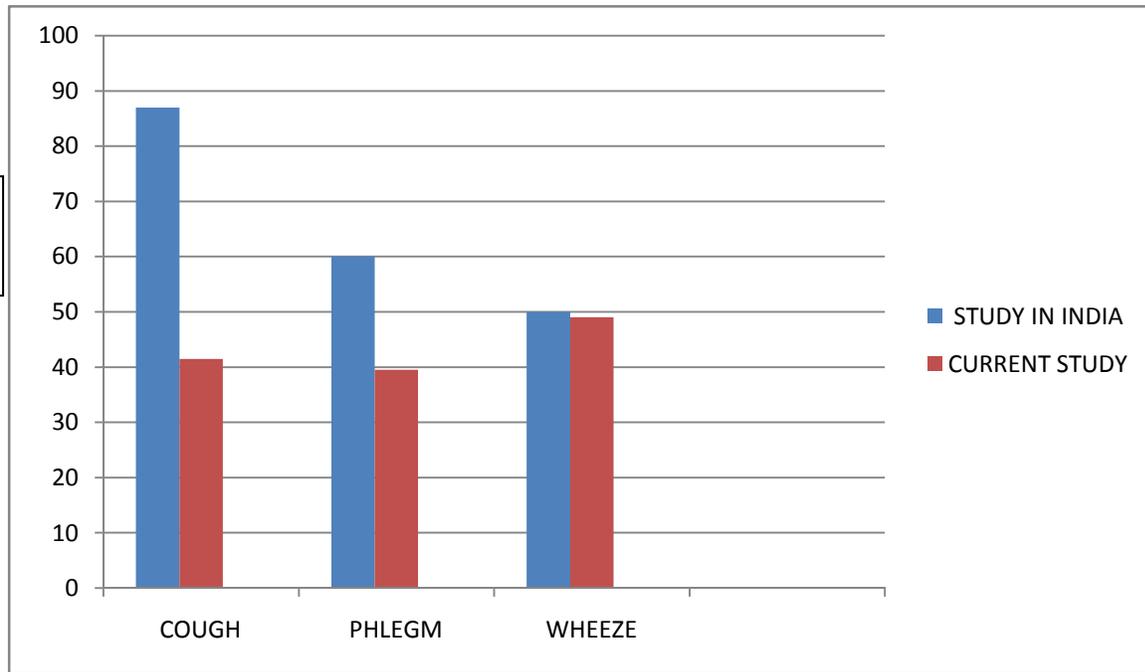
*p<0.05

7. Discussion

This study has come up with the finding that the use of biomass as a cooking fuel produces high concentrations of CO (238 ± 40 ppm) in the indoor environment. Related study in solid-fuel-using households of rural India reported an average concentration of CO (237.8 ± 40.5 ppb) (Naeher *et al*, 2000).

Respiratory disease symptoms were higher in the exposed group than in the control group. Similar result was reported in an Australian study (Pilotto , 2009), where the presence of wood heaters at home was significantly associated with increased prevalence of asthma in females. Wood cooking was also associated with increased risk of respiratory symptoms and impaired lung function in nonsmoking women in Singapore (NgTP, Hui, 1993). Phlegm was the most prevalent respiratory symptom in biomass users group, 17.8 times more in biomass users than control (OR=17.8) and significantly correlated with carbon monoxide level (correlation coefficient =0 .478, $p < 0.01$). In the present study, as carbon monoxide levels increase the phlegm increase. Wheezing was also higher, 8.11 times, more in biomass group than the control group (OR= 8.11). Related study showed that smoke from solid fuels is a complex mixture of many potentially relevant components many of which are toxic to the bronchial mucosa and alveoli because of their ability to form free radicals (Haponic, 2003). When inhaled in sufficient concentrations it tend to produce acute neutrophilic airway inflammation associated with symptoms consisting of cough, bronchorrhea, and dyspnea and wheezing (Laffon et al, 2009). From the respiratory disease asthma was the most prevalent, 7.03 times more in biomass users than the controls (OR= 7.03). Similar study showed that repeated exposures to low concentrations of smoke may contribute to the development of chronic respiratory illness including asthma (Kinsella *et al*, 1991), chronic bronchitis and chronic obstructive pulmonary disease (COPD; Pauwels *et al* 2001).

Fig 2. Comparison between respiratory symptoms in current study and related study (Ellegard, 1996)



Lung volumes, especially PEFR (181.45 ± 72.14 , $p=0.0003$) and FEV_1 (1.67 ± 0.77 , $p=0.0002$) in biomass users were highly reduced than the predicted value compared to the control PEFR (243.52 ± 98.13) and FEV_1 (2.24 ± 0.82) which was close to the predicted value. The reason may be that the measurement was done at the time of cooking which may be resulted in an acute decrease in upper respiratory tract diameter. Related study of British adults (Moran *et al*, 1999) showed a significantly reduced forced expiratory volume in one second (FEV_1) in subjects who currently used wood for cooking compared to those who used electricity. Another related study conducted in Turkey reported highly significant reduction of FEV_1 , FVC, and FEV_1/FVC ($P < 0.00001$) in case of biomass fuel users (Sumer *et al*, 2004). Also study conducted in an urban Indian slum showed significantly lower FVC, FEV_1 , $FEV_1\%$ and PEFR values in bio-fuel using women in comparison to modern fuel users (kerosene and LPG) (Dutt *et al*, 2006) Whereas a similar study undertaken involving rural Indian women could show the prominent adverse effect of biomass fuel use on FVC only (Behera *et al*, 1998). Another study by Asim Saha(2005) reported that there were no effect observed on FVC. These conflicting reports may be due to the

extent of lung volumes deterioration that depends on biomass fuel type. Confounding effect of different other factors may also be responsible for this kind of conflicting findings and the need of more such studies including intervention studies must be stressed in order to gather stronger scientific evidence.

Lung volumes were negatively associated with CO level, (CO<100, PEFR=212±13.58; FVC=2.66±0.155; FEV₁=2.10±0.118: CO=101-200, PEFR=176±5.42, FVC=2.09± 0.69; FEV₁=1.57±0.06: CO level >200 the lung volumes further decreased to PEFR=149± 24.1; FVC=2.02±0.252 and FEV₁=1.53±0.29. (r= -0.219, p=0.002(PEFR), r = -0.249, p=0.0003 (FVC), r = -0.228, p=0.001(FEV₁)). Related study also showed Changes in NO₂, CO and black smoke concentrations were found to be negatively associated with FVC, FEV₁ and PEF, but only the associations of NO₂ and CO with PEF, and CO with FEV₁ reached the nominal level of statistical significance (Kymisis *et al*, 2008).

Another interesting finding in the current study is that even though the CO level was associated negatively with the lung volumes, the strength of association was weak i.e. r< 0.5. This may show that there are plenty of pollutants that reduces lung volumes and must be measured in biomass fuel pollution study. Another peculiarity observed in this study was that no correlation was found between respiratory symptoms and reduction in the lung function indices. This may be due to that the respiratory status was measured when acute exposure was considered.

To sum up, the present overall mean reductions in lung function indices, especially PEFR and FEV₁ observed in biomass users (while cooking) were considerable. The CO concentrations recorded in the kitchen seem to correlate fairly with reduction in the lung function indices.

There was no correlation observed between respiratory symptoms and reduction in the lung function indices. However, since these reduction correlate with respiratory diseases that shows presence of cumulative pulmonary impairment in women's subjected to prolonged exposure.

This deterioration of pulmonary function in biomass fuel users has been attributed to the fact that the amount and concentration of particulate matter and other toxic gases emitted during biomass combustion while cooking (WHO, Geneva, 2002).

8. Conclusion

This study shows the adverse effects of biomass fuels use on the deterioration of pulmonary function. The findings of this study also point towards an important environmental health problem involving mostly the poor women and indicate that the health consequences of exposure from biomass and other solid fuels in developing countries should not be ignored not only because the health burden is high but also because of the fact that such fuels will continue to be used throughout the world by a large number of households in the foreseeable future.

Intervention technologies such as adding chimney to kitchen and modernizing uses of bio energy must be given due attention.

9. Limitation of the study

Limitation of the study is its small control group of women with no exposure, which reduces the power of this otherwise rather large study. Even more important is the fact that practically all women had previous exposure to biomass fuels, most of them in their childhood. This means that current biomass fuel exposure could not be contrasted to “never exposure,” but instead to “no recent exposure”. The strongest effects on lung function were detected in relation to high current concentrations of carbon monoxide (CO), so how much of the effect is acute and perhaps reversible and how much of it is long-term reduction that cannot be recovered remains somewhat unclear. Distinguishing these two types of effects is important from a preventive point of view and, in the future, development of better assessment methods for long-term exposures and longitudinal assessment of the change in lung function over time are needed. In many developing countries, smoking by men indoors is also common, and the interactions between tobacco smoke and biomass fuel exposures may add to the health problems, but this has not been studied.

10. Recommendations

Based on this finding and other related findings we recommend that kitchen separate from the living room, and better ventilated houses be used. There should also be interventions that improve stoves and that also educate women to reduce the exposure of family members. Also recommend that these interventions should be affordable and easy to implement. Research on biomass fuels and evidence based interventions should be a high global priority, since reducing indoor biomass fuel exposures locally in developing countries would contribute to simultaneous

reduction of harmful outdoor pollutants (Smith KR., 2002). Indeed, giving more emphasis to such interventions could be a cost-effective way to reduce globally the harmful pollutants leading to the greenhouse phenomenon. More studies should also be done to measure more pollutants, assess effects of indoor air pollution on systems other than respiratory, and compare various types of biomass fuels and control various confounders.

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11. Appendices

A NEX I: CONSENT FORM (ENGLISH VERSION)

A. Subject information sheet

My name is _____ I am a graduate student in department of physiology from AAU the objectives of the study are

- 1) To evaluate effect of indoor air pollution by biomass on respiratory function
- 2) To measure extent of CO from biomass fuels
- 3) To compare lung functions at various CO exposure
- 4) To compare lung function of biomass fuels users and non-biomass fuels users

1. Regarding the participation: If you are agree to take part in the research work

I would like to interview you regarding respiratory symptoms as a result of exposure to indoor air pollution and do physical examination to examine your lung function with spirometer.

2. Risks

You may experience mild exhaustion associated with deep breathing. This just as a result of routine lung function test using spirometer. There is nothing else which may make you discomfort.

3. Benefits

For all participants, health education on respiratory disease will be given at the end of the study. For those who have respiratory problem further diagnosis and treatment will be given at Gonder university hospital.

4. Confidentiality

The information contained in the questionnaire will be kept confidential and the nature of the questionnaire is private. Code numbers will be used instead of your name for all the information. In addition, the results from physical examination will be identified by code numbers.

5. Right to get information

This study gets ethical clearance from RPC of department of physiology and IRP of faculty of medicine, AAU. The main objective of the committee is to protect the participants from any risk and discomfort that may result due to the procedures of the study.

B. Agreement form

For participation as a volunteers in research undertaking

Code number

I have been informed about. It is, therefore, with full understanding of the informed consent and voluntarily allows the researcher to ask the questionnaire and measure my lung functions for the investigation. Moreover, I have had the opportunity to ask questions about it and received clarification to my satisfaction. I have also been informed that the nature of the questionnaire is private.

Signature or thumbprint of participant: _____

Interviewers name _____

Signature _____

Date of interview _____ / _____ / _____

Supervisors name _____

Signature _____ Date of checking

/ /

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Annex II

RESPIRATORY QUESTIONNAIRE

Preamble

I am going to ask some questions, mainly about your chest. I would like you to answer **Yes** or **No** whenever possible.

If the subject is disabled from walking from any condition other than heart and lung disease, please begin questionnaire at **Question 5** and mark the adjacent box

COUGH: cough most days for three consecutive months or more during a year

PHLEGM production: bring up phlegm most days for three consecutive months or more in a year

Wheezing- whistling or wheezing sound in the chest

Breathlessness- trouble by shortness of breath when hurrying or on the level walking up slight hill

Breathlessness and Wheezing

During the last month:

1. Are you troubled by shortness of breath when hurrying?

On level ground or walking up a slight hill? Yes No

If Yes to 1:

2. Do you get short of breath walking with other people of your age on level ground?

Yes No

If Yes to 2:

3. Do you have to stop for breath when walking at your own pace on level ground?

Yes No

4. If you run, or climb MOUNTAINS fast do you ever

a. cough? Yes No

b. wheeze? Yes No

c. get tight in the chest? Yes No

5. Is your sleep ever broken?

a. by wheeze? Yes No

b. difficulty in breathing? Yes No

6. Do you ever wake up in the morning (or from your sleep)?

a. with wheeze? Yes No

b. difficulty with breathing? Yes No

7. Do you ever wheeze?

a. if you are in a smoky room? Yes No

b. if you are in a very dusty place? Yes No

If Yes to Q5, Q6, Q7

8. Are your symptoms better

a. when not cooking? Yes No

b. when you are out of home? Yes No

Cough

9. Do you usually cough first thing in the morning in winter?

Yes No

10. Do you usually cough during the day – or at night –in the winter?

Yes No

If Yes to Q9. Or Q10.

11. Do you cough like this on most days for as much as three months each year?

Yes No

Phlegm

12. Do you usually bring up phlegm from your chest first thing in the morning in winter?

Yes No

13. Do you usually bring up any phlegm from your chest during the day – or at night – in winter? Yes No

If Yes to Q12. or Q13 :

14. Do you bring up phlegm like this on most days for as much as three months each year?
Yes No

Periods of cough and phlegm

15. In the past three years, have you had a period of (increased) cough and phlegm lasting for three weeks or more? Yes No

If Yes to Q15 :

Q16. Have you had more than one such episode? Yes No

Chest Illnesses

17. During the past three years, have you had any chest illness that has kept you from your usual activities for as much as a week? Yes No

If Yes to Q17.

18. Did you bring up more phlegm than usual in any of these illnesses?
Yes No

If Yes to Q18 :

19. Have you had more than one illness like this in the past three years?
Yes No

Past Illnesses

20. Have you ever had, or been told that you have had:

a. An injury, or operation affecting your chest? Yes No

b. Heart Yes No

c. Bronchitis? Yes No

d. Pneumonia Yes No

e. Pleurisy? Yes No

f. Asthma? Yes No

g. Other chest trouble? Yes No

h. Hay fever? Yes No

Tobacco Smoking

21. Do you smoke? Yes No

If No to Q21

Q22. Have you ever smoked as much as one cigarette a day for as long as one year?
Yes No

If No to Question 21 or 22, omit remaining questions on smoking.

23. How old were you when you started smoking regularly? _____

24a. Do (did) you smoke manufactured cigarettes? Yes No

If Yes to Q24a :

