Exposure reduction to indoor air pollution within Indonesian rural communities using wood fuel

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SUMMARY

The current majority in rural Indonesian households still relied on wood fuel for their cooking energy needs. It is expected the wood fuel users continue to increase for years to come and still will be concentrated in Java island where wood fuel resources go into diminishing. In this study, national average wood fuel consumption was estimated to be 1.06 m^3/capita/year. Adoption of dual fuel energy (LPG-wood fuel) is common in rural areas and is mainly driven by economical motive.

With respect to housing characteristics the households in mountainous area using wood fuel were potent to have the indoor air pollution episode than in coastal area owing to smaller room volumes, smaller ventilation area and space heating need. This potential indoor air pollution was exacerbated by improper behavior of the majority of the people in mountainous area where the windows were kept closed during cooking period. Indeed, the rural people had identified indoor air pollutions in their own home properly, however it requires a knowledge and change of the habits to mitigate the indoor air pollution issues in the households.

The disadvantages of using a traditional wood stove were confirmed compared to other stoves in terms of performance and pollutant emissions. Traditional stove had the lowest thermal efficiency and high specific fuel consumption compared to charcoal stove, kerosene stove, improved wood stove (SAE stove) and improved stove using *Jatropha curcas* seed fuel. Ventilation during cooking was important to reduce the exposure of pollutants to the cooks. Cooking without proper ventilation, even using a gas stove, obviously produced considerable amounts of $PM_{2.5}$ and CO in an indoor kitchen at cooking site. When the wood stove was used in the non-ventilated room, cook's exposure to $PM_{2.5}$ was increased by 4 fold than that under natural ventilation. Alternative cook stove, i.e.

Jatropha curcas stove may replace traditional wood stove as this stove emitted less indoor $PM_{2.5}$ (about one tenth) than traditional wood stove did.

Indoor air pollutants concentrations ($PM_{2.5}$ and CO) in rural mountainous area were higher than those in coastal area on average. This could be attributed to bigger room volume, more sufficient ventilation and less frequent cooking with wood fuel in coastal area. Assuming well mixed concentration in the kitchen, the relative risk of cardiopulmonary and cardiovascular was higher for mountainous communities than coastal communities. Using kitchen parameters based on field measurements and secondary data, the prediction of pollutant concentration using single box model showed the ratio of simulated concentration to actual concentration is better for Lembang site i.e. 0.9 and 1.7 compared to Juwana site i.e. 1.13 and 1.8 for wet season and dry season respectively. In fact, the $PM_{2.5}$ concentrations showed comparable values at the cooking sites of both areas. This indicated the human exposure on cooking site was quite high irrespective of the kitchen volume and ventilation. It is recommended to minimize activities in the kitchen during cooking period without specific measures because the indoor $PM_{2.5}$ mass size fraction was dominated in sub-micron particles which are respirable and pose a health threat.

Rural indoor air pollution in Indonesia is related to rural socio-economic situation, people's behavior and government policies. Therefore short-term, medium-term and long-term programs are presented to mitigate the indoor air pollution based on the on-site measurements and questionnaires.

List of Abbreviations

ALRI	: Acute Lower Respiratory Infections in childhood
BPS	: Biro Pusat Statistik (Central Agency of Statistics)
CDIEMR	: Center for Data and Information on Energy and Mineral Resources
CO	: Carbon monoxide
COPD	: Chronic Obstructive Pulmonary Disease
DR	: Deforestation Rate (%/year)
EC	: Elemental Carbon
FA	: Forested Area
JCS stove	: *Jatropha Curcas* Seed stove
NIHRD	: National Institute of Health Research and Development
OC	: Organic Carbon
OPC	: Optical Particle Counter
PICs	: Product of Incomplete Combustions
PM_{10}	: Particulate Matter less than 10 µm in aerodynamic diameter
$PM_{2.5}$	: Particulate Matter less than 2.5 µm in aerodynamic diameter
TC	: Total Carbon
UCB monitor	: University of California Barkeley monitor device
USB monitor	: Universal Serial Bus monitor device
WBT	: Water Boiling Test
WS	: Wood Stove
(V)	: under ventilated condition
(NV)	: under non-ventilated condition

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CHAPTER-1

Introduction

Chapter outline

This chapter describes brief information on the biomass fuel use and the related health impacts in developing countries as well as in Indonesia as a background of the whole work. The importance of this work and associated works are elucidated concisely. In this chapter, the objectives and the scope of this work are defined and the relation between each chapter or dissertation organization is illustrated.

1.1 Biomass fuel use in developing countries

About 2.6 billion people in developing world still rely on the traditional use of biomass for cooking (IEA, 2010). In Asia-Pacific region, the woodfuel consumption was around three-quarters of world roundwood production or equivalent to 780 million m^3 roundwood production (Gumartini, 2009). With historical biomass fuel data (1973 – 2006), it is expected that this biomass fuel will continue to be used for many years to come particularly in the poverty region (Rose et al., 2009). The consumption increase in the future is driven by accessibility, affordability and cultural preferences to the resources. Parikka (2004) calculated that about only two-fifths of the available biomass worldwide were used for energy.

As suggested in energy ladder concept, with respect to affordability, the dominant users of wood fuel in developing world are low income families category. Usually, the urban communities showed higher percentage of expenditure of energy than rural communities (IARC, 2010). The expenditure share of total energy in the rural communities in selected developing countries of Asia and Africa were about 8.4% compared to 8.9% in urban ones, however the share of biomass only rose up to 3.9% in rural and 1.8% in urban (Bacon et al., 2010). This resembles the preference of rural households for biomass fuel. Interestingly, with an increase in the rural people's income and more fuel options to choose, the low-grade fuels were substituted except wood in many cases. The reason was that in the transition process to modern fuels, the households tended to use a combination of fuels and technologies at all income levels (IEA, 2010). The use of multiple fuels improves household energy security against the price variations as a result of modern fuel shortage. Rural communities are commonly located remote from the modern fuel supplier then unreliable service may occur. In addition, the persistent and widespread use of biomass in rural areas also depends on government policies such as subsidies and taxes on modern fuel (IARC, 2010).

The wide range issues emerge as a socio-economic impact of energy use of wood fuel, and the main concern of these impacts are on labor conditions and land-related issues (land contamination, landscape alteration etc. (FAO, 2010). In some areas, this wood fuel use was subjected to indirect cause of deforestation and desertification (Bolaji, 2012). But, perhaps, the most important impact of wood fuel use in the rural areas is its health impact which increases health care costs and has been lasting for decades.

1.2 Indoor air pollution related to fuel energy use

In developing countries, the usage of biomass fuel has adversely affected human health, particularly respiratory disease for the cooks in decades. Nearly 2 million deaths annually were attributed to cooking smoke using biomass as well as coal fuel and about 99% of them occurred in developing countries (WHO and UNDP 2009). This situation arose mainly due to the high level of pollutant exposure from inefficient and incomplete burning in traditional stoves. This inefficient burning of the stoves produces major health damaging pollutants of inorganic gases, hydrocarbons, oxygenated organics, chlorinated organics, free radicals and particulate matters (Smith et al., 2007a).

Due to enclosed environment, the housing characteristics and people's behavior inside the house will determine the exposure of pollutants to household members. Even though the total amount of pollutants inside the house is relatively small compared to that of outdoor, the exposure to pollutants is relatively higher than outdoor due to longer time spent inside (UNDP, 2000; Desai et al.,2004; Smith and Mehta, 2003). The time spent inside the house is defined as time–activity budgets of individual household members e.g., time spent inside or near the stove and direct participation in cooking tasks (Ezzati, 2008). This exposure and the pollutant concentrations are the key parameters of health effect studies of indoor air pollution. The concentrations of various indoor air pollutants due to wood fuel use at locations inside the house depend on energy technology (stove–fuel combination), house design (e.g., the size and construction materials of the house, the arrangement of rooms, and the number of windows), and stove-use behavior (Ezzati, 2008)

There are some evidences that biomass fuel usage lead to several respiratory diseases such as acute lower respiratory infections (ALRI, pneumonia) in young children, chronic obstructive pulmonary disease (COPD), chronic bronchitis and emphysema in adult. The relative health risk of solid fuel use in terms of ALRI and COPD are enhanced to be 2.3 and 3.2 (Desai et al., 2004). In 2004, it was estimated that DALYs (Disability Adjusted Life Year) from indoor air pollution relevant to solid fuel use was 32 million for ALRI and 6.4 million for COPD worldwide (Bruce et al, 2006). It is imperative therefore to intervene immediately to reduce this risk in the developing world, and generally the intervention encompasses the sources (fuel and stoves), living environment and user behaviors (Bruce et al, 2006; Ezzati, 2008). Moreover besides three interventions above, education plays a vital role for better indoor air quality (Desai et al., 2004).

1.3 Indonesian household biomass fuel use and related health impact

Based on energy statistics, the household sector using biomass[1)] is estimated to be increasing on average by 1.6% per year from 2000 to 2010 in Indonesia (CDIEMR, 2011). Based on the national social economic survey, the wood fuel user's fraction was 69 % in rural areas and 15 % in urban areas.

Likewise in other developing countries, some parts of the wood fuel users are located in urban areas in addition to huge consumers in rural areas (see Figure 1.1). Interestingly many of these users, both in urban and rural regions, are not simply categorized as "poor" or low-income households[2)]. The share of wood fuel users is over 60% and the fraction of poor households is below 20% except Papua in rural areas. It seems that culture and accessibility influenced the fuel choices of these affluent households.

Commonly the wood fuel of households in rural areas is self-collection or homegrown wood. In this scheme, they do not accelerate deforestation and desertification (Rose et al., 2009). In Indonesia case, the fraction of wood fuel users collecting the wood from the forest was only 19% in Java island while it rose up to 37% for outside of Java island (Tampubolon, 2008).

As wood fuel users are still high in proportion, particularly in the rural areas, there are some indications of health effects burden that may be the result of wood fuel use. The incidence of pneumonia in children under 5 years old is still prevalent. In 2010 about 499,259 cases of pneumonia for children < 5 yr were detected throughout the 33 provinces and the biggest shares was in West Java provinces i.e. 38% (BPS 2012). The number of the pneumonia children corresponds to 2.1% of the total children under 5 years old across Indonesia. The other study reported, that among 9,106 children under 5 yr being tested, there were strong correlation between wood fuel use and ALRI as well as infant mortality (Kashima et al., 2010). In fact, pneumonia is the second cause of death in Indonesia for

1) Biomass fuel term especially in this statistics reflect mostly to wood fuel

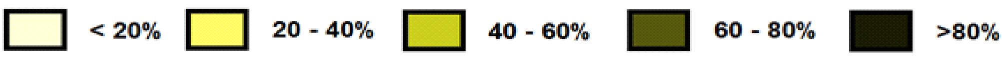
2) The "poor" or low income family definition is based on government statistic category on family income. It differs in inter-provinces throughout the country

children under 5 yr for years. Furthermore, based on village statistics in 2008, about 1411 villages in coastal area and 7065 villages in non-coastal one reported respiratory diseases (BPS, 2008).

(a) Urban area

(b) Rural area

Figure 1.1 Proportion of household using wood fuel based on provinces in Indonesia



Wood fuel use is not likely to be the only determinant of the indoor air pollution episode in rural areas. The housing characteristics and householder behavior are suspected to be the key determinants of the problem of indoor air pollution in Indonesia. Wood fuel users are generally categorized as low-income families then it is supposed that their house living are not in healthy conditions. According to the survey by the Ministry of Health, Indonesia, about 83.2% of housing in rural areas are unhealthy[3)] compared to 67.5% in urban areas (NIHRD, 2010). It is likely that wood fuel users have unhealthy households as depicted in Figure 1.2. Unhealthy housing environment will exacerbate health effects related to indoor air pollution attributable to harmful pollutant exposure emitted from unprocessed wood fuel in a traditional wood stove. To date there is no thorough analysis of household characteristics which is likely a key determinant of indoor air pollution.

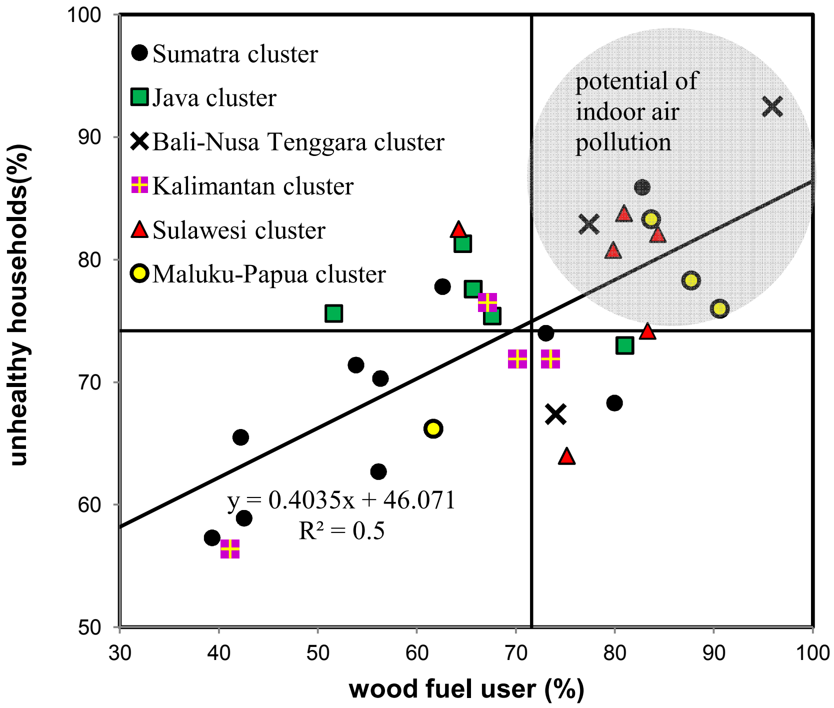


Figure 1.2 Relationship between wood fuel user and unhealthy household

Note : Wood fuel users are for rural only, while unhealthy household variables denote average of rural-urban

Ironically, Indonesia which is estimated to have 45,300 deaths per year and 4 DALYs /1000 capita per year due to solid fuel use (WHO, 2009) has very few studies or even none on indoor air pollution in rural areas. This stands in sharp contrast to China, India and Latin American countries where massive studies were conducted. Typical related-studies were mostly carried out in the workplaces (Sari, 2009; Prasasti et al., 2005; Fitria et al., 2008). Some studies measured indoor air pollutants (PM_{10} and black carbon) in the urban households periphery using different fuel types (Huboyo and Budihardjo, 2009a; Huboyo et al., 2009).

Moreover, the indoor air pollutant concentrations and characteristics of Indonesian rural households are basic data providing valuable information for supporting exposure analysis. The data allows to strategically develop the guidance pathways for improving health quality particularly of wood fuel users across Indonesia which are still persistent in a high proportion of the population.

1.4 Research objectives

The main goal of this research work is to give an understanding of wood fuel energy use and related indoor air pollution problem in order to reduce its exposure in Indonesian rural areas.

To grasp the scope of the main objective, this research work has the sequence objectives as follows:

*1) Analysis of current use and future threat of biomass fuel use in rural Indonesian households***.** The actual wood fuel consumption during cooking in combination with previous studies on wood fuel consumption will make up the total wood fuel consumption throughout Indonesia. The distribution of wood fuel was also visualized.

2) Describing household characteristics of two distinctive areas i.e. mountainous and coastal areas in relation to indoor air pollution potential. In this work, the perspectives of household to improve indoor air quality were also discussed.

3) Analysis of indoor air pollution emitted from gas stove with different cooking method and wood stove with boiling test. In this work, indoor aerosol at cook site was characterized as a basis for understanding the distinctive emission magnitude of modern fuel and traditional fuel. An alternative biomass fuel i.e. *Jatropha curcas* fuel as cooking fuel was also tested for its viabilities

4) Quantification of indoor air pollution in rural mountainous and coastal areas. The pollutants of interest were $PM_{2.5}$ and CO. The pollutant characterization (aerodynamic size segregation and carbonaceous components) is important to evaluate the related health effect.

It is expected that the information presented here represents a small, incremental step toward better understanding for further studies of indoor air pollution exposure within rural Indonesian households.

1.5 Dissertation organization

To reach the objectives and delineate the scope, this dissertation is organized through the way of thinking as outlined in Figure 1.3.

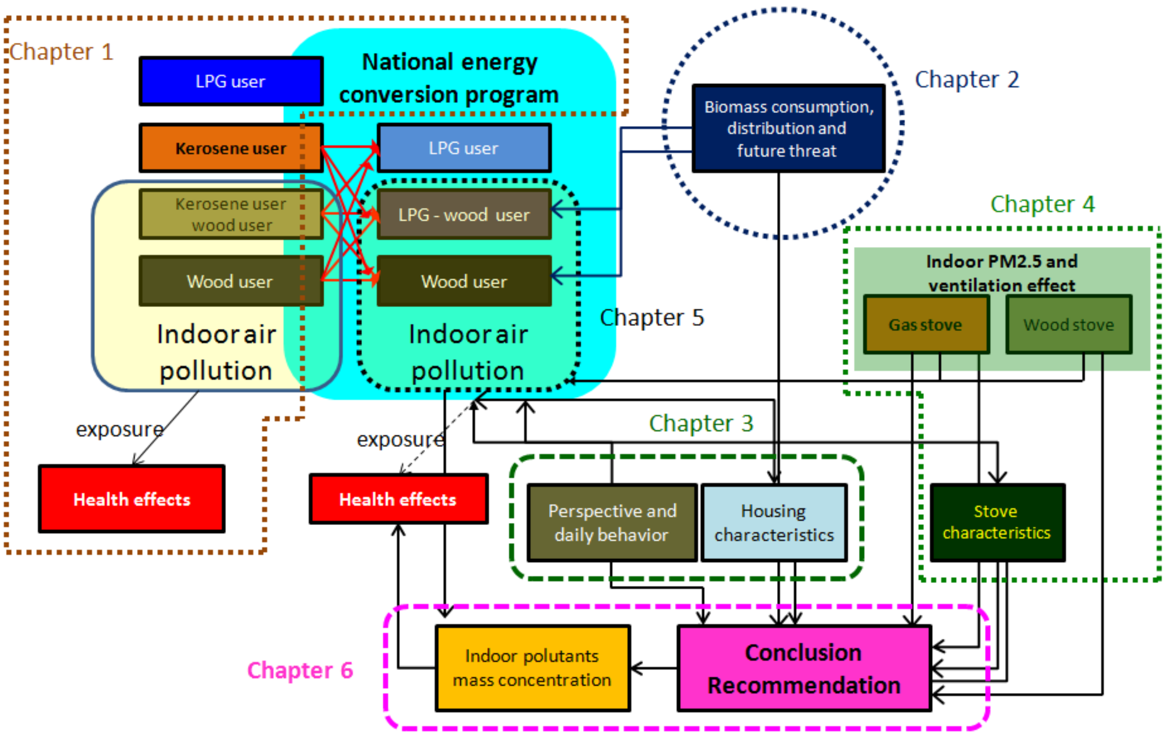


Figure 1.3 Dissertation organization

Chapter 1 describes the background of the research work, objectives and the research scope. Chapter 2 reviews the history, current biomass fuel consumption and future threat. From field measurement, the result of wood fuel consumption in this chapter is compared with that in chapter 5. Household characteristics in rural areas, householder behavior and related indoor air pollution potential are described in chapter 3. This information is useful to analyze the results in chapter 5. Chapter 4 includes the experiments of indoor air pollution at cook site using a gas stove and traditional wood stove as well as alternative stoves. The results of stove efficiencies for wood stove and the effect of ventilation on indoor air pollution are key parameters for the analysis of chapter 5. Chapter 5 covers the field measurements of indoor air pollution in rural Indonesian areas. This chapter includes the supporting data of the findings in the previous chapter. The last chapter (chapter 6) summarizes all the key problems found in each chapter and elaborates proposed timeline recommendation to achieve the goal and reduce the exposure from indoor air pollution.

CHAPTER-2

Household wood fuel consumption in Indonesia and indoor PM_{10} characteristics

(Woodfuel utilization for cooking in Indonesian household: Assessment of indoor PM_{10} pollution and wood consumption at national level, In: Yao T (ed) Zero-Carbon Energy Kyoto 2012, Green Energy and Technology, Springer, pp.123 - 131)

Chapter outline

This chapter describes the household wood fuel consumption at national level based on literature studies and measurement in the field. This chapter covers preliminary measurement of particulate matters (PM_{10}) related to wood stove combustion in rural Indonesian households. Potential biomass fuel scarcity in certain areas and potential exposure to the cooks are also discussed. The result of wood fuel consumption in this chapter will be compared with that in chapter 5

2.1 Introduction

Low income households in developing countries still rely on old biomass fuels, i.e. wood, charcoal and other solid fuels. In 2005, the share of wood fuel consumption for Asia-Pacific region was 41% (equivalent to 787 million m^3/year) of the total world consumption (Gumartini, 2009). The survey conducted by the Ministry of Health, Indonesia showed that at least 17.3% of urban households and 64.2% of rural households still use biomass fuels, i.e. wood and charcoal (NIHRD, 2010) for their cooking energy. Wood fuel was gathered from the forest, garden, plantation and agricultural waste. Historically during 2000 – 2010, the wood fuel users at national level increased by 0.7% where household consumption itself accounts for 84.5% of the increment (CDIEMR, 2011). In addition, there are indications of additional users of wood fuel who were originally kerosene users after kerosene subsidy phase out program (Dwiprabowo, 2010). However the percentage of this shift has not been known yet. Practically, there are open options to choose cleaner fuel among many candidates and wood fuel continues to be an attractive option for the households.

Unit consumption of wood fuel in rural developing countries (after converting to m^3/cap/year unit) is in the range of 0.58 – 1.39 m^3/cap/year (Nansaior et al., 2011; Wijesinghe, 1984; Rojas et al., 2011; Jashimuddin et al., 2006). This consumption may change with urbanization, household income and wood accessibility. In Indonesia case, the studies on household wood consumption were scattered. However until now, there are no full scale studies to reveal unit consumption of wood fuel across the country. Adopting dual fuel (wood and LPG) is currently common for part of urban as well as rural households to secure their energy needs. This is partly due to the unstable subsidized LPG stock in terms of price or availability in the retail market.

Use of wood fuel for cooking poses health consequences for the cooks. Fullerton et al. (2008) listed respiratory and non-respiratory diseases related to biomass usage for both children and adults. It is associated with acute lower respiratory tract infection, low birth weight, nutritional deficiency (for children), chronic obstructive lung disease, tuberculosis, lung cancer, cardiovascular disease and cataracts (for adults). Since biomass is widely used in most of rural areas, it is expected that high exposure of housewives and children to biomass emission causes long-term health effects. For instance, Tana et al. (2009) revealed that cataract was prevalent for Indonesian housewives using biomass fuel rather than gas and kerosene fuel. The main cause of potential harm of biomass emission is fine particles which are generally within inhalable size range. PM_{10} and $PM_{2.5}$ are the two parameters that have been typically adopted for aerosol characterization. Nowadays, ultrafine particles (<100 nm) are more important with respect to acute effects of asthma (AQS, 2012). Conventional wood stove combustion generally emits high mass proportion of fine particles (representing by high $PM_{2.5}$ mass). Moreover, the size distribution of emitted particles can be altered by modifying stove design. For example, using chimney will reduce the fine fraction of the emission (Armendariz et al., 2010).

This study is aimed at quantifying PM_{10} of aerosols related to cooking emission and estimating the demand of wood fuel for cooking energy of Indonesian households.

2.2 Methodology

2.2.1. The location of this study

The case study was conducted in two distinctive rural villages in Indonesia, namely at Sunten Jaya, Lembang, West Bandung regency (West Java province) and at Bakaran Wetan, Juwana, Pati regency (Central Java province). Figure 2.1 shows the map of the two locations with Java island as an inset.

The Sunten Jaya village is a mountainous area with an altitude of 1280 m ASL, having 7,539 people (3459 households). The village having an area of 576 ha is divided into 16 sub-villages. About 81% of the area comprises of non-paddy agricultural field, while the rest is for residential house and cattle breeding which sparsely spread over the village. On the other hand, Bakaran Wetan village is situated in a coastal area of 2 m ASL altitude and the population is 4,994 people (1,532 households). The village having an area of 630 ha is divided into 3 sub-villages. More than 92% of this village area is brackish-water pond while the residential quarters are clustered on the periphery of the brackish-water pond.

The annual rainfall of both sites was almost comparable showing 1300 – 2600 mm. The recorded average outdoor temperatures were 18 – 20°C and 32 – 34°C in Lembang and Juwana, respectively.

Since the end of 2008, these villages have already engaged in LPG conversion where each household gets a 3 kg cylinder of LPG package including the stove. However wood fuel is still used by a large number of people here. Some of these households resell their 3 kg LPG package in fear of gas explosions.

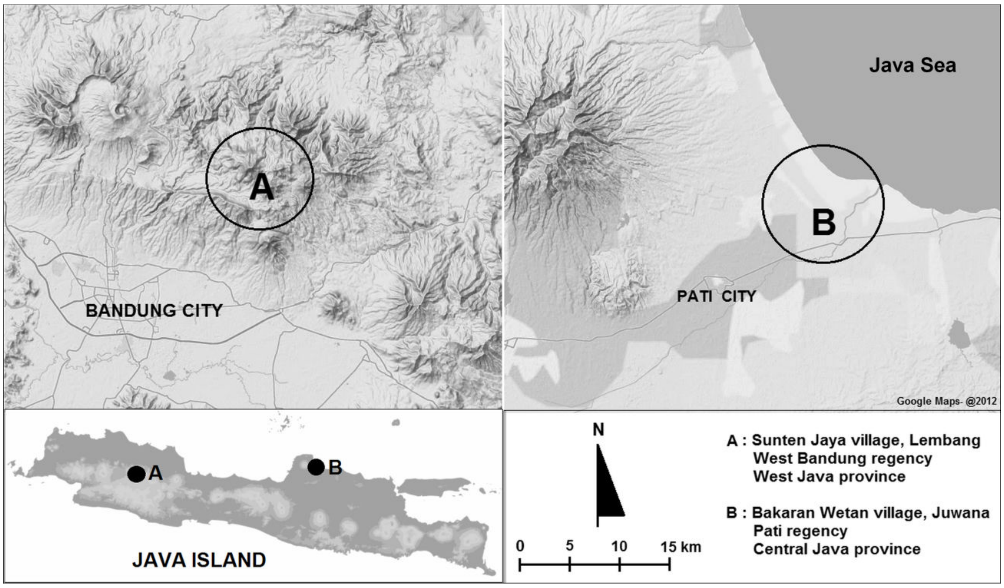


Figure 2.1 The location of this study

Based on national survey in 2010 (BPS, 2011a), among 158,205 surveyed households in rural areas in West Bandung Regency, about 62.4% still use wood fuel as a main cooking fuel and 36.3% use LPG as the main cooking fuel. On the other hand, among 237,388 surveyed households in rural areas of Pati Regency, the proportion of household whose main fuel was wood fuel was 47.3% and that of LPG was 51.7%. Nonetheless it seems high percentage of households have been using dual fuel (LPG-wood fuel) after the national program on conversion of kerosene to LPG implemented in this area.

2.2.2 Measurement of particulate matter concentration in the households

The measurements were carried out during the wet season of December 2010 – January 2011. On each site, PM measurements were conducted for 20 households which use wood fuel as the main fuel, however only 15 samples and 14 samples were valid for Lembang and Juwana, respectively.

The mass size distributions of $PM_{2.5}$ were measured by an SKC Sioutas Cascade Impactor (SKC Inc) combined with a Leland Legacy® sample pump at a constant flow rate of 9L/min. This pump was calibrated using a Defender (model 510H Dry Cal Inc). The sampler was positioned 30 – 40 cm apart from the stove perimeter to closely investigate indoor particles related emission. Collected particles on the filters were analyzed gravimetrically using a micro-balance with 1 μg precision (MX-5 model, Mettler Toledo Inc).

2.2.3 Calculation of household wood fuel consumption

The wood fuel consumption was evaluated on a daily basis. The data were then modified to obtain annual unit consumption per capita. We estimated the annual consumption of wood fuels in both urban and rural areas. Generally the wood fuel users in both areas are not necessarily categorized as low-income people. According to the government definition (in 2011), lower-income people in urban area had an income less than 27.2 USD/cap/month meanwhile in rural area income was less than 22.95 USD/cap/month (using current exchange rate 1 USD = Rp. 9300). About 15% people in urban areas were categorized as low-income households while around 9% people were wood users. In rural areas, about 69% people were wood users while people categorized as low income households were only 17%. The formula to calculate total wood fuel consumption is as follows:

$$\sum_{i}\left\{\mathrm{Cr_i}\times\left(\sum_{m}\mathrm{Fr_{i,m}Pr_{i,m}}\right)\right\}+\sum_{i}\left\{\mathrm{Cu_i}\times\left(\sum_{m}\mathrm{Fu_{i,m}Pu_{i,m}}\right)\right\}\ldots.(2.1)$$

where:

Cr: unit (per capita) consumption of wood fuel in rural areas (m^3/person/y); Cu: unit (per capita) consumption of wood fuel in urban areas (m^3/person/y); Fr: fraction of rural people using wood fuel; Fu: fraction of urban people using wood fuel; Pr: rural population; Pu: urban population; i: island or island cluster; m: province

The unit consumption used here and the related sources are shown in Table 2.1. The assumptions used for estimation are: concerned biomass are addressed to wood fuel only, unit consumption of wood fuel was same in each island than each province, and wood density was 600 kg/m^3

For ease, we will show the results on island basis. In urban area, wood fuel consumption per capita was adopted from ESMAP surveys (Barnes et al., 2004) in urban developing countries including Indonesia (middle income: 0.11m^3/cap/year, middle-low income: 0.14m^3/cap/year). To determine the income group for each province, we took into account minimum wage per month by province and gross regional domestic product by province (BPS, 2011a).

Table 2.1 Unit consumption (UC) of wood fuel used in this study (m^3/cap/year)

Island /(cluster)	UC	Sources	Island /(cluster)	UC	Sources
Sumatra	1.06	National average	Sulawesi	1.61	NFP, 2012
Java	0.88	Average of this study and Tampubolon, 2008; Sumardjani and Waluyo, 2007; Budiyanto, 2009	Maluku	1.06	National average
Bali-N.Tenggara	1.06	National average	Papua	10.9	Rachman et al., 1996
Kalimantan	1.01	Sumardjani and Waluyo, 2007			

Note: Papua was excluded from the national average calculation

2.3 Results and discussion

2.3.1 Assessment of indoor PM pollution related to wood fuel burning for cooking

Cooking stoves used in the two sites have a comparable design of U-shape. The difference is that in Lembang site, the stoves are rectangular U-shaped and made of cone block, while in Juwana the stoves were rounded U-shape and made of concrete. These stove types have differences in the hole where the pot is placed and the shape of the outer stove (Figure 2.2). During the measurements, the average temperature and relative humidity in the kitchen were 23 ± 2°C and 77 ± 6% (in Lembang), and 27 ± 1°C and 86 ± 3% (in Juwana). The average PM_{10} concentrations related to the stove emissions were 1209 ± 918 μg/m^3 in Lembang and 1375 ± 884 μg/m^3 in Juwana (Table 2.2).

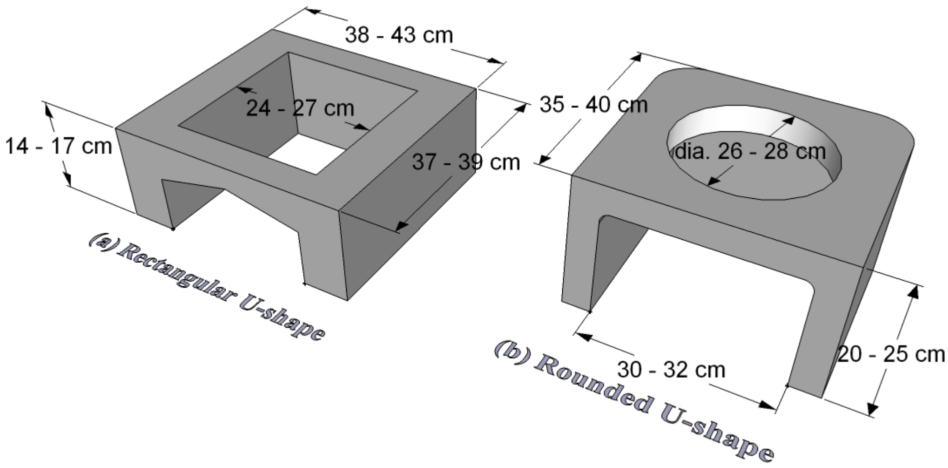


Figure 2.2 Typical stoves used in two sampling sites

The average mass fractions of PM_1 and $PM_{2.5}$ to PM_{10} were 86±5 % and 90±3% for Lembang. While in Juwana, the fractions were 88±4% and 92±3%. Our mass fraction results were comparable to another study (using the same device) related to open burning emission (Armendariz et al., 2010).

Daily wood fuel consumptions were 3.3 ± 1.6 kg/day in Lembang and 3.8 ± 1.9 kg/day in Juwana. In terms of unit consumption, these values correspond to 0.57 and 0.68 m^3/cap/year, respectively. In most cases, our PM_{10} exposure estimations for cooks showed lower values than those in Bolivia (i.e 940 – 1,260 μg m^{-3} h^{-1}) by Albalak *et al.*(1999).

Table 2.2 PM_{10} concentrations, wood fuel consumed and exposure estimate

Sample (Lembang)	PM_{10} conc. ($\mu g/m^3$)	Wood fuel consumed (kg/day)	Exposure estimate $\mu g/(m^3h)$	Sample (Juwana)	PM_{10} conc. ($\mu g/m^3$)	Wood fuel consumed (kg/day)	Exposure estimate $\mu g/(m^3h)$
L1	2,292	3.3	724	J1	1,383	5.3	494
L2	1,831	3.6	631	J2	366	2.2	179
L3	1,280	2.4	422	J3	1,170	3.5	816
L4	3,253	1.2	1,574	J4	946	4.9	293
L5	1,520	5.4	512	J5	1,326	7.2	324
L6	892	1.6	357	J6	1,437	0.8	2,156
L7	1,552	3.3	711	J7	1,012		542
L8	2,349	3.3	1,146	J8	1,187	6.6	1,003
L9	619		167	J9	902	2.4	712
L10	432	2.0	204	J10	526	2.4	272
L11	199	5.5	55	J11	3,690	2.4	1,800
L12	271	1.5	85	J12	2,508	4.5	1,031
L13	808	2.4	288	J13	640	4.4	315
L14	726	6.7	276	J14	2,158	2.3	1,823
L15	124	3.7	41				

Note : The exposure was estimated at maximum case (based on cooking period, not activity time of the cooks).

2.3.2 Assessment of wood fuel consumption in Indonesia

Calculation results of the household wood fuel consumption (see Table 2.3) revealed that Java island stood as the highest percentage of wood fuel consumption due to the high percentage of wood fuel users (15% in urban, 66% in rural) as well as the largest population. The second position was Papua island owing to extremely high biomass unit consumption. Papua island is the least developed island in Indonesia leading to importance of forest stock as the main cooking energy resources. Table 2.3 indicates that the total forest area per person of wood user varies and Java island shows the lowest. Therefore it is expected that wood fuel users (particularly for urban low income) in Java island will suffer the most resource scarcity in the future as a result of deforestation across the country.

Table 2.3 Calculated national wood fuel consumption (thousand m^3/y) and deforestation rate/DR (% / year)

Island (cluster)	Urban	Rural	Classified FA	DR	Unclassified FA (ha/capita)	DR
Sumatra	245	20,060	0.52	0.53	0.92	0.41
Java	1,504	31,016	0.03	0.09	0.22	0.08
Bali-Nusa Tenggara	190	7,198	0.19	0.03	0.56	0.02
Kalimantan	58	5,330	1.92	0.12	2.12	0.94
Sulawesi	103	13,392	0.70	0.04	0.73	0.16
Maluku	19	1,545	1.33	0.02	0.40	0.09
Papua	12	25,070	7.74	0.09	0.08	1.70
INDONESIA	2,133	103,611	0.55	0.18	0.57	0.41

Note : Classified Forest Area (FA) comprises of conserved forest and protected forest only (production forests were not included). The capita of interest is addressed to wood user only. The deforestation rate (DR) was recalculated based on 2006 – 2009 data (Ministry of Forestry, 2011)

Our estimated total consumption (106 million m^3/year) is much lower than national household consumption calculated by the Ministry of Energy, i.e., 175 million m^3/year (CDIEMR, 2011) mostly due to the difference of unit consumptions used. Their unit consumptions rely on subjective quantification of the respondents to a large-scale questionnaire survey and the accuracy is low. By contrast we rely on objective quantifications based on the limited field measurements. Moreover, we measured only for wood fuel that might not be specifically addressed in the Ministry of Energy data sources such as illegal-logging waste, wood waste from wooden industry and plantation, wood briquette, and charcoal briquette. To improve the accuracy, the unit consumption on a mass basis of used wood fuel shall be considered by the Ministry of Energy in calculating biomass consumption at nationwide. Also the unit consumption of biomass should be updated after kerosene to the LPG conversion program was launched in 2007.

2.4 Conclusion

The average mass fractions of PM_1 and $PM_{2.5}$ to PM_{10} were 86±5 % and 90±3% for Lembang. While in Juwana, the fractions were 88±4% and 92±3%. The average exposures to the cooks at Juwana were higher almost two folds (839 ± 651μg m^{-3} h^{-1}) than in Lembang site (479 ± 429 μg m^{-3} h^{-1}). Java population still consumes wood fuel at the greatest rate nationally, however resource scarcity in the future will threat to the wood users due to deforestation.

CHAPTER-3

Household characteristics and potential indoor air pollution issues in rural Indonesian communities using wood fuel energy

(Household characteristics and potential indoor air pollution issues in rural Indonesian communities using wood fuel energy, submitted to Indoor and Built Environment, SAGE Journal)

Chapter outline

This chapter describes household characteristics in mountainous and coastal rural areas. The householder behavior, their views in identifying indoor air pollution sources in their own home are the topics covered in this chapter. The potential indoor air pollution and the preliminary measurements results in these areas are used for further discussion in the fifth chapter.

3.1 Introduction

It is estimated that over three billions of people use biomass fuel for cooking and heating in developing countries (IARC, 2010). Furthermore, in this region about 730 million tons of biomass were burnt each year releasing more than 1 billion tons of carbon dioxide (World Bank, 2011). According to historical biomass fuel data (1973 – 2006), it is expected that biomass fuel continue to be used for many years to come (Rose et al., 2009). Basically, the use of biomass fuel in the developing world is driven by its accessibility, affordability, availability, and acceptability. Referring to energy ladder terminology, the biomass fuel users are closely related to low-income household. WHO and UNDP (2009) plotted an inverse correlation between percentages of household using biomass and the income (GDP/capita). Generally the energy choice – GDP relation is true for all countries, though it was found that the more affluent families do not necessarily use cleaner fuel in some area (Saatkamp et al., 2010, Heltberg, 2003). It is reported that household income will influence fuel choice in urban area, while it has less influence in rural area (IARC, 2010).

The housing characteristics, stove and cooking time play an important role in determining the exposure of pollutants to the cooks. The stove parameters are stove type and fuel type, while kitchen location is an important parameter for housing characteristics (Balakrishnan et al., 2002). Likewise, Clark et al. (2010) detailed the housing characteristics as the total area of the kitchen windows, the number of kitchen walls, and the primary material of the kitchen walls and the volume of the kitchen, and the number of walls with eave spaces.

In addition, the other significant factors that could discharge high-level pollutants are fuel moisture, burning rate, and cooking behavior (Smith, 2006). Different cooking behavior could change the peak pollutant concentrations. This could happen particularly when fuel is added or moved, the stove is lit, the cooking pot is placed on or removed from the fire, or food is stirred (Ezzati and Kammen, 2002).

The effects of these several factors on indoor pollution may be well understood in the rural communities but some are not. The basic critical issue is on how the people choose for their own cooking energy which is best suited for them. By using multiple fuel linear model, Masera et al. (2000) found the following factors which are essential for household decision in fuel choice: (a) economics of fuel, stove type and access conditions to fuels, (b) technical characteristics of cooking stoves and cooking practices; (c) cultural preferences; and (d) health impact.

In Indonesia, the villages are basically categorized into no-coastal area (including in mountainous areas) about 77% and coastal area, i.e. 23% of the total of 67,245 villages. In both areas, the proportions of wood fuel users were almost comparable value of 67% (BPS, 2008). It is predicted the percentage of wood fuel users in the mountainous region will be higher than 67% due to the remoteness of its location. This will ultimately increase risks of health effect due to indoor air pollution in the mountainous region. The cross-sectional study in Indonesia reported that high indoor air pollution from coal/lignite, charcoal, firewood/straw, and dung evidently increased infant mortality i.e. adjusted Odds Ratio (OR): 1.305, 95% confident interval (CI) = 1.003-1.698 in rural areas (Kashima et al.,2010). Furthermore, regarding to the health outcomes, the prevalence of ALRI in rural areas was higher than that in urban areas.

Since household conditions are varied in the field due to its location, social-economic status, and resources availability, in relatively different areas, i.e mountainous and coastal areas, the people might have different health impact caused by different household characteristics and householder behavior.

For example, if we focus on two provinces in Indonesia i.e. West Java province and Central Java province, then we have two different characteristics. Based on BPS (2008) survey, the West Java provinces had a low number of villages with wood fuel users in non coastal area (42%) than that in Central Java provinces (78%). However the pneumonia incidence in West Java province in 2011 was 9 times higher than that in Central Java province (Ministry of Health, 2012). Historically, West Java province experienced high pneumonia diseases for children <5 year although the wood fuel users showed moderate level. Household characteristics and behavior is a key determinant to this occurrence.

To know the differences in household characteristics and household behavior related to energy use and indoor air pollution in mountainous and coastal areas, no study was so far found in the literatures. Some studies, however, were conducted to characterize the households dwelling in mountainous areas or coastal region as part of indoor air pollution monitoring such as Lee et al.(2009); Sakseena et al.(2007) in coastal region, or Gao et al.(2009); Clark et al.(2010) in highland.

The objectives of this research are to provide housing characteristics of two distinctive rural locations, define cooking practice with wood fuel (stove usage, fuel consumption, the reason for still using wood fuel, and ventilation practice), and analyze descriptively indoor air pollution potential (outdoor sources, ventilation sufficiency and probable health effect). Furthermore, we also show household views that reflect to indoor air quality improvement by ranking the important indoor air pollution sources provided.

As a part of the surveys, the preliminary study on $PM_{2.5}$ measurements in the kitchens at both sites is also addressed in this work. The findings of the study are expected to contribute to the development in rural Indonesian communities to maintain sustainable energy use, promote healthy life, and achieve better environment.

3.2 Methodology

The case study was conducted in the two villages as described in chapter 2 i.e. at Sunten Jaya village, Lembang district, West Bandung regency and at Bakaran Wetan village, Juwana district, Pati regency. This study consists of two works: the survey questionnaires to the householders and the measurements related to indoor $PM_{2.5}$ in selected household kitchens.

The survey questionnaires were conducted in two steps i.e. by random sampling (rapid survey) and by in-depth survey. We determined the sample size referring to the formula by Krejcie & Morgan (1970) with the degree of confidence of 95%, a margin of error of 0.07 (in the first rapid survey) and a margin of error 0.09 (for the second survey). The first survey for randomly collected 360 households in total at both sites was aiming at knowing the percentages of people using only wood fuel and adopting the combination of LPG-wood fuel. The second survey was conducted by random sampling only for LPG-wood fuel users and wood fuel users. These sampling numbers were addressed for representing 2591 households using wood fuel in both sites. In the Sunten Jaya village, since the area was quite wide then we took four sub-villages randomly from 16 sub-villages. In case of Bakaran Wetan village, we sampled for all sub-villages. The second stage survey was carried out by considering the first survey results on wood fuel users, number of households with wood fuel users and the sub-village size. Then in Sunten Jaya, we collected 100 samples consisting of 95 LPG-wood fuel users and 5 wood fuel users, while in Bakaran Wetan we sampled 97 samples comprising of 85 LPG-wood fuel users and 12 wood fuel users.

In this second stage survey, we gathered the following household information: family member, the education background, housing parameters (living room-kitchen area, ventilation area, wall-floor material), fuel use (sort, monthly consumption estimate, daily stove usage, cooking practice), activities related to indoor air pollution (smoking, mosquito repellant use, outdoor infiltration), household income and perceived health related to indoor air pollution.

In order to reveal indoor air pollution in both areas, we sampled 13 households in each site for determining indoor $PM_{2.5}$ concentrations simultaneously with measurements as explained in chapter 2. The measurements took place in the kitchen of rural households for 22 – 23 h using in-expensive photoelectric monitor (UCB monitors). The UCBs were set in the middle of wall in front of the stove. To minimize interference, the UCBs should be hung at least 1.5 m away from the door and window and at 150 cm above the floor. These devices were already calibrated in the simulated kitchen as well as in the field with gravimetric-based principles devices. The UCB photoelectric chambers were cleaned after every five measurements, and prior to use the UCB was zeroed in a ziplock bag for at least 30 minutes.

3.3 Results and discussion

Based on the survey, it was approximated that the percentages of LPG users, combined LPG-wood fuel users and wood fuel users in Sunten Jaya were 40%, 57%, and 3%, respectively. Meanwhile in Juwana the percentages of the corresponding users were 68%, 28%, and 4%, respectively. Based on government statistics, although it was not clearly stated the quantity, the majority of householder in both sites are LPG users only. This means wood fuel used in dual fuel user (LPG-wood fuel vice versa) were not quantified, therefore the wood fuel consumption was underestimated.

We found the proportion of LPG only users in Juwana was higher than that in Lembang. It was presumably caused by better accessibility of Juwana than Lembang. In addition, wood fuel only users were dominated in the elderly who seems to feel resistance in the operation of newly introduced technology for cooking. For the next analysis, we will discuss the results of the second step survey.

3.3.1 Education and occupation background

The majority of household heads and housewives have a low level education. More than 80% of them finished only elementary school in both sites. This may attribute to their occupations that do not need a high-level education background. Within Lembang site, the predominant occupation of householder is a farmer (54.6%), while in Juwana site brackish-water farmers and workers (43%) dominate it.

3.3.2 Housing materials

The housing characteristics between the two sites were quite distinctive (Table 3.1). In Lembang site, brick was the dominant material for the wall and the kitchen. Furthermore the wall materials of living room as well as kitchen were mostly identical. In contrast, the major dominant wall materials in Juwana site were concrete blocks so as to adhere to cultural prohibition of using brick. Interestingly, the wall materials of living room and kitchen were not always alike. Some householders in Juwana did not view the kitchen room as a component part of the main building. Therefore, low-end materials were chosen for the kitchen.

Table 3.1 Housing materials in both sites

Site	Wall material		Floor material	
	Living room	Kitchen	Living room	Kitchen
Lembang	Brick (50%)	Brick (49%)	Cemented (38%)	Plank (44%)
	Plank (30%)	Plank (30%)	Plank (33%)	Earthen (34%)
	Bamboo (20%)	Bamboo (20%)	Tiles (25%)	Cemented (20%)
Juwana	Conc. block (71%)	Conc. block	Tiles (65%)	Earthen (52%)
	Bamboo (16%)	Plank (21%)	Earthen (19%)	Conc. block (23%)
	Plank (11%)	Bamboo (20%)	Cemented (16%)	Cemented (21%)

It is suggested that popular wall materials of better quality give inferior ventilation quality. High quality materials were preferably used for floor materials in the living room than in the kitchen. This is a common condition in high-income households too. Saatkamp et al.(2000) also observed that even affluent households were not willing to improve the kitchen room quality in Mexico. Indeed, in developing countries, the kitchen is often placed in a leftover space, even in the newly-built houses (Nyström, 2003). The high proportions of plank material for the kitchen floor in the Lembang site were primarily caused by elevated building floor to adapt the land terrain.

3.3.3 Room volume and ventilation aspects

The average room volumes of living room and kitchen on Juwana site were higher than those in Lembang site as shown in Figure 3.1. This result is an agreement with that of province-level average where household room area in Central Java province is larger than that in West Java province. At province level, the dominant room areas are 50 – 99 m^2

(56.2%) and 20-49 m^2 (43.4%) for the Central Java province and for West Java province, respectively (BPS, 2012).

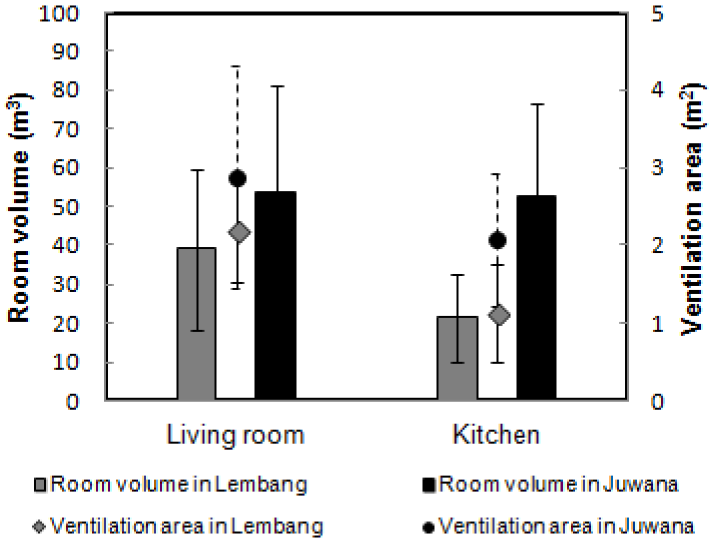


Figure 3.1 Room volume and ventilation area

Note : The ventilation consists of door, window and specified wind opening, the volume did not include outliers in Juwana (4 living rooms, 10 kitchens)

Javanese culture influences higher room volume of the kitchen in the Juwana site providing good natural ventilation (Prianto et al., 2000) where this kitchen also serves for social interaction medium occasionally. It is expected that the indoor air pollution potential in Lembang site is higher than that in Juwana site because the bigger room can dilute air pollutant more effectively. The low room volumes were aggravated with a low ventilation area in the dwelling room in Lembang site. We measured definite total ventilated area of the living room and kitchen such as doors, windows, and wind opening spaces in each household. The ratios of ventilation area in Juwana to Lembang are 1.3 and 1.8 for living room and kitchen respectively. However, if we inspect to ventilation sufficiency (percentage of the floor area to be ventilated) based on technical guideline on a building from the Ministry of Public Works (MPU, 1998) i.e. ventilation area in residential building should be at least 5% of the floor area to be ventilated, then several rooms in Lembang and Juwana particularly in the kitchen were ventilation-deficit (Figure 3.2).

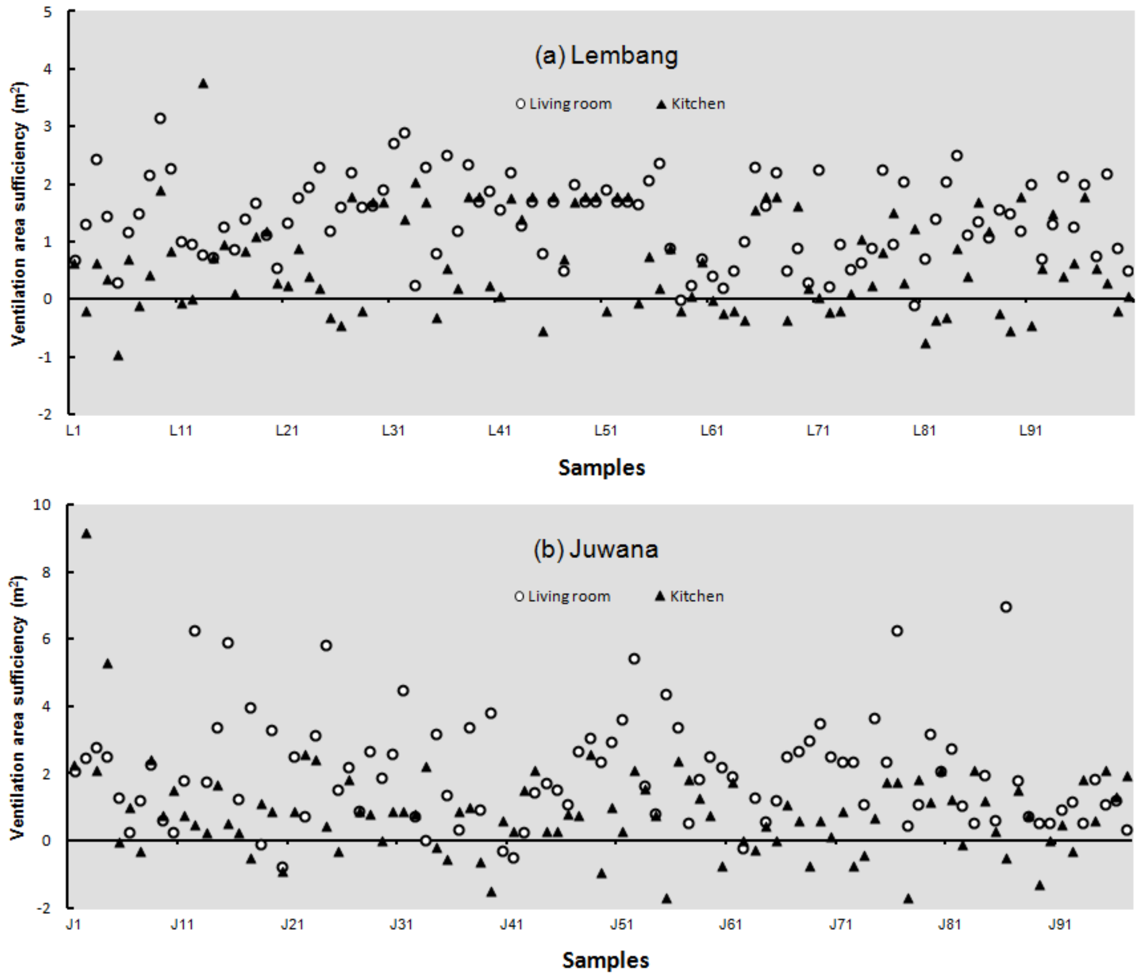


Figure 3.2 Ventilation area sufficiency of the sampled houses

Note : ventilation-deficit is denoted by negative value; calculation did not consider unspecified opening such as eaves, hole in roof etc. and door between rooms.

Despite having low ventilation areas, the people on Lembang site (58%) tend to keep closing their doors and windows in the kitchen during cooking events. Only 11%, householders in Lembang opened their window during cooking period. They relied on ventilation mainly through the roof, permeable walls and eave spaces in the kitchen. Relatively cold temperature, about 18 – 20˚C, might be the reason in keeping the door and window closed. In contrast, about 82% of people in Juwana opened their doors to the outside in the course of cooking. This will, ultimately, reduce significantly the accumulated air pollutants in the kitchen because natural ventilation plays a pivotal role in dissipating pollutants out of the living space. Small fraction (5%) of Juwana`s households opened both door and window

As studied by Still and MacCarty (2006), keeping the door open during burning biomass stove will reduce as much as 95% of pollutants (PM and CO) emissions compared to that in a closed room. Re-organizing the room architectures to bigger room would be costly, then it is recommended that the householders ventilate the kitchen without cost during cooking period. Widespread use of ventilation can be promoted by media, i.e. TV because our survey indicated about 90% of people in Lembang and Juwana use TV as information media.

3.3.4 Fuel used

Table 3.2 shows the used hours of LPG stove is generally shorter than those of wood fuel stove in all combinations.

Table 3.2 Estimated daily usage time of the stove (h/day)

Sites	Fuel type combination	LPG stove	Wood stove
Lembang	LPG –wood	1.42±1.04	1.91±0.62
	Wood-LPG	1.56±0.96	1.72±0.66
	Wood only		1.8±0.27
Juwana	LPG –wood	1.42±0.84	1.20±0.87
	Wood-LPG	1.25±1.12	2.22±1.48
	Wood only		2.13±1.28

Note : Based on the value of householder estimation (frequency of cooking×maximum cooking duration)/day

This is due to the higher efficiency of LPG stove than woodstove. LPG stove can cook faster without fire preparation and with easy adjustment of the stove power. Theoretically, the LPG stove is superior to the traditional wood stove; typical stove efficiency of the former is 60% compared to only 15 % of the latter (World Bank, 2011).

Figure 3.3 shows the fuel consumption at each household based on the subjective answer of the respondents to our questionnaires. Our previous measurement (pre-weighing and post-weighing) showed fuel consumption in the same field was 106.2 kg/month (Huboyo et al., 2012) then the questionnaire-based wood fuel consumption in Lembang was underestimated by a factor of two or more. In Juwana site, average wood fuel consumption by field measurement was 114 kg/month, only LPG-wood fuel users were consistent. The other results were underestimated too. Hence, the estimation of biomass consumption by means of questionnaires (as government does through national survey) is prone to be biased.

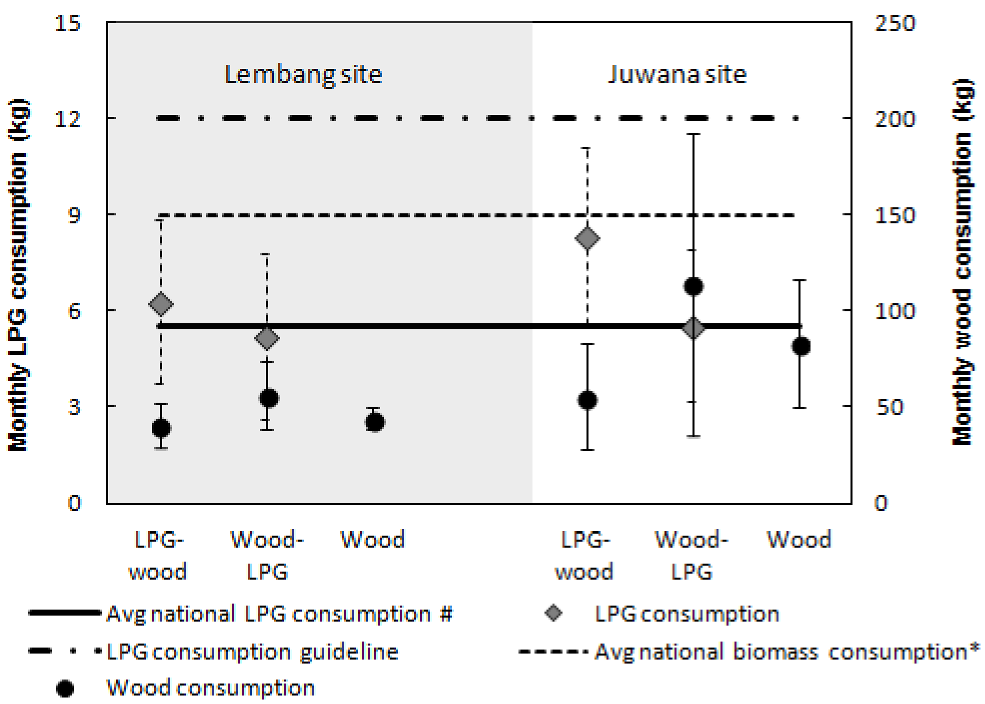


Figure 3.3 Monthly fuel consumption per family

Note : * Recalculated from CDIEMR, 2011, # 3 kg cylinder of subsidized LPG (Kembaren, 2012)

By comparing Table 3.2 and Figure 3.3, we found a discrepancy between LPG consumption and stove usage time on Juwana site, namely the consumption of LPG was quite high while usage hours of LPG stove were short. Several LPG-wood fuel users have large family members and a few others were merchants that may increase the LPG consumption in case of a wood shortage occur. Misestimation of cooking duration would be a reason because LPG consumption (represented by how many cylinders consumed per month) was more accurate.

Nonetheless, this high consumption (8.3 kg LPG/month) is still normal in the sense that it does not exceed standard usage/month as pointed in government guideline (4 cylinders/month = 12 kg LPG/household/month). Pranadji et al. (2010) found the average consumption of subsidized 3 kg LPG in urban areas was about 3.8 cylinder/household/month with a cost of at least 54,000 rupiahs/month. Adopting dual fuel (LPG-wood fuel) seems to be a reasonable behavior for rural households because wood is still widely available. Economy is the main reason why wood fuel is still used by a high proportion of the rural people though subsidized LPG fuel is available. It reached up to 49% and 31% of the reason in Juwana and Lembang respectively. The other reasons in Lembang are easy accessibility, to save LPG usage, for space heating and for boiling water. While in Juwana, the fear of LPG explosion and boiling water purpose are the other reason on keeping use of wood fuel.

The reason suggests the dual fuel users (LPG-wood fuel) are versatile. If LPG fuel price increases (due to shortage for instance) or irregular supply of LPG occurence (Bacon et al., 2010), they are most likely to adopt wood fuel only. The reason of "to save gas (LPG) usage" in Lembang site, in fact, could be categorized as an economical reason too. Then combining the two parameters will build up more than 46%. According to the government guideline on the poverty line, the low-income families or "poor households" fraction was

61% in Lembang site, whilst at Juwana site it showed only 33%. The income classification here is defined as top value in the given range income choices to prevent underestimation income provided by the respondents. The range classification consists of the income below poverty line, in the range and over standard minimum wage at province level. There are many options to reduce the wood fuel resources, which eventually will reduce the exposure of the household members to harmful pollutants in those areas. Raising the household welfare or poverty alleviation is the leading option for securing LPG users in both sites. However, that option requires long-term to accomplish. Instead, many farmers are breeding livestock, and can generate potential in-stock biogas locally combined with human waste. Or, in both sites, installing efficient and low-cost improved wood stove could be a viable alternative. These improved stoves will also reduce the GHG to some extent besides reducing exposure (UNDP, 2000). These improved stoves were adapted from local stoves and were successfully disseminated to the local people in developing countries (GERES, 2009; Shastri et al., 2002)

3.3.5 Pollution perception

About 78% of householders in Lembang perceived indoor air pollution in their houses, while only 13% believed that outdoor pollution is a problem. Whereas in Juwana site, about 55% householder felt no pollution at all derived from indoor as well as outdoor sources, 22% of the people believed the outdoor air pollution affected indoor pollution. Only 11% householders in Juwana realized the presence of indoor air pollution. Furthermore the open burning of garbage and neighborhood smoke were justified as the main sources of outdoor pollution in Lembang site.

In Juwana site, the road traffic also contributes to outdoor pollution because several households reside near roads.

Apparently, the mainstream perspectives on health problem for the cooks in Juwana site when they do cooking were surprising. More than 78% people did not feel any health problem associated with indoor biomass smoke. In contrast, about 51% people in Lembang a bit complained about their physical health during cooking due to eye irritation (25%) and combined breathing problems and eye irritation (26%). For the same question, only 18% of people in Juwana suffered breathing problem due to cooking fuel smoke. It seems that the people were able to endure these conditions by reducing the exposure to the smoke through cooking intermittently and frequent moving to the living room.

Other important factors in generating indoor air pollutants are smoking at home and burning mosquito coils. In Lembang, 70% of respondents smoked at home (68% of householder head) showing an average consumption of 9.5±4 cigarettes/day. Lower percentage of smoking at home was shown on Juwana site, i.e. 44% with an average consumption of 4.6±3 cigarettes/day. Mostly they did smoke in the evening after having dinner or during watching television together with the family members. Ironically, besides bringing about indoor air pollution in the dwelling room and exposing harmful pollutants to family members, this activity also undermines household income. On average estimation, they spent approximately 32.8% and 12.3% of their monthly expenditures on cigarettes for Lembang and Juwana sites respectively.

Since Juwana is located in plain areas, many brooks undergo stagnant waste water providing breeding grounds for mosquitoes. This condition occurs unlikely at Lembang site, because the terrain enables wastewater in the brooks to flow easily. In Juwana 52% of the people preferred to use mosquito coils. By contrast, 96% people at Lembang site did not use mosquito repellant. This fact will augment the indoor air pollution in Juwana site particularly in the living room in addition to smoking pollution.

If we consider the $PM_{2.5}$ emission factor of mosquito coils burning is the same as 75 – 137 cigarettes burning as suggested by Liu et al. (2003), the indoor air pollution levels in Juwana`s living rooms are predicted to be much higher than those in Lembang, at comparable-sized room.

Taking the causality of indoor air pollution into account comprehensively, we analyzed all prominent indoor pollution factors such as smoking indoor/at home, using non-electricity lamp, changing fuel type, burning mosquito coil repellant and applying ventilation. These factors are common activities which rural people do indoor on a daily basis. Actually, we also asked about the frequency of room cleaning (generally only sweeping the floor) which may increase re-suspension of deposited fine particles. Yet we believe this activity does not have a significant effect on indoor pollution. The $PM_{2.5}$ emission rate (mg/min) of sweeping the floor is about 2% to 5% of cooking (frying) and smoking respectively (He et al., 2004a). In addition, this re-suspended fine PM emission is not related to mortality compared to combustion-generated constituents (Jantunen et al., 2002). We asked the householder to prioritize the above factors that should be managed at first in order to improve indoor air quality. Figure 3.4 shows that the priorities of each factor are more evenly distributed in Juwana site.

While in Lembang site, the striking differences are found in certain priority level of each factor. Thus, people in Lembang had a common sense of what are the priority sources of indoor air pollution. Based on statistical Friedman`s Test, by eliminating non-electricity lamp factor in both sites and mosquitoes coil burning in Lembang site, the respondents expressed different factor prioritization in Lembang site ($\chi^2 = 42$, $p<0.01$). On the contrary, householders in Juwana viewed relative comparable factor prioritization ($\chi^2 = 4.6$, $p>0.01$). The people in Lembang site prioritized to reduce smoking at home then to use cleaner fuel/stove and to manage house ventilation. The result indicates that what is perceived as the main source of pollution in the dwelling room and what should be controlled first for improving indoor air quality. Nonetheless, it is not necessarily the countermeasures option to improve indoor air quality in line with this priority. Smoking and mosquito coil burning seem to be habits rather than awareness.

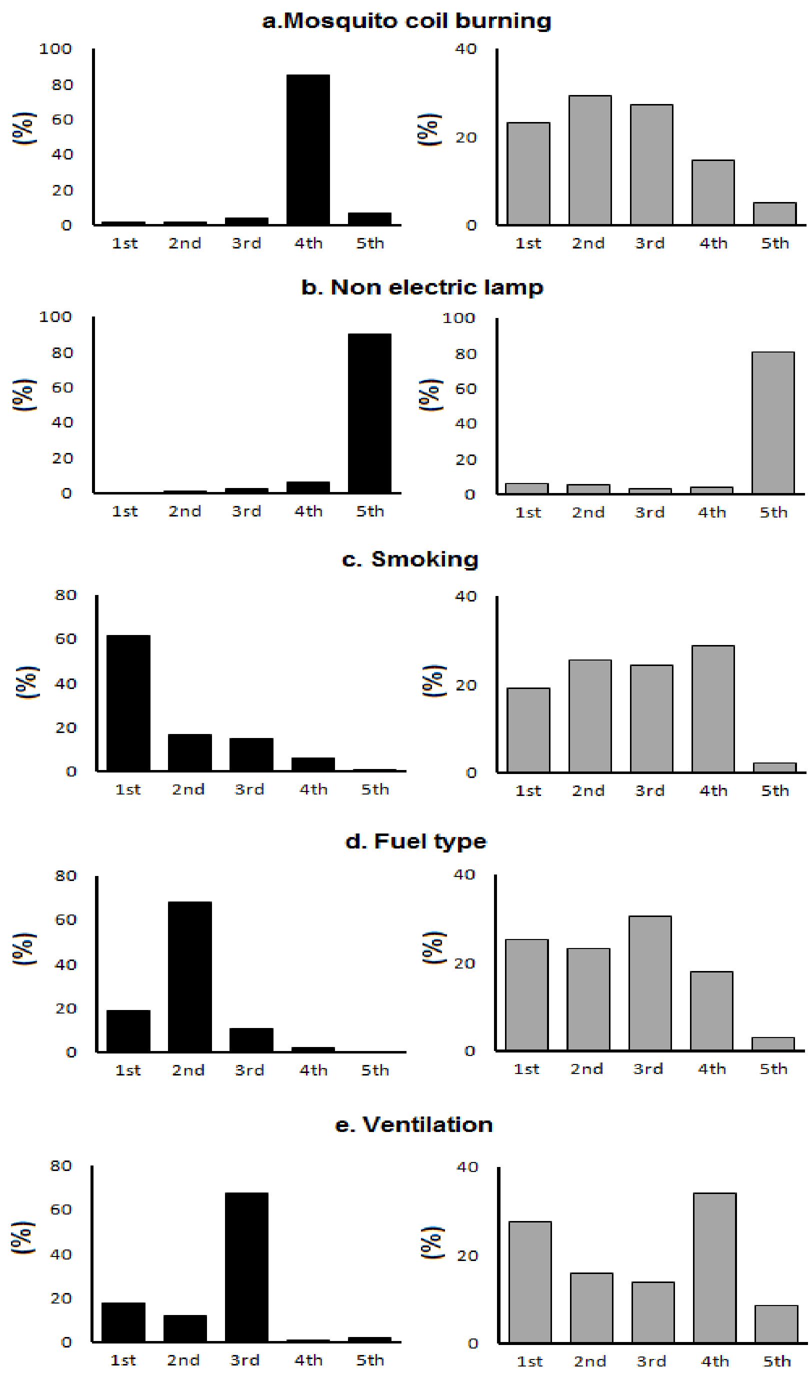


Figure 3.4 Percentage of householder responses on priority ranking of indoor air pollution sources

Lembang Juwana

Hence it will take longer time for the people to really extricate from these habits. For that reason, it is expected that conversion of wood fuel by LPG will not reduce the exposure of harmful pollutant significantly in the near future, as other indoor pollutant sources still exist in the living room where the householder members spend the longer time than in the kitchen. It is imperative, therefore, to formulate indoor air pollution countermeasures embedded in the energy policy program.

3.3.6 $PM_{2.5}$ concentrations in the household kitchens

Preliminary study on $PM_{2.5}$ measurements of 13 households in each site as featured in Figure 3.5 showed the $PM_{2.5}$ concentrations in Lembang site kitchens on average were higher (1.64 times) than those in Juwana site.

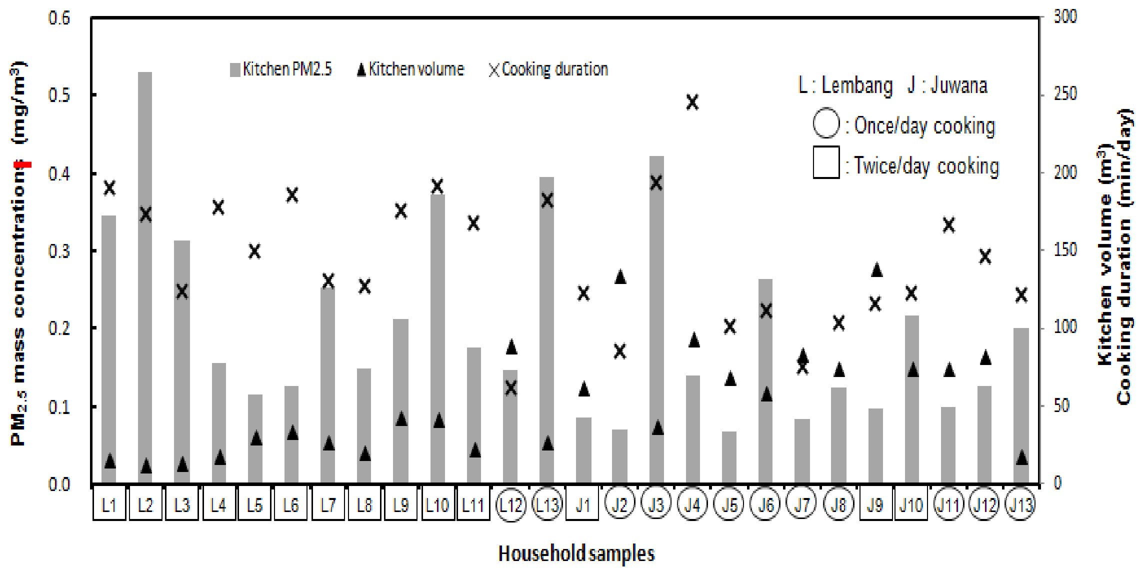


Figure 3.5 Indoor $PM_{2.5}$ concentrations in the household kitchens

With respect to cooking duration, as households in Lembang generally cook twice a day, it showed a slight longer time period i.e. 157 ± 37 min than in Juwana householders (132 ± 47 min) which mainly cooked once per day. This condition will potentially increase indoor air pollution in Lembang site than in Juwana site. The low ratio of kitchen volume in

Lembang to Juwana of 0.4 might be the other reason of lower concentrations of indoor $PM_{2.5}$ in Juwana site kitchens. However the relations between kitchen volume and cooking duration to indoor $PM_{2.5}$ concentrations were weak as described in Figure 3.6, suggesting the influence of other factors. The other factors such as ventilation design and practices, stove positions in the kitchen, stove operations and wood fuel conditions might have significant contributions to indoor $PM_{2.5}$ concentrations.

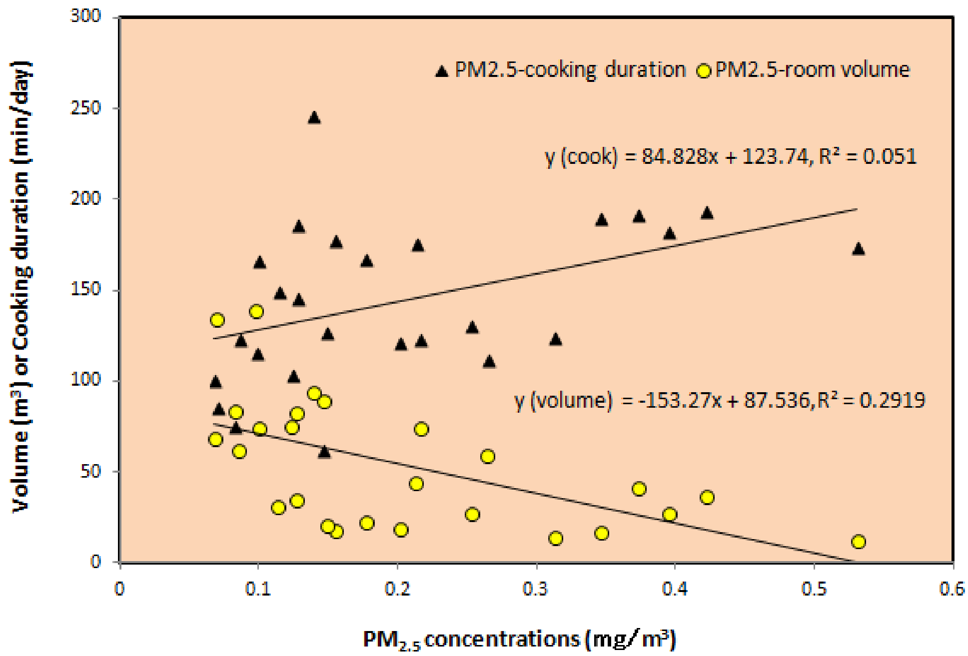


Figure 3.6 The relation between $PM_{2.5}$ concentrations and two factors of volume and cooking duration

The short-term increments in $PM_{2.5}$ concentration were observed during wood fuel burning as shown in Figure 3.7. The fluctuation of $PM_{2.5}$ concentrations in most cases continued as the cooking period was over because the cook usually left the wood stove in smoldering position to warm the water in the kettle or the food in pan or frying pan. During this period the cooks moved to the living room, thus the direct exposure of the cooks was ended, while the indoor air pollution still continued until the smoke vanished.

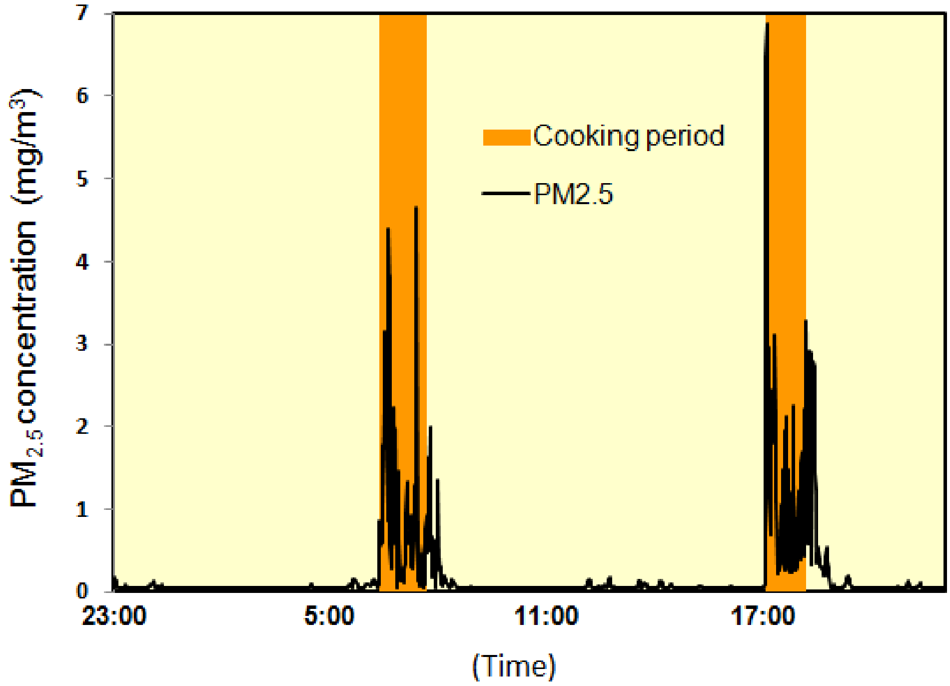


Figure 3.7 Typical temporal variations of $PM_{2.5}$ concentrations during cooking with wood fuel

3.4 Conclusion

Adoption of dual fuel energy (LPG-wood fuel) is still common in rural households. As the rural people have generally low income, then the economic motive was the main reason in selecting the fuel in addition to accessibility and water cooking purpose. Local housing characteristics influenced by local wisdom, culture, climate, and location have potentially affected the indoor air pollution level. The people in mountainous areas have small rooms as well as insufficient ventilation area and need heating due to cold temperature. Then they encounter the risk of indoor air pollutant exposure rather than the people in coastal areas. On the other hand, mosquito breeding is a real problem in this coastal area where the massive use of mosquito coil burning will eventually deteriorate indoor air quality.

People in these two locations were aware of such indoor air pollutions and therefore prioritized the factors to be managed based on their perspectives of the air pollution causes. This awareness is important in designing integrated indoor air pollution countermeasures to be adaptive and to secure sustainable living. This will aid the efficiency of energy conversion that not only promotes cleaner fuel use but also reduces exposure to air pollutants. The indoor $PM_{2.5}$ concentrations in the kitchen of households in the mountainous region were 60% higher than those in the coastal area. The difference in the kitchen volumes as well as cooking durations was suggested as the potential reason.

CHAPTER-4

Modern and traditional stove usage and related indoor air pollution characteristics

(Indoor $PM_{2.5}$ Characteristics and CO Concentration Related to Water-Based and Oil-Based Cooking Emissions Using a Gas Stove, Aerosol and Air Quality Research, 11, TAAR, pp. 401–411)

(Comparison between *Jatropha curcas* seed stove and woodstove: Performance and effect on indoor air quality. Energy for Sustainable Development, Elsevier, in press)

Chapter outline

This chapter contains two different topics i.e. indoor air pollution resulted from gas stove and wood stove use. The assessment was based on cooking method for gas stove, while a standard water boiling test was adopted for wood stove. Both tests were performed under natural ventilation for the measurement. The experimental outcome of indoor air pollutants emitted from gas stove offers useful information to compare with wood stove in chapter 5. On the other hand, the performance comparison of a traditional wood stove with other stoves including improved wood stove enabled to review proposed stove applied in the rural areas as covered in chapter 6. Ventilation aspect was discussed as an important part to be included in chapter 5.

4.1 Indoor $PM_{2.5}$ characteristics and CO concentration related to water-based and oil-based cooking emissions using a gas stove

4.1.1 Introduction

It is believed that cooking emissions in controlled experiments are influenced by the fuel used and the food being cooked. However, in the actual cooking, emission measurement is influenced by many factors such as room arrangement, building materials, outdoor infiltration, other combustion devices, ventilation, and cooking methods.

Gas stoves (either using propane gas or natural gas) are widely used throughout the world, particularly in developed countries. In 2008, world gas consumption (all sectors) was around 3.14 trillion m^3; the consumption increases by 3% per year (IEA, 2010). Compared to other cooking fuels (except for electricity), gas is located in the upper end of the energy ladder, which means that it produces relatively low air emissions than other fossil fuels. However, it should be used cautiously. Gas stoves emit large amounts of ultrafine particles (UFP) with aerodynamic diameters of less than 100 nm. Wallace et al. (2008) found that gas stoves contribute to higher emissions of UFP whose size distribution has a peak around 5 nm in particle size. Meanwhile Li et al. (1993) reported that submicron-sized aerosols generated from cooking activities constitute about 60%–70% of the UFP in indoor aerosol.

Several recent studies have characterized gas stove emissions with respect to the cooking method that may have distinctive emission patterns, although the term "cooking method" itself still seems indefinite (depending on region, customs, and countries). For instance, on the basis of cooking temperature, Yeung and To (2008) found that aerosol peak number concentrations occurred in the 100–160 nm range and that at higher cooking temperatures, the aerosol mode diameter increased. Moreover, in their experiments, bimodal distributions of submicron-sized aerosols could be expected to be generated. According to Buonanno et al. (2009), temperature significantly affected cooking emissions, such that the mass emission factor at the maximum stove power could reach 29 times that of the minimum power, which was used as a baseline. Moreover, the emission factors of high-fat foods were substantially higher than those of low-fat foods. During cooking, temporal variability in emissions due to coagulation, condensation, and evaporation may occur.

Wallace et al. (2004) found that frying increased the total particle concentration by factors of 6–10 over other cooking methods, while Afshari et al. (2005) indicated that the maximum particle concentration reached 150,900 particles/cm^3 when frying meat on an electric stove in a full-scale test chamber. In fact, frying is not the only method for generating remarkable amounts of pollutants; grilling also emits large quantities of pollutants. For example, Lee et al. (2001) observed that different cooking styles in commercial restaurants had different emissions of $PM_{2.5}$ and CO, and hot pot barbecue emitted the most pollutants.

More straightforward studies, e.g., chemical characterization studies conducted by See and Balasubramanian (2008), revealed that frying emitted more than three times higher $PM_{2.5}$ than boiling and at least five times higher than that of the background levels, and organic carbon constituted more than 70% of $PM_{2.5}$ in the kitchen. These findings suggest that the risks of household residents' exposure to fine particles emitted from cooking activities vary with the cooking method. Their measurements, however, were carried out under the maximum condition (in an enclosed space and at a distance of around 20 cm from the stove). Yet, there is no information about the relationship between the cooking method and mass size distribution of generated $PM_{2.5}$ particles.

Indoor cooking is believed to increase the indoor/outdoor (I/O) pollutant ratio in the kitchen. Cao et al. (2005) reported that, in several houses (roadside, urban, rural) in Hong Kong, the average 24 h $PM_{2.5}$ I/O measurements had a narrower range (0.8–1.6) than the selected 20 min I/O sampling, which ranged from 0.5 to 6.7. Massey et al. (2009) showed that I/O ratios in rural areas were higher than those in roadside and urban areas in Agra, India, indicating more indoor sources of pollutants were present in those settings, particularly from cooking and smoking. Because cooking activities influence the I/O pollutant ratio, the ratio is expected to change according to the cooking method, even if the same fuel is used.

In general, CO emissions are associated with dirty fuels used in developing countries. As a result of low CO emissions from gas stoves, there have been only a few studies concerning this issue. In addition, many people in developed countries use electric stoves instead of gas stoves. Tian et al. (2008) reported that the 3 h-mean CO concentration in the kitchen reached up to 1.96 mg/m^3 even by using natural gas. However, CO emissions related to the cooking method have not been studied sufficiently.

This study aims to investigate the characteristics of fine particles ($PM_{2.5}$) associated with cooking, particularly temporal variations in the mass and number concentrations in a kitchen and the adjoining room for different cooking methods using a gas stove. Size distributions of carbonaceous particles were also determined for some samples with regard to different cooking methods. Furthermore, to consider human health impacts, we measured CO concentration related to the cooking method used in the kitchen.

Although this study was conducted in Japan, we set up the measurement conditions to represent those in developing countries (i.e., natural ventilation and tropical weather conditions). Because a combination of cooking methods are used in most households, temporal variation patterns of the number and mass concentrations of fine particles in the kitchen and other rooms should be revealed with regard to the cooking method.

We used natural ventilation in cooking in order to emulate actual conditions in the field. The rate of natural ventilation is difficult to control; however, it is superior to mechanically driven ventilation in terms of energy savings and is the most appropriate in tropical areas where outdoor temperatures do not change considerably throughout the year. Hence, a sufficient natural ventilation system reduces the risk of exposure to fine particles for the persons in charge of cooking in households.

4.1.2 Methodology

4.1.2.1 Sampling site characteristics

The experiment was performed from July 15 to August 18, 2010 in a single apartment in Kyoto city comprising of a kitchen and an adjoining room. During this period, the weather was somewhat similar to that in a tropical climate.

This apartment had a living area of approximately 8.5 m^2 and a kitchen area of 3 m^2. This condition is advantageous in terms of minimizing factors with respect to room arrangements. The layout of the sampling sites is depicted in Figure 4.1. This apartment is on the first floor of a two-story house. The kitchen is close to the other building, while the adjoining room is adjacent to open space. A standard exhaust fan with a capacity of 550 m^3/h (18 W) was installed in the kitchen. To emulate the ventilation conditions in developing countries, we used natural ventilation by partially opening windows in the kitchen and in the adjoining room. We set the window opening area in the kitchen at 0.13 m^2 and that in the adjoining room at 0.18 m^2. During measurements, a common single gas stove for cooking was operated at medium setting instead of maximum or minimum to approximate common practices during cooking. This stove was cleaned with a wet cloth immediately after each cooking task.

We placed all measuring equipment in the spots marked S1 in Figure 4.1. S1 was about 1.1 m from the stove. In the adjoining room, the measurement equipments were located near the center of the room (S2). We monitored cooking temperature, ingredients including oil and water, cooking time, stove power, and cooking method. Stove power was controlled by marking the adjustment knob at a specified position, giving moderate power.

4.1.2.2 Measurement setting

During these measurements, outdoor meteorological data from the Japan Meteorological Agency showed the ranges of temperature, relative humidity, and wind speed to be 24–35.6°C, 40%–87%, and 0.1–5.3 m/s, respectively. Background $PM_{2.5}$ concentrations were measured three times (on July 20, July 21, and August 17) to reveal the trend in concentration. There were no continuous emission sources nearby. To prevent disturbance from uncontrolled emission sources except from the stove, no other activities were conducted in the apartment. Simple distinctive cooking methods were selected as follows:

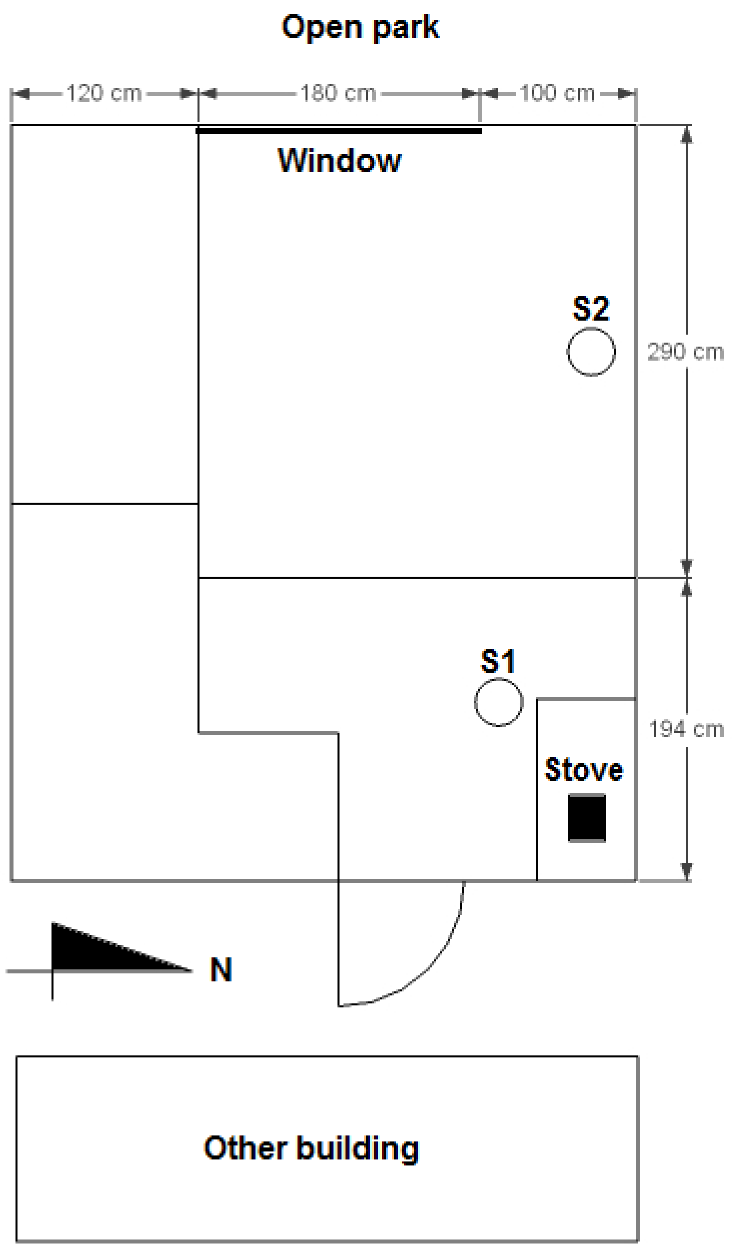


Figure 4.1 Sampling sites in the apartment

background, stove firing without cooking, frying, and boiling (pot without lid). Soybean curd (tofu) and chicken were chosen to represent low- and high-fat foods. For each cooking cycle, we used approximately 400 g (for 1 serving) of each food item. It was expected that there were negligible variations of chemical compositions between the two food items because we chose all samples from the same type or brand. We did not use the deep frying method, which is commonly employed in commercial cooking. During our cooking, the recorded maximum temperature was around 163°C during frying and 100°C during boiling. We used a two-step frying method to ensure that all food was immersed in sunflower oil. Half of each ingredient was placed into the heated oil at a time, and the process was repeated again using the rest of ingredients.

Cooking time was determined on the basis of previous studies of household measurements in Indonesia (Huboyo et al., 2009). We cooked on a daily schedule, i.e., in the morning 07.00–07.30 a.m., at midday 11.00–11.30 a.m., and in the afternoon 04.30–05.00 p.m. However, all measurement equipments were run for 12 h (from 6 a.m. to 6 p.m.) to capture indoor air pollution during the day, covering cooking and non-cooking periods. Moreover, this time period assures that the indoor pollutant concentration returns to the initial background levels, which minimizes the collection of generated pollutants from the cooking task. For each cooking method, the measurement was replicated on different days.

4.1.2.3 Measurement instrumentations

Particle mass size distribution was measured using a Sioutas Cascade Impactor/CI (SKC Inc) with a Leland Legacy® sample pump at a constant flow rate of 9 L/min. The impactor separates and collects airborne particles into five 50% cut-off size ranges: larger than 2.5 µm, 1.0–2.5 µm, 0.50–1.0 µm, 0.25–0.50 µm, and less than 0.25 µm. As we were interested in $PM_{2.5,}$ particles with aerodynamic diameter larger than 2.5 µm were not included in the subsequent analysis. We used a pre-heated (600°C, 4 h) quartz filter (Pallflex) with 25 mm diameter for each collection stage and a 37 mm filter for the backup stage. A quartz filter was selected for carbon analysis, as described below. The pump was secured in a semi-closed container to prevent air buoyancy from its outlet. Before weighing the sampling filters on a microbalance (Sartorius, M5P-F) with ± 1 µg accuracy, the filters were conditioned in a desiccator for at least 48 h followed by treatment with zerostat (Milty) to neutralize the static charge accumulated in the filters. Inexpensive UCB particle monitors (Barkeley Air Monitoring Group) were also installed for monitoring temporal variations in $PM_{2.5}$ concentration by the light scattering principle. The outputs of the UCB monitors were calibrated using the impactor; details are specified elsewhere (Huboyo and Tohno, 2010). As part of each cooking task, the photoelectric chambers of the UCB monitors were cleaned.

To account for the uncertainties in handling filters during measurements and for carbon analysis, field blanks were provided. We used a USB-CO data logger (Lascar Co.) to measure indoor CO concentration, which has a measurement range of 0–1000 ppm and ± 6% reading accuracy. Span calibration was performed for the CO monitor using CO standard gas (Sumitomo Seika Co). In addition, daily average indoor temperatures and humidity data were monitored by a USB thermo hygrometer (Lascar Co.). Because this study attempts to measure indoor $PM_{2.5}$ concentration from the viewpoint of its health impact, the samplers were set at a height of 1.5 m (roughly at the respiration height of a cook) and at a distance of 1 m from the edge of the stove. To minimize interference, the equipment were placed at least 1.5 m from the doors and windows.

Particle number concentrations were continuously measured using an optical particle counter (OPC; KC-01D, Rion Co. Ltd) in five size classes of 0.3–0.5 µm, 0.5–1 µm, 1–2 µm, 2–5 µm, and larger than 5 µm. Particles larger than 2 µm in diameter were omitted from the data because we are interested in fine particles only. The OPC measurements were set to 2 min cycles. Two OPCs were used simultaneously in the kitchen and the adjoining room; the OPCs were factory calibrated.

OC and EC analyses of particles collected on the quartz filters by the cascade impactor were conducted using a Lab OC-EC Aerosol Analyzer with National Institute for Occupational Safety and Health (NIOSH) Method 5040 (Sunset Laboratory Co.). The OC–EC split time was fixed at 420 s because the deposited particle area was a small slit and optical transmittance correction of pyrolysis did not work well in the automatic split time mode.

Throughout the measurement period, the average indoor temperature and the average relative humidity in the kitchen were 30.5°C and 74.6%, respectively. In the adjoining room, the temperature was slightly lower (29.9°C) and the humidity was slightly higher (76.1%). Because we did not measure the indoor air stream velocity, we used outdoor meteorological data to analyze the effect of the wind on indoor $PM_{2.5}$ concentration. Westerly wind likely contributed to much of the outdoor air infiltration because of the apartment's orientation. In general, the wind was stronger during the afternoon than in the morning and at midday.

Our site had natural cross ventilation (semi cross ventilation to be precise) because of non-symmetrical opening locations; hence, the ventilation rate was generally high, particularly in the adjoining room, where the window directly faced an open park (Figure 4.1). This non-symmetrical cross ventilation provided well mixed indoor air (Stavrakakis et al., 2008).

For a substantial analysis, we define "cooking effect" as the period during which indoor particles are highly affected by cooking activities. This simply facilitates comparative analysis of particle properties between the cooking methods and between the two rooms. The cooking effect is quite different for the mass and number concentrations of particles, because in most cases, cooking effects lasted much longer on a quantity basis than that on a mass basis.

Approximately 30 min after each cooking period, the number and mass concentrations of fine particles returned to the initial conditions. Therefore, choosing a period of 1 h (from ignition of the stove) as the timeframe for comparison between the cooking methods and between the rooms is reasonable.

4.1.3 Results and discussion

4.1.3.1 Outdoor measurements

Typical diurnal variations in ambient $PM_{2.5}$ concentration from continuous monitoring in Kyoto city (i.e., Fushimi ward in the south and Sakyo ward in the north) during this study are shown in Figure 4.2. We used ambient $PM_{2.5}$ monitoring data from Sakyo ward to approximate outdoor $PM_{2.5}$ concentration because the sampling location is near our study site (about 1 km away). $PM_{2.5}$ mass concentration in Sakyo ward (measured by the Energy and Environment Laboratory at Kyoto University) was monitored by TEOM1400 (Rupprecht & Patashnick), while in Fushimi ward (measured by the Kyoto Prefectural Institute of Public Health and Environment), the measurements were carried out by a $PM_{2.5}$ monitor (Kimoto) based on beta-ray attenuation. From Figure 4.2, it is clear that ambient $PM_{2.5}$ concentrations tend to increase in the afternoon with small variations from day to day. Therefore, a westerly wind in the afternoon will strongly affect indoor air quality at our location. To quantify the contribution of outdoor air to the indoor environment, we calculated the I/O ratio.

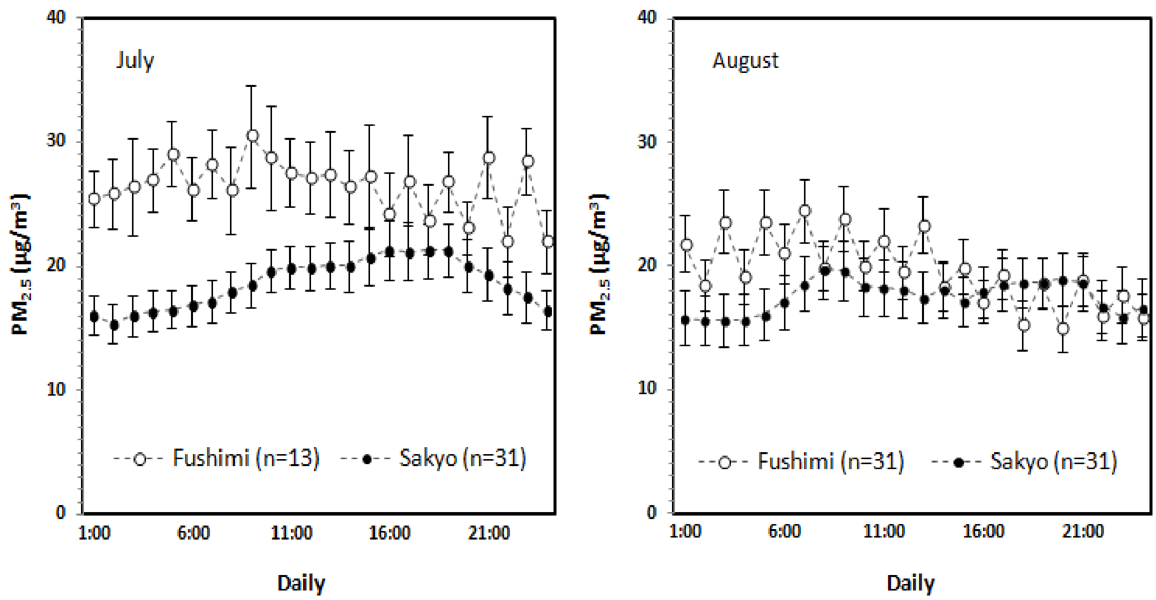


Figure 4.2 Diurnal variations of ambient $PM_{2.5}$ concentrations in Kyoto city in July and August, 2010

Average ratios of paired indoor to outdoor $PM_{2.5}$ concentrations during the measurement period are presented in Table 4.1. Table 4.1 shows that cooking activities resulted in high I/O ratios both in the kitchen and in the adjoining room. In the kitchen, I/O ratios during cooking were 3–4 folds higher than 12 h average I/O ratios, while in the adjoining room, the ratios were 1.1–2.9 fold higher. Our ratios are higher than those of Lee et al. (2001), who found that the mean I/O ratio of $PM_{2.5}$ was around 15 for frying. Moreover, our outdoor $PM_{2.5}$ concentrations were relatively lower than those of other studies in urban areas of other Asian countries (Tsai et al., 2000; Zhao et al., 2009) and were comparable to other data measured in Japan (Khan et al., 2010). Nonetheless, note that because the outdoor concentration during the measurements fluctuated widely (0.1–56.5 $\mu g/m^3$), the I/O ratio also oscillated, particularly when 10 min average $PM_{2.5}$ concentration was used.

Table 4.1 Average of paired indoor to outdoor ratios (I/O) of $PM_{2.5}$ concentrations

Cooking Method	Outdoor conc*($\mu g/m^3$)	Indoor conc‡($\mu g/m^3$)	I/O Ratio during cooking*		12-h average I/O Ratio†	
			K	A	K	A
Tofu boiling	0.3 - 18.1	1.21 - 294	8.92 (1.93)	2.39 (0.54)	2.84 (0.88)	2.09 (0.31)
Tofu frying	0.5 - 50.5	1.76 - 707	28.41 (7.05)	4.49 (0.86)	7.19 (2.45)	1.78 (0.32)
Chicken boiling	0.1 - 56.5	5.36 - 1082	17.30 (6.33)	0.97 (0.19)	3.96 (2.00)	0.62 (0.09)
Chicken frying	0.2 - 51.9	1.67 - 1366	27.13 (6.09)	4.65 (0.79)	6.18 (1.82)	1.59 (0.29)

Note : *Averaged over 10 minutes interval, † averaged over 1h interval, ‡ measured over 2 min interval, kitchen only. In parentheses are standard errors, K = Kitchen, A = Adjoining room

4.1.3.2 Temporal variation in mass concentration

Temporal variation patterns of mass concentrations in the kitchen and the adjoining room were similar for either tofu or chicken frying for the three consecutive cooking periods. The mass concentration in the kitchen was around six times higher than that in the adjoining room. This indicated that particle concentration was reduced during transportation to the adjoining room. This could be caused by air exchange between the rooms, deposition of the particles on surrounding surfaces, or other removal processes (Hussein et al., 2006). In contrast, boiling showed different pattern profiles in the three consecutive cooking tasks. Only frying emitted a high load of fine particles in the kitchen and still substantially affected indoor air in the adjoining room. Temporal variations in $PM_{2.5}$ concentration in the kitchen showed a distinctive peak with narrow-base shape during frying (Figure 4.3 (a)), which means a high concentration lasted for a short time. In contrast, in the adjoining room, the concentration peak was shorter with a wider base (Figure 4.3(b)). Spreading of cooking smoke from the kitchen to the adjoining room caused a time lag between concentration peaks in the two rooms and a broader peak in the adjoining room. Hussein et al. (2006) observed that PM concentration in a living room elevated to as much as 30% of the peak concentration in the kitchen, with a time lag of minutes to half an hour, during cooking in a home in Prague.

Figure 4.3 also shows that particle contributions from the stove itself (from fuel burning) were relatively small because its background concentration profile oscillated only to a little extent during cooking periods. In the adjoining room, the concentration profile of the stove background was somewhat similar to the overall background concentration.

According to the studies of Wallace et al. (2008) and Fan and Zhang (2001), higher concentrations of UFP (5–100 nm) are emitted from the burning of combustion devices alone, but it is difficult to detect them through the UCB particle monitor. This photoelectric monitor is sensitive to $PM_{2.5}$; however, it is less sensitive to particles with aerodynamic diameters less than 1 μm (Chowdhury et al., 2007)

Our study also confirmed that, as compared to low-fat foods, high-fat foods have higher PM mass emissions during cooking. In addition, frying generated more fine particle emissions than water-based cooking, as previously described by See and Balasubramanian (2008) and Buonanno et al. (2009).

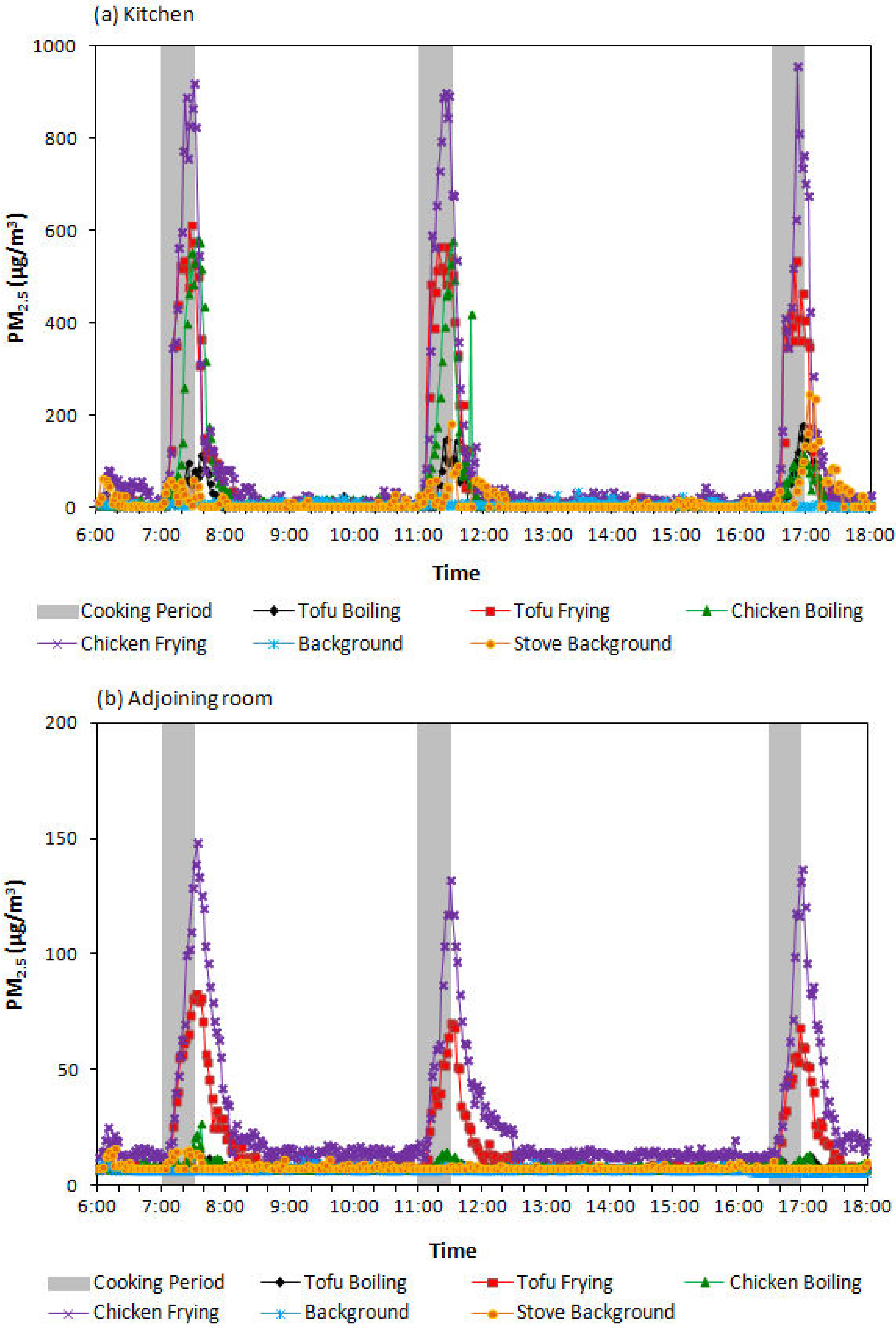


Figure 4.3 Two-day average variations in fine mass concentrations (a) in the kitchen and (b) in the adjoining room. Background concentrations are three-day averages.

If we assume negligible emission variations for each repetition of a cooking method, then natural ventilation helped to dissipate the pollutants in indoor air. As shown in Figure 4.4, strong westerly prevailing winds reduced the average concentration of $PM_{2.5}$ both in the kitchen and in the adjoining room. These results were observed on the first day in the afternoon during tofu frying, on the first and second days in the afternoon during chicken boiling, and during the second day in the afternoon during chicken frying. Nikas et al. (2010) confirmed that beside the geometry of the openings of a building and the incidence angle of the wind, the magnitude of wind velocity has the most significant effect on the air exchange rate of a building because of its proportionally to the inlet volume and flow rate of the ventilation.

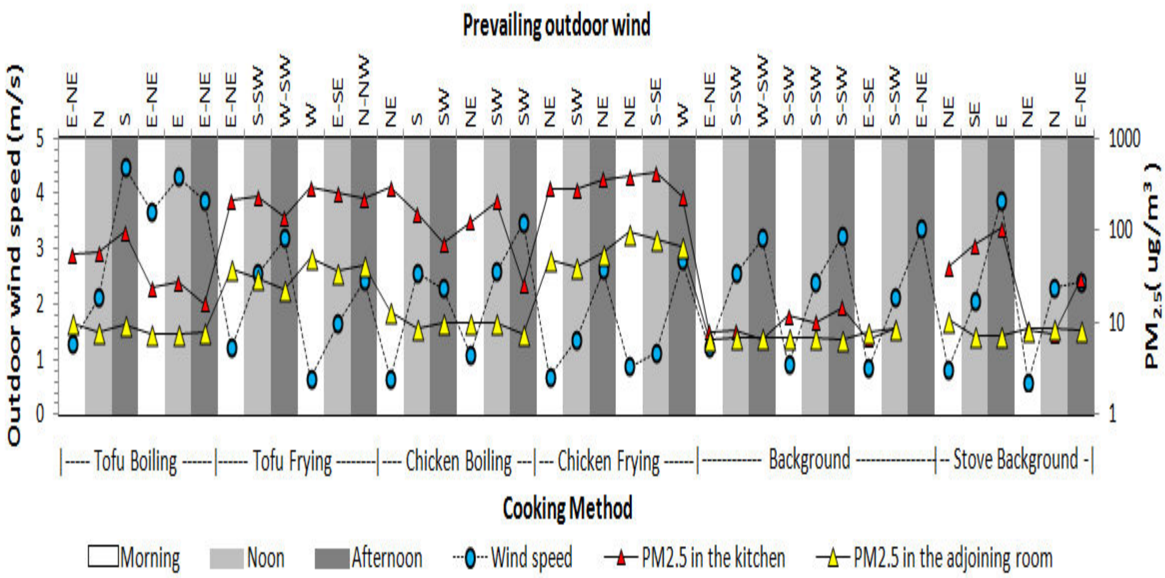


Figure 4.4 Prevailing outdoor wind directions and wind speed related by cooking methods.

Note : ‡ All samples were duplicated in the other day except for background (in triplicate)

Thus, wind speed considerably affects indoor $PM_{2.5}$ concentrations if the wind approaches the indoor opening from a fixed direction.

4.1.3.3 Particle number concentration

In general, number concentration in sub-micrometer mode was significantly affected by cooking activity, irrespective of the cooking method. Temporal variations in the number concentrations (Figure 4.5) showed particles with diameters of 0.3–5 μm fluctuated widely during frying, while during boiling, only those of 0.3–1 μm fluctuated.

On average, number concentrations of particles in the diameter range of 0.3–0.5 μm increased by 29%–48% over initial conditions during boiling (chicken and tofu). During frying, number concentrations of the particles in this size range increased by 134%–247% over the initial values. Comparable results were obtained in the adjoining room, where the increases over the background levels were 20%–36% and 127%–237% for boiling and frying, respectively. Sjaastad et al. (2008) found that during frying a beefsteak, the highest number concentration of fine particles (in the size range of 0.3–0.5 μm) in the adjoining room was only 5.8% of that in the kitchen. Dominance of fine particles in the number concentration can be explained by the coagulation shifting of UFP, which are the most notable products of combustion. The shift of the UFP to larger particles, related to stove combustion, has been suggested by Dennekamp et al. (2001) and Wallace et al. (2008).

Table 4.2 indicates that during the cooking, particle number concentrations in the kitchen and the adjoining room correlate better for boiling than for frying. During boiling, aerosols were homogeneously distributed, unlike during frying. This might be due to the existence of water droplets during boiling, as suggested by See and Balasubramanian (2006). In contrast, frying generated more submicron-sized particles than boiling, and the emitted aerosols were less volatile (remaining in particle state) and more easily coagulated (Yeung and To, 2008). These growing particles settled down during transportation to the adjoining room.

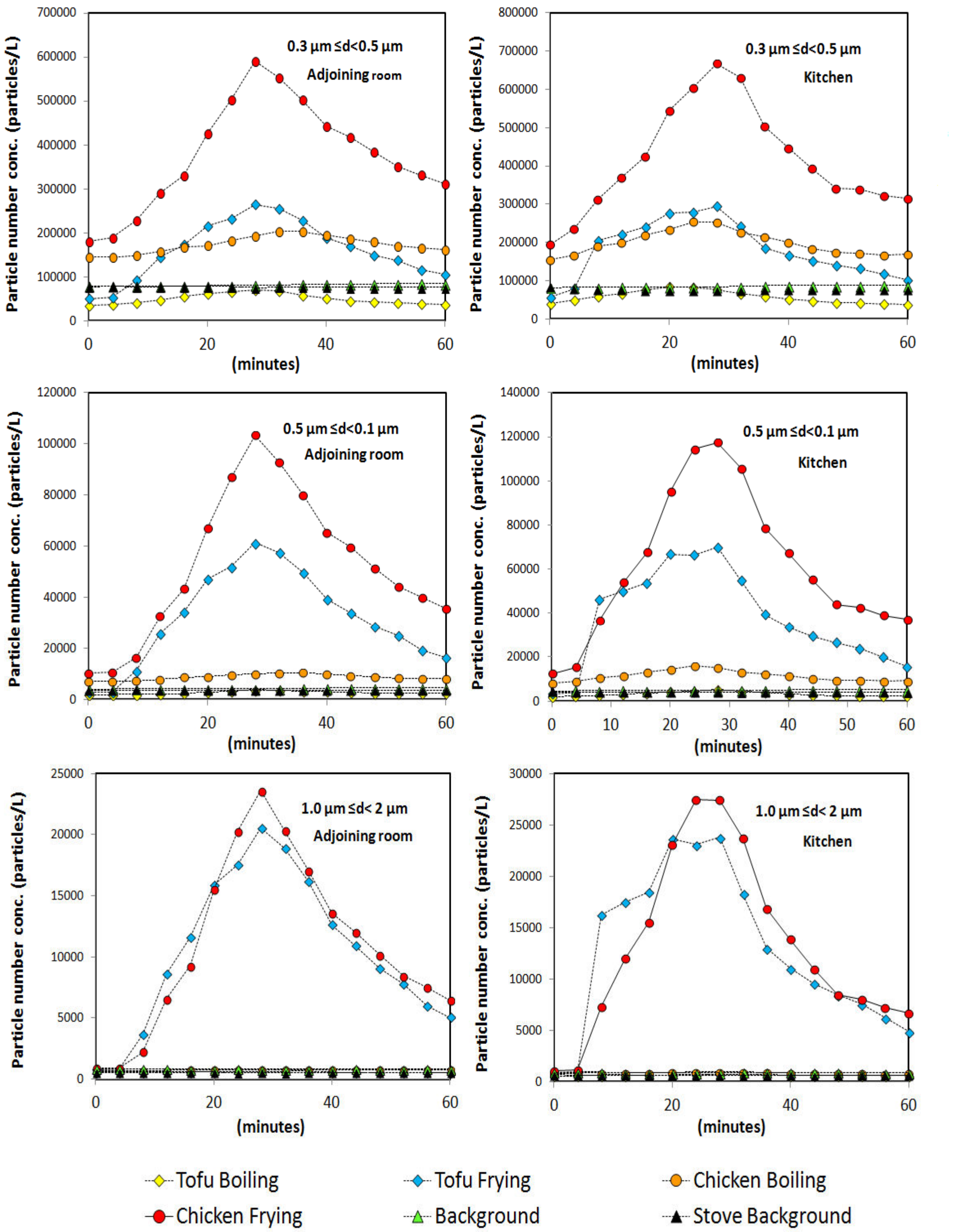


Figure 4.5 Average temporal variations in the number concentrations of fine particles in the kitchen and the adjoining room during cooking

Note : Each cooking method: n = 6, except for background: n = 9

Therefore, fine particle concentration decreased in the adjoining room. Gravitational settling is the major removal process of fine particles as they become larger because of coagulation (Afshari et al., 2005). Correlation coefficients for the overall background as well as stove background were almost unity, indicating relatively no difference in the behavior of fine particles between the two rooms

Table 4.2 Relationship between fine particle number concentrations in the kitchen and the adjoining room during cooking.

	Slope (β)	Intercept*	Std error (S_{YeX})*	Correlation coef†
0.3–0.5 µm				
Tofu Boiling	0.825	1305	9927	*r* = 0.967
Tofu Frying	0.728	29303	44193	*r* = 0.833
Chicken Boiling	0.765	21426	32718	*r* = 0.956
Chicken Frying	0.844	26517	61417	*r* = 0.920
Background	0.961	−964	1281	*r* = 1.000
Stove Background	1.038	−3894	4550	*r* = 0.991
0.5–1.0 µm				
Tofu Boiling	0.710	257	488	*r* = 0.962
Tofu Frying	0.667	6574	12812	*r* = 0.793
Chicken Boiling	0.616	1615	2096	*r* = 0.928
Chicken Frying	0.801	3375	13128	*r* = 0.911
Background	0.817	354	218	*r* = 0.996
Stove Background	0.898	4	257	*r* = 0.991
1.0–2.0 µm				
Tofu Boiling	0.919	2	42	*r* = 0.991
Tofu Frying	0.634	2321	4337	*r* = 0.792
Chicken Boiling	0.728	109	59	*r* = 0.954
Chicken Frying	0.774	753	3187	*r* = 0.911
Background	0.908	28	53	*r* = 0.948
Stove Background	0.870	28	39	*r* = 0.972

Note: * The units are in particles/L; † Pearson correlation coefficient at $p < 0.01$ level (two-tailed).

4.1.3.4 Size-fractioned carbonaceous $PM_{2.5}$

As summarized in Table 4.3 and depicted in Figure 4.6, a high percentage of OC was found in $PM_{2.5}$ and very high OC concentration was observed during chicken frying. Because we did not characterize the sunflower oil used in frying or the compositions of the ingredients, it was hard to estimate conversion factors for OC to Organic Matter (OM). See and Balasubramanian (2008) found that the proportions of EC to $PM_{2.5}$ were 9% in boiling and 8%–12% in frying; however, these were 3% and 2.6%, respectively, in our results (using the same ingredient, tofu). Our results for OC proportions were much lower, i.e., 39% compared to 44% in boiling and 39% compared to 52%–63% in frying. Note that our sample was taken about 1 m away from the stove (closely related to ambient indoor air) while See and Balasubramanian (2008) sampled near the stove (about 20 cm away). Therefore, fewer fine particles were captured in our case. Moreover, lower frying temperatures in this study produced fewer oil mist emissions. Another possible reason for the variations was that outdoor EC and OC particles might penetrate indoors and alter the indoor carbonaceous $PM_{2.5}$ concentration because we adopted natural ventilation and 12 h measurements.

Table 4.3 OC and EC mass concentrations in $PM_{2.5}$

Samples	Concentration		
	$PM_{2.5}$ (μg/m^3)	OC (μg C/m^3)	EC (μg C/m^3)
Tofu boiling	22.88	8.93	0.78
Tofu frying	41.12	16.31	1.11
Chicken boiling	30.86	6.82	1.16
Chicken frying	101.64	43.27	4.09
Background	21.71	10.12	0.86
Stove background	23.27	9.66	1.33

Strangely, the background OC concentration in this study was higher (46% in $PM_{2.5}$) than those of tofu boiling and chicken boiling. It originated from a nearby pollutant source because only at that particular daytime, the author suspected smoke from burning incense came up from a neighborhood building. The ambient ratio of OC to $PM_{2.5}$ was only around 13% in previous measurements in Kyoto (He et al., 2004b). Outdoor $PM_{2.5}$ might alter the composition of indoor $PM_{2.5}$ if the concentrations are much different. On the basis of the total mass size distribution, the dominant size range was less than 0.25 μm, followed by 0.25–0.5 μm. Tofu boiling generated the fewest number of fine particles (compared to the background levels), particularly in the size range of 1–2.5 μm. All samples exhibited unimodal distributions in the size range of less than 0.25 μm. Our results are similar to those of Chao et al. (2002), who showed that the dominant size range was below 0.4 μm. This measurement was conducted with only one sample per cooking method; thus, uncertainty may arise regarding the result.

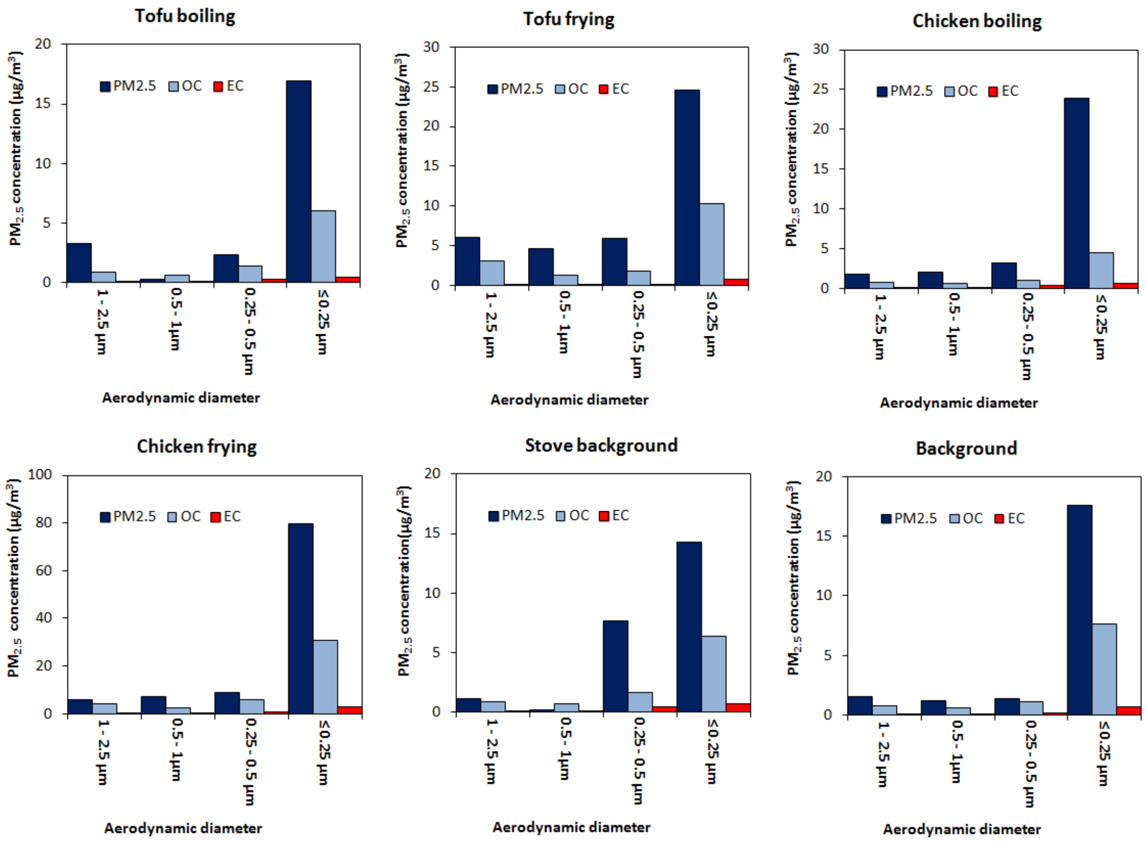


Figure 4.6 Mass size distributions of indoor carbonaceous particles related to cooking methods.

4.1.3.5 CO profiles related to the cooking method

We assume that there was no difference in energy (city gas) consumption for the cooking methods, as we followed the same procedure to treat the stove power for all measurements. Because we could not control the outdoor CO, relative CO concentration to the background was selected, as described in Figure 4.7. In Japan, ambient outdoor CO is quite low, i.e., below 1 ppm for a 24 h average (Ministry of the Environment, Government of Japan, 2005). Measured average background CO was below 0.5 ppm because our CO monitor has a resolution of 0.5 ppm.

The unique result is that stove background showed the highest concentration of CO during cooking, while boiling generated the least CO. This finding may be due to the fact that CO in the kitchen, which mainly originates from stove emissions, might not be easily absorbed by hot oil mists generated by frying. In contrast, boiling produces water mist, which can absorb CO gas because of comparable polarities. CO gas with a solubility of 0.024 g/kg of water (at 30°C) has a similar degree of polarity (1.95) compared with water (1.45) (Weast, 1988).

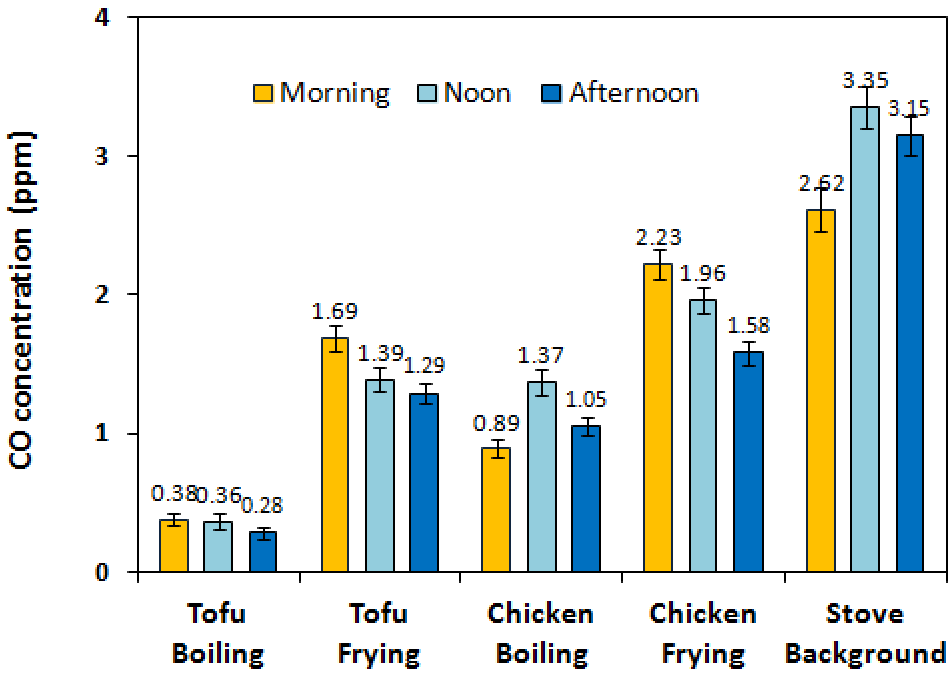


Figure 4.7 Average CO concentrations during cooking

In addition, we did not use a lid in this study; therefore, much water mist was generated during boiling. In full-scale experimental studies, Fang et al. (2006) used water mist to quench cooking oil fires and found that this mist could reduce both CO and CO_2 concentrations. However, further study with fully controlled variables in a test kitchen such as a chamber should be conducted to confirm whether CO is absorbed or dissipated from the room because of ventilation.

In general, using the same ingredients of food as a basis for comparison, frying increased the CO concentration over boiling by a factor of 1.4–2.5 (for chicken) and 3.8–4.5 (for tofu). During chicken frying, CO concentrations increased by a factor of 1.2–1.4 over tofu frying. During chicken boiling, CO concentrations increased 2.3–3.8 times over tofu boiling. These results indicate that frying produces more CO than boiling if we use low-fat foods. Replacing low-fat foods with high-fat foods resulted in even higher CO generation; the difference in CO concentration between the foods was more significant for boiling than for frying. Our average indoor CO concentrations were much lower than WHO indoor CO guidelines of 30.55 ppm for 1 h average and 8.73 ppm for 8 h average (WHO, 2010). Thus, this scheme of cooking is still safe for people, even in households using natural ventilation.

4.1.4 Conclusion

Frying emits higher amounts of $PM_{2.5}$ than boiling in terms of mass and number concentrations. There was a time lag between changes in concentration in the kitchen and in the adjoining room, and the particle size distribution in the adjoining room was lower and wider than that in the kitchen. With regard to the spatial distributions of fine particles in the kitchen and the adjoining room, frying exhibited less homogenous distribution of fine particles than boiling. Frying resulted in high proportions of organic carbon in $PM_{2.5}$, while there was little difference in the ratio of elemental carbon between the cooking methods. Boiling produced lower emissions of CO in indoor air, possibly because of the absorption of the generated CO gas by steam. Ventilation with prevailing wind direction perpendicular to the window will reduce considerably indoor concentration of $PM_{2.5}$.

4.2 Comparison between *Jatropha curcas* seed stove and woodstove: Performance and effect on indoor air quality

4.2.1 Introduction

Low-income families in developing countries are still attracted to biomass fuel, especially solid biomass fuel, as an energy source for daily household cooking. About 730 million tons of biomass fuels are burned each year by households in developing countries in various cook stoves (World Bank, 2011).

It is estimated that biomass fuels are used in as many as 70% of rural households in Asia (Aunan et al., 2009). In Indonesia, based on national survey in 2010, about 65.68% of rural households still use wood fuel compared to only 0.81% of their use of charcoal as the main source of fuel at home (BPS, 2011a). The kerosene users, LPG users and electricity users for cooking constituted 15.75%, 13.23% and 0.47% of the households respectively.

Use of solid biomass fuel for cooking is important worldwide and especially in developing countries from the viewpoints of global energy demand as well as impact on health. Many researchers are aiming to develop alternative stoves to not only reduce fuel use but also achieve improved emission performance. The goal of improved biomass stoves in the 1980s and 1990s was to save fuel. In fact, these improved biomass stoves still emitted higher amounts of PICs (Smith et al., 2000). In recent years, the goal of developing an improved biomass stove is not only to achieve a design that would save fuel (higher efficiency) but also reduce air pollution and contribute to mitigate climate change (MacCarty et al., 2005).

Many improvements have been introduced in biomass stoves in various parts of the world, either by modifying the stove configuration, operation, and design or by introducing new types of biomass fuel. Researches on the indoor air quality (e.g. $PM_{2.5}$ concentration) of the room where improved stoves are in use have been also conducted (Chengappa et al., 2007;

Dutta et al., 2007; Armendriz et al., 2008). Since woodfuel resources for cooking are depleting, it is desirable to optimize usage of available local biofuel resources in the development of improved stoves considering that wood is not the only biomass fuel.

As a developing country, Indonesia is also looking for effective alternative fuels for cooking since the phase-out of subsidy for kerosene started in 2007. In 2001, the government kerosene subsidies to the end users (consumers) amounted to 1.29 billion USD and increased to 5.24 billion USD in 2008 due to the large gap between the market price of kerosene and the price of subsidized kerosene (Arofat and Budya, 2011). As depicted in Figure 4.8, since 2007 subsidized LPG was introduced to provide domestic fuel for the poor and small business activities. As a result LPG consumption increased dramatically during 2007 – 2010 while kerosene consumption decreased. However, due to the price regulation by the government, the regular LPG (unsubsidized LPG) retail price was still below the economical/market price of LPG (except for 2009). Until now, there was no large scale survey to determine how many households (former kerosene users and wood users) had converted their main fuel to LPG. Recent spot surveys during 2007 – 2009 in urban areas of greater Jakarta and nearby cities by individual researches, consulting firms and government indicated that the conversion program was successful. For example, Latifah et al. (2010) revealed that before the conversion program in the low income people of the urban city of Bogor, there were 45% and 55% of kerosene and wood users respectively. After the conversion program, the composition changed to 82%, 10% and 8% of LPG users, kerosene users and wood users respectively. Arofat and Budya (2011) summarized from two studies in 2007 that about 86% of 550 respondents preferred to use LPG instead of kerosene, 74% considered that the expenditure on LPG was much lower than kerosene. Moreover, 87.2% of the respondents also supported the conversion program from kerosene to LPG.

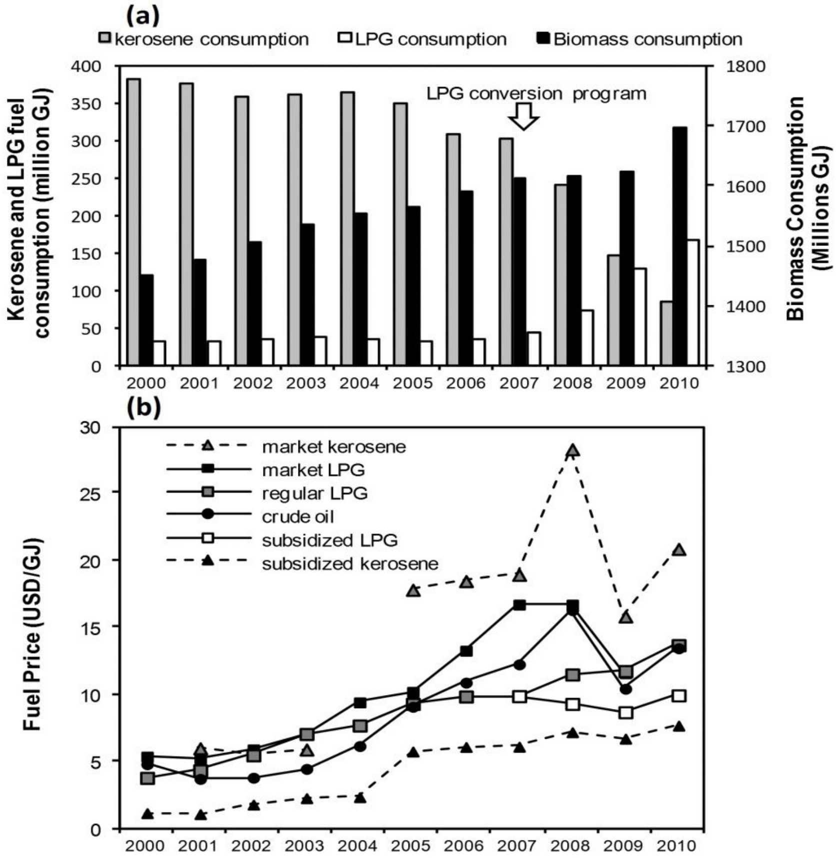


Figure. 4.8 (a) Variation of fuel consumption in Indonesian households and (b) Variation of fuel prices from 2000 to 2010

Sources : recalculated data from CDIEMR (2011), Abdini and Andyawarman (2012)
(data are unavailable for kerosene market price in 2000, 2004 and LPG market price in 2010)

However, a field survey in 12 provinces (YDD-EBTKE, 2010) indicated that this conversion program was not particularly successful in rural households. It was found that accessibility and cost were the main factors considered for choosing fuel type for domestic cooking energy in addition to availability and safety. For that reason, besides developing cleaner wood stoves, in rural areas, it is advisable to find alternative domestic cooking fuels which are cheap, clean, and easy to gather and provide reliable cooking. Despite certain drawbacks such as its toxicity and peeling-off requirement to get the seed from its shell, *Jatropha curcas* might be a candidate as an alternative fuel for cooking in rural areas for the following reasons: it can grow even in severe drought and low soil fertility (FACT, 2010), the plants can be harvested six months after the seed is sown and it may live for more than 50 years. Moreover, this plant is very common in Indonesia and therefore can be easily introduced and accepted as a fuel source for stoves by the local population. This is an advantage for acceptability of this stove, since acceptability is another key factor in evaluating improved stove development (Berrueta et al., 2008)

In Indonesia, the land suitable for *Jatropha curcas* cultivation is distributed widely across the archipelago. It is estimated that up to 19.8 million ha land (across 31 provinces) is suitable for this purpose and will play a significant role in the rural energy system (JIE, 2008). Considering current wood fuel users (around 24.3 million households), stove efficiencies data, and approximate cooking energy demand for each household (if all wood fuel users are converted to *Jatropha curcas* fuel), it is estimated that about 1.79 million ha will be needed for *Jatropha curcas* plantations. Thus it is just 9% of the estimated maximum cultivable land based on the JIE calculation.

In this study, we review a *Jatropha Curcas* Seed (JCS) stove that was manufactured locally in Malang, East Java province in Indonesia. This stove is simple and looks similar to the kerosene stoves, which were in common use across Indonesia before the kerosene subsidy was phased out. According to the manufacturer's information, 11,126 of these stoves were sold before 2009 (Widaryanto, 2010). There are many types of JCS stoves in Indonesia (FACT, 2010); however many of them are improvised designs which have not been adequately tested.

Based on the national blue print on LPG conversion in the year 2007, it was projected that about 71% of the households (including those in rural areas in Indonesia will be provided with subsidized LPG by 2012. However, according to a pre-survey study, there are still a large number of rural households that use wood fuel despite having the provided gas stove package. The reasons behind this situation are: modern fuel retailer accessibility, safety concerns (i.e., fear of explosion/fire with the use of LPG, of particular concern to the elderly), fuel price comparison with wood fuel, and the belief that LPG cooked food does not have the desired taste.

Around the globe, there are numerous stove types designed to achieve higher thermal efficiency as well as heat transfer efficiency. As a reference for comparison of the thermal efficiency of different stoves, a standardized WBT (Water Boiling Test) established by Approvecho Research Center was used in this study (Bailis et al., 2007). This test includes but is not limited to thermal efficiency and specific fuel consumption derived from three tests (high-power cold start, high-power hot start, low-power hot start). Although a bias in performance exists between the WBT performed in a lab and one performed in the field with the same stoves (Smith et al., 2007) or between the stove used for testing and the real stove in use (Johnson et al., 2008), this test is still useful in preliminary understanding of the stove performance during the design process. MacCarty et al. (2010) tested 50 stoves using WBT in a controlled lab for benchmarking and stove comparison (traditional and improved) but did not include this JCS stove in the study. Wagutu et al. (2010) extracted *Jatropha curcas* seed oil and processed it to fatty acid methyl esters (FAME) fuel through transesterification process. Then they used this fuel in a stove with a wick. They proved that the efficiency of the stove was comparable to that of a kerosene stove. Our study measured the performance (thermal efficiency and specific fuel consumption) of the JCS stove compared to other stoves (charcoal, kerosene, wood stove and improved wood stove). In order to assess the indoor air pollution caused by the JCS stove, we conducted a WBT (with lid), measured the pollutants and compared these with the pollutants produced by a traditional woodstove. With respect to indoor air quality, we were interested in knowing the probable health impacts on the household cook exposed to the pollutants at the cooking site. The findings of this study do not reflect real cooking stove performance or indoor air pollution in the field. We did not conduct any stove-fuel combination tests as these would be impractical on current stove designs. For instance it is necessary to chop the wood into small pieces that can fit into the JCS stove fuel chamber.

4.2.2 Methodology

This study was conducted during September to October 2010 in Indonesia during the transition of weather from the dry season to the wet season. However, the testing was conducted indoors without significant weather effect.

4.2.2.1. Measurement setting

We used a standardized WBT (ver 3.0) at the Asian Regional Cookstove Project (ARECOP) laboratory owned by the Indonesian Cookstove Network - YDD in Kaliurang Yogyakarta, Indonesia. This laboratory is experienced in testing cooking stoves. In this test we used an aluminum pot, with inner diameter 26 cm, weight 360 g. The amount of water used was 2.5 liters with respect to the JCS stove which has a limited fuel capacity. This test consists of cold, hot and simmering phase tests in thrice with coefficient of variation <25%. We compared the WBT results of JCS stove with the results of other stoves: a traditional wood stove (U-shape), an anglo charcoal stove, kerosene stove and recent improved woodstoves i.e. SAE stove (see Figure 4.9).

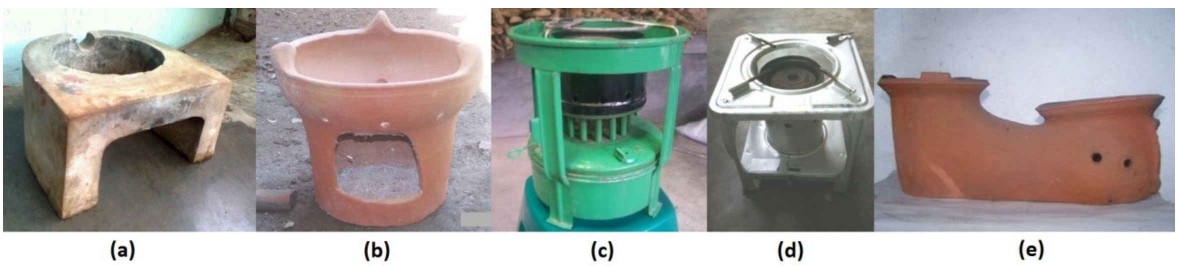


Figure 4.9 Stove types for WBT test (a. wood stove, b. charcoal stove, c. kerosene stove, d. JCS stove, e. improved wood stove-SAE stove)

The charcoal stove which is mainly used by street hawkers has low fuel capacity and small stove ventilation holes. The kerosene stove tested here was wick type. This type was widely used by most householders in Indonesia prior to the kerosene to LPG conversion program. The SAE stove was designed to optimize the excess heat waste from primary stove pot hole to be used in secondary pot holes. Both the charcoal stove and SAE stove are made of burnt clay.

In order to assess indoor air pollution caused by using the JCS stove, we utilized a field simulated kitchen with a door and a window which represents the common design in semi-rural areas. The room's walls were made of brick without cement coating and the roof was made of asbestos sheet. In order to set different ventilation conditions, we applied no ventilation (both window and door were kept closed) and ventilation (the window was opened, while the door was kept closed). However, some air infiltration around the door edges was possible. During the no ventilation scheme, the emission plume was mainly drawn up in the direction of the holes in the roof. A sketch of the room and the setting of the devices used are shown in Figure 4.10.

All the wood used in this experiment had a comparatively low moisture content (less than 15 % wet basis by weight), while for the JCS stove, we utilized piled-up seeds with moisture content up to 5 % wet basis by weight. The pieces of wood used had approximate dimensions of 6 × 6 × 30 cm each. We did three 1-hour water boiling tests of cooking: in the morning, noon and afternoon. This was to prevent accumulation of the emissions from the preceding cooking. To verify if the indoor air quality went back to the background condition (relatively similar or comparable to outdoor air quality), we used a hand-held CO monitor (AZ Instrument) to measure indoor and outdoor CO concentration levels.

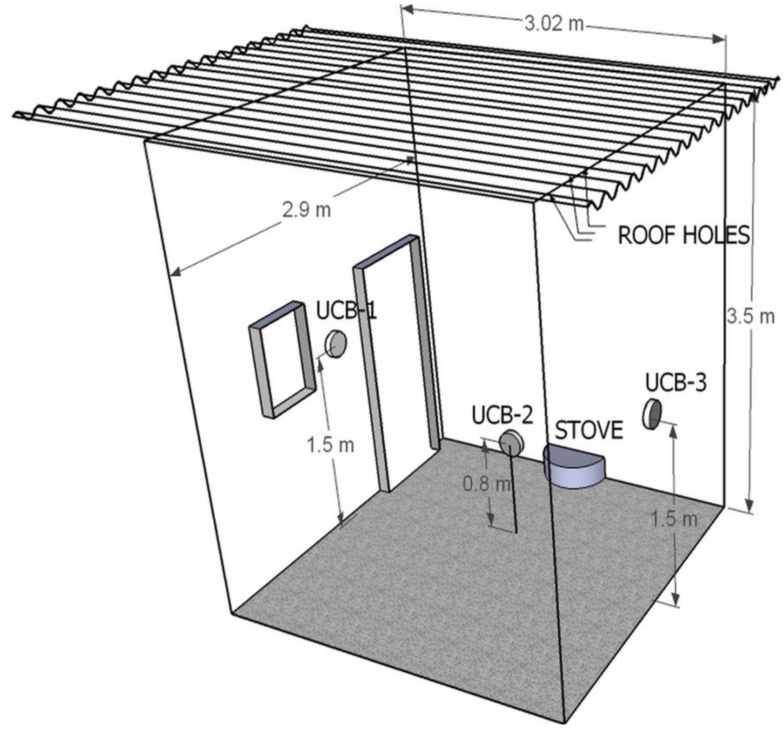


Figure 4.10 Schematic view of simulated kitchen

Also the background concentrations of $PM_{2.5}$ and CO were measured for several hours intermittently over two days. Since the object of this study was to measure indoor $PM_{2.5}$ concentration related to its health impact from inhalation, the samplers (the impactor, UCB (University of California, Berkeley) monitor as well as Universal Serial Bus/USB CO monitor) were set at the sitting height of the cooks, i.e 80 cm, which was roughly at the breathing zone of the cooks and at a distance of 1 m from the outside perimeter of the stoves. In addition, to minimize interference, the samplers in use were placed 1.5 m apart from the door and window although only the door was kept closed throughout this study.

4.2.2.2 Instrumentation

Mass size distribution of particulate matter

Measurement of particle mass size distribution was conducted using an SKC Sioutas Cascade Impactor (SKC Inc). It uses a Leland Legacy® sample pump at a constant flow rate of 9 L/min. The flow rate was calibrated against a DryCal primary flow meter (Bios International, USA) and the difference was under 10% in the post-sampling period. The impactor separates and collects airborne particles in five 50% size-cut point ranges: >2.5 μm, 1.0 to 2.5 μm, 0.50 to 1.0 μm, 0.25 to 0.50 μm, and <0.25 μm. In this study, we were interested in particles below 2.5 μm in cutoff size. The $PM_{2.5}$ samples were collected in quartz filters (Pallflex) pre-heated at 600°C (4 h) with a 25 mm diameter (collection stage) and a 37 mm filter (back-up stage). The quartz filter was selected for the carbon analysis as described later. Prior to weighing, the filters were conditioned for at least 48 h. At least three weighings of a single filter were conducted for weight consistency using a balance having ±1 μg accuracy (Mettler Toledo MX-5) in a conditioned room (40%–50%). To account for the uncertainties in handling the filters during measurements, field blanks were also provided.

Temporal variation of $PM_{2.5}$ mass and carbon monoxide concentrations

Co-located with the cascade impactor, the inexpensive monitor UCBs (these monitors were designed by Berkeley Air Monitoring Group) were installed for monitoring temporal variation of $PM_{2.5}$ during measurement by photoelectric principle. These UCB`s are sensitive to fine particle concentration resulted from combustion and have been used extensively elsewhere (Chowdury et al., 2007; Armendriz et al., 2008;Chengappa et al., 2007; Dutta et al, 2007) . Since there is no cut-size particle information on UCBs results, we calibrated the UCBs results with the impactor (gravimetric principle) data to ensure the validity of the temporal variation of $PM_{2.5}$ mass concentration. Figure 4.11 is the relationship between three UCBs outputs and gravimetric results.

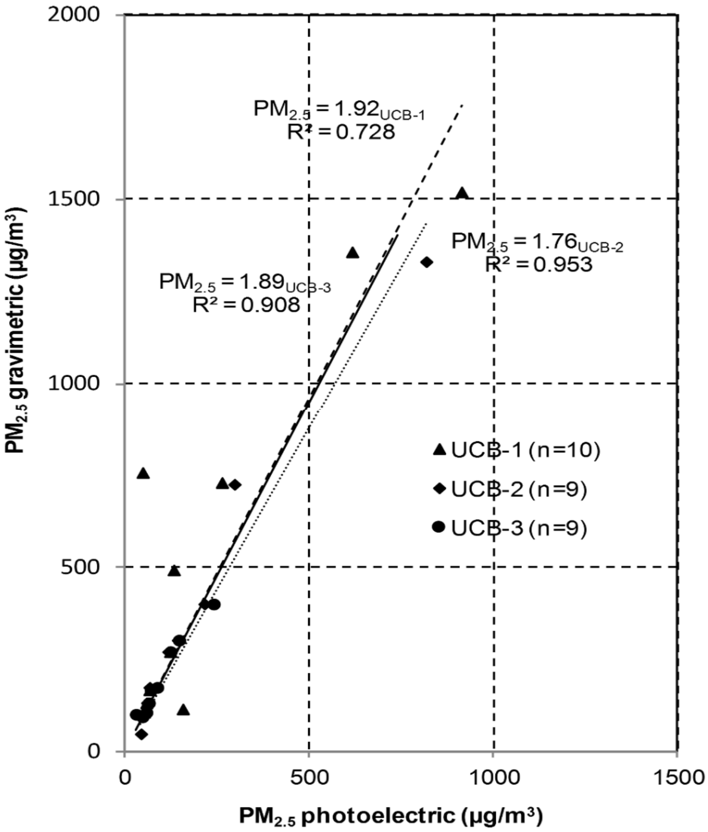


Figure 4.11 Calibration curves for each UCB monitor for photoelectric $PM_{2.5}$ mass concentration

We have also activated simultaneously all UCB`s in the same location in a common room for 542 minutes previously and they gave the following ratio of average concentration (relative to UCB-2):

UCB1 : UCB2 : UCB3 = 1.019 : 1 : 1.014

This result indicates that there is little difference in three UCBs under baseline measurement. Therefore the calibration values in Figure 4.11 are still reasonable in the sense that the ratio did not have much bias against the UCB baseline measurement ratio.

Three UCB monitors were deployed as follows: the main one at the cooking site, standing at 80 cm above the ground (UCB monitor-2), and the other two near the ventilation and away from the ventilation standing at 1.5 m above ground (UCB monitors 1 and 3, respectively) for control. At the end of each cooking cycle, the photoelectric chambers of these monitors were cleaned to prevent distortion of the baseline measurement.

Carbon monoxide concentrations were monitored using a universal serial bus (USB) CO data Logger (Lascar Co), which has a measurement range of 0–1000 ppm with ±6% reading accuracy. This CO monitor was standardized before and after the measurements by span-calibration using CO standard gas (Sumitomo Seika Co, 0 and 92.9 ppm). We also measured the average indoor temperature and humidity using a USB thermo hygrometer (Lascar Co).

4.2.2.3 Chemical analysis

To determine the size-segregated OC-EC mass concentrations after sampling by the cascade impactor, we used thermal optical OC-EC analysis (DRI model 2001) with the Improve_A protocol. The calculation detail of the OC-EC contained in the deposited particles on the stages filters (25 mm and 37 mm) was described elsewhere (Huboyo et al., 2011b). In this study, only samples with ventilated condition were subjected to OC-EC analysis. In addition, water soluble inorganic ions (Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}) were analyzed using ion chromatography (HIC-10A, Shimadzu Co). We ignored F^- because fluoric ion was detected excessively in the blank of pre-heated filter. Ionic balance (both cations and anions) was summarized for each stove. We finally summed up both cations and anions for each filter and formed the percentage summary of the $PM_{2.5}$ mass concentration. For comparison of ionic composition, background sample was also provided.

4.2.3 Results and discussion

4.2.3.1 Water boiling test

At first approximately 10 mL kerosene was added to the stove for ignition. From the test results of the WBT (Figure 4.12), the JCS stove's performance with regard to thermal efficiency was higher than that of the traditional wood stove or even improved wood stove (SAE stove). Yet, the JCS stove efficiency was below that of the kerosene stove, and was comparable to that of the charcoal stove. The biomass consumption of the JCS stove was a third to a half than that of the traditional wood stove.

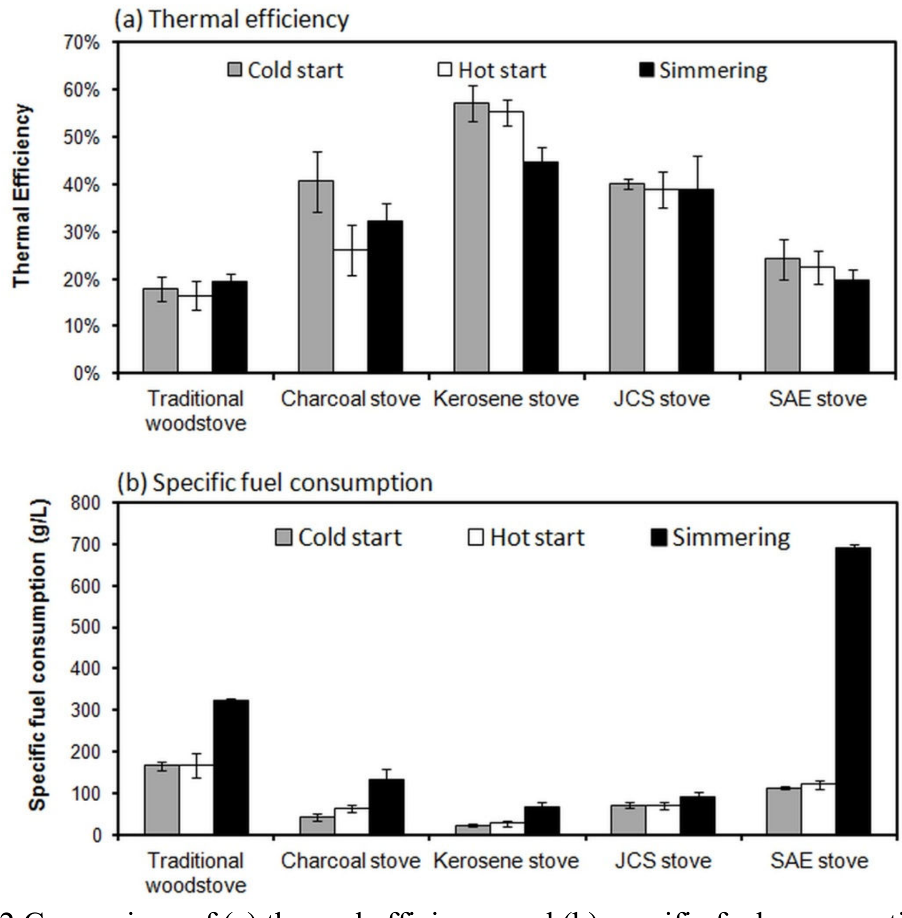


Figure 4.12 Comparison of (a) thermal efficiency and (b) specific fuel consumption during WBT among JCS and other stoves

The JCS stove is attractive because it is made of lightweight aluminum and is similar in shape to the familiar kerosene stove. However, it takes time to produce a consistent fire, therefore it might not be suitable for the ordinary household in daily use if we compare it with the kerosene stove. However if we compare the JCS stove with the traditional stove and charcoal stove on this ignition time parameter, then the JCS stove is preferable. The JCS stove is less suitable for cooking large quantities or for a long duration (more than 60 min), because it is quite difficult to add fuel while the stove is in use.

Table 4.4 Different performance means of tested stoves with JCS stove (indicated by *p*-value of *t*- test)

Stoves	Thermal efficiency			Specific Fuel Consumption		
	C	H	S	C	H	S
Traditional woodstove	0.0002	0.0012	0.0109	0.0002	0.0061	0.0001
Kerosene stove	0.0018	0.0037	0.2629	0.0003	0.0018	0.0471
Charcoal stove	0.8886.	0.0273	0.2369	0.0133	- *	0.0628
SAE stove	- *	0.0053	0.0126	0.0007	0.0037	0.0001

Note : C = Cold start, H = Hot start, S = simmering test

Due to its fuel vessel configuration (a maximum fuel holding capacity of 300 g), it was difficult to adjust the stove power particularly for reducing the fire for the simmering test. Hence, the JCS stove has only one type of fire intensity as indicated by its small turn down ratio (ratio of high power intensity to low power intensity was only 1.1); this means that the low power level of the stove was little different from its high power level.

The times taken for the water to boil and the amount of biomass consumed during the WBT (with lid) for the JCS and the traditional wood stove with and without ventilation are shown in Table 4.5.

Table 4.5 Comparison of time to boil and biomass consumed during WBT with ventilation (V) and without ventilation (NV)

Parameter	**JCS (NV)** n = 8	**JCS (V)** n = 9	**WS (NV)** n = 7	**WS (V)** n = 5
Time to boil (min)	18.5 (2.62)	18.25(1.75)	19.29(3.19)	16 (3.31)
Biomass consumed (g)	123.33 (8.50)	124.5 (7.33)	520.14 (89.80)	488 (120.88)

Note : Values in the bracket represent standard deviation

If we inspect time to boil and biomass consumed during WBT (with lid) as described in the table, for the wood stove, increasing the airflow in the kitchen by ventilation reduces the consumption of biomass and shortens the time to boil. However, for the JCS stove, there seems to be no difference in the boiling time as well as biomass consumed due to ventilation. We estimated air exchange rate (AER) as a function of natural logaritmic (Ln), using formula Eq (4.1) by McCraken and Smith (1998) i.e :

$$S\ (h^{-1}) = (LnC_0 - LnC_i)/t_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ (4.1)$$

using CO as a parameter. Where S (h^{-1}) denotes air exchange rate (per hour), C_0 represents the initial CO concentration, C_i denotes CO concentration at t_i, and t_i represents duration time of CO concentration for decay (hour). We estimated that the AER during the ventilation event were 2.4 – 2.7 h^{-1}. During non-ventilation scheme, it is likely the AER`s were lower as the window was closed. This phenomenon might be due to the stove configuration. The wood stove has a front opening large enough for cross ventilation allowing inflow of free air from outside through ventilation. On the other hand, although the JCS stove has cross ventilation too, the effect was quite small as the ventilation was through tiny holes in the seed vessel. Instead this stove has main ventilation upward from the bottom of the stove through small holes whose openings can be adjusted by a lever. Thus side ventilation has little effect in this stove. Nonetheless, student t-test demonstrated that there were no significant mean differences between using ventilation and non-ventilation in both stoves with respect to time until boiling and biomass consumed ($p > 0.05$, two-tailed).

4.2.3.2 Temporal variation of $PM_{2.5}$ mass and CO concentrations during WBT

As shown in Figure 4.13, the $PM_{2.5}$ concentrations rose slightly at the start of combustion using the JCS stove because of the start-up fire in the course of the stable phase of flaming combustion. Throughout the combustion phase, the JCS stove seemed to have concentration profiles that continued to decline with negligible fluctuations (even when the fire was maintained by adjusting the lever) because of gradual depletion of the biomass fuel stock.

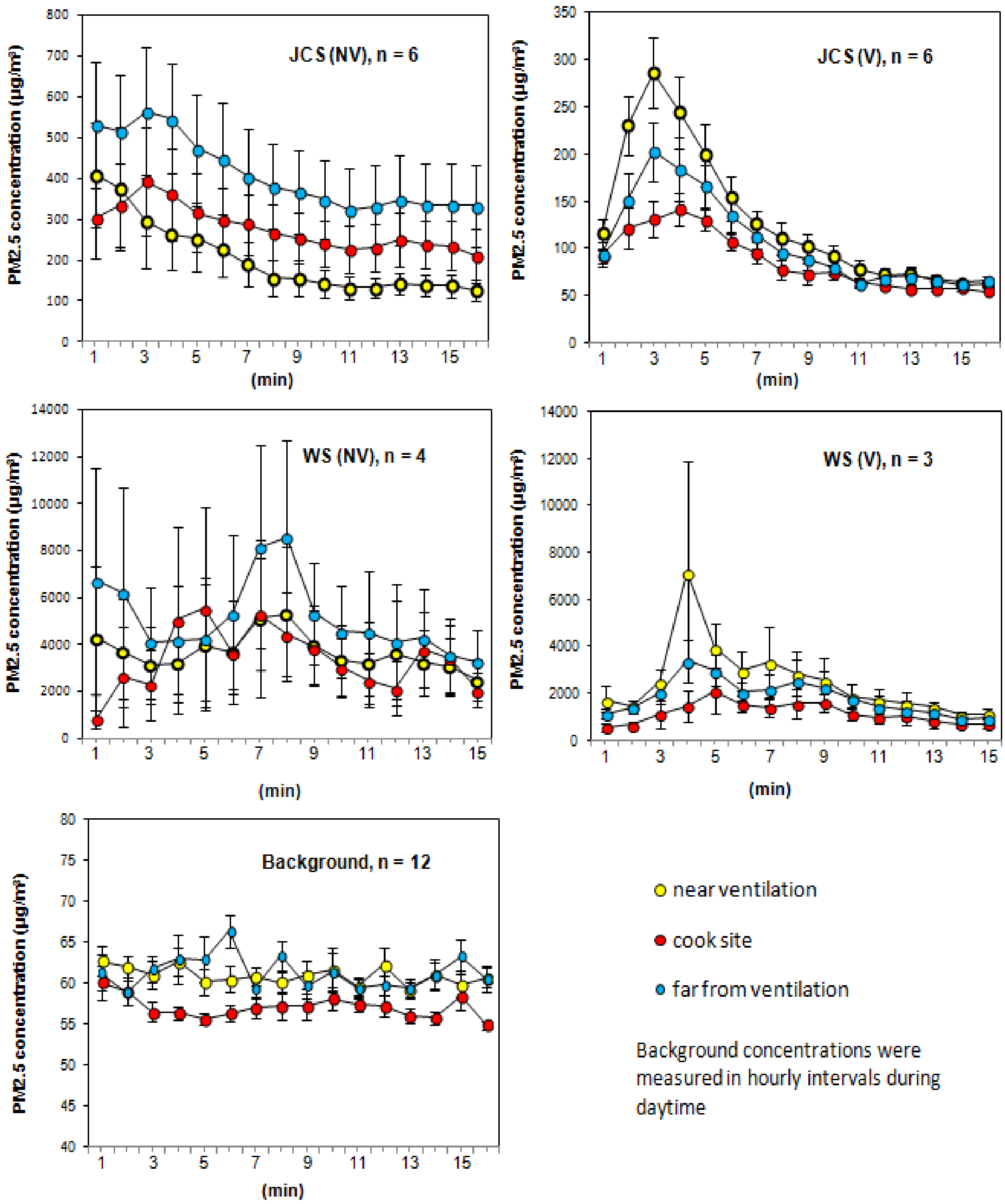


Figure 4.13 Average temporal $PM_{2.5}$ mass concentrations during stove combustion as well as background condition with and without ventilation.

In contrast, with the wood stove, $PM_{2.5}$ concentrations continued to fluctuate during the combustion period. During the middle of the combustion period, the $PM_{2.5}$ concentrations reached their peak. Note that during the combustion of wood, a high intensity fire was maintained to simulate normal household cooking practice.

Due to the uneven height of the UCBs position settings, the concentrations measured near and away from the ventilation were greater compared to those measured at the cook site. Our observations suggested that the emission plume tended to move vertically (upward) rather than horizontally. In many cases the emission plume showed movement toward the direction of the position of ventilation.

In general, the ventilation did not change the $PM_{2.5}$ concentration patterns drastically, but it did change the magnitude of the concentrations. Figure 4.14(a) indicates that in non-ventilated condition, the average indoor $PM_{2.5}$ concentrations of the JCS and wood stoves increased by 335% and 299% (at cook site) respectively than those in ventilated condition. Background concentration level of $PM_{2.5}$ concentration was relatively stable in the range of 55 - 65 $\mu g/m^3$.

A similar result to $PM_{2.5}$ was observed in CO concentration as shown in Figure 4.14. (b) where wood stove without ventilation had the highest average CO concentration during wood fuel combustion. Providing air circulation around the stove allows near-complete combustion and also vents the CO product out of the room; thus, using ventilation reduces the CO concentration.

In general, the JCS stove might emit less CO than the wood stove if we analyze the concentration during ventilation and no ventilation conditions. In another study using different improved stoves, Roden et al. (2009) found that improved stoves (using the chimney to vent out the pollutants) reduced the CO emission of traditional cooking stoves by 20%–50%. According to the t-test, all average CO values have significant differences (*p*

< 0.05 two-tailed). In this case, ventilation reduced the indoor CO concentration by about 31.5% and 52.5% compared to the non-ventilated room for the JCS and the wood stove respectively. Moreover, in a ventilated room, the CO concentration of the JCS stove was 37.4% lower than that of the wood stove.

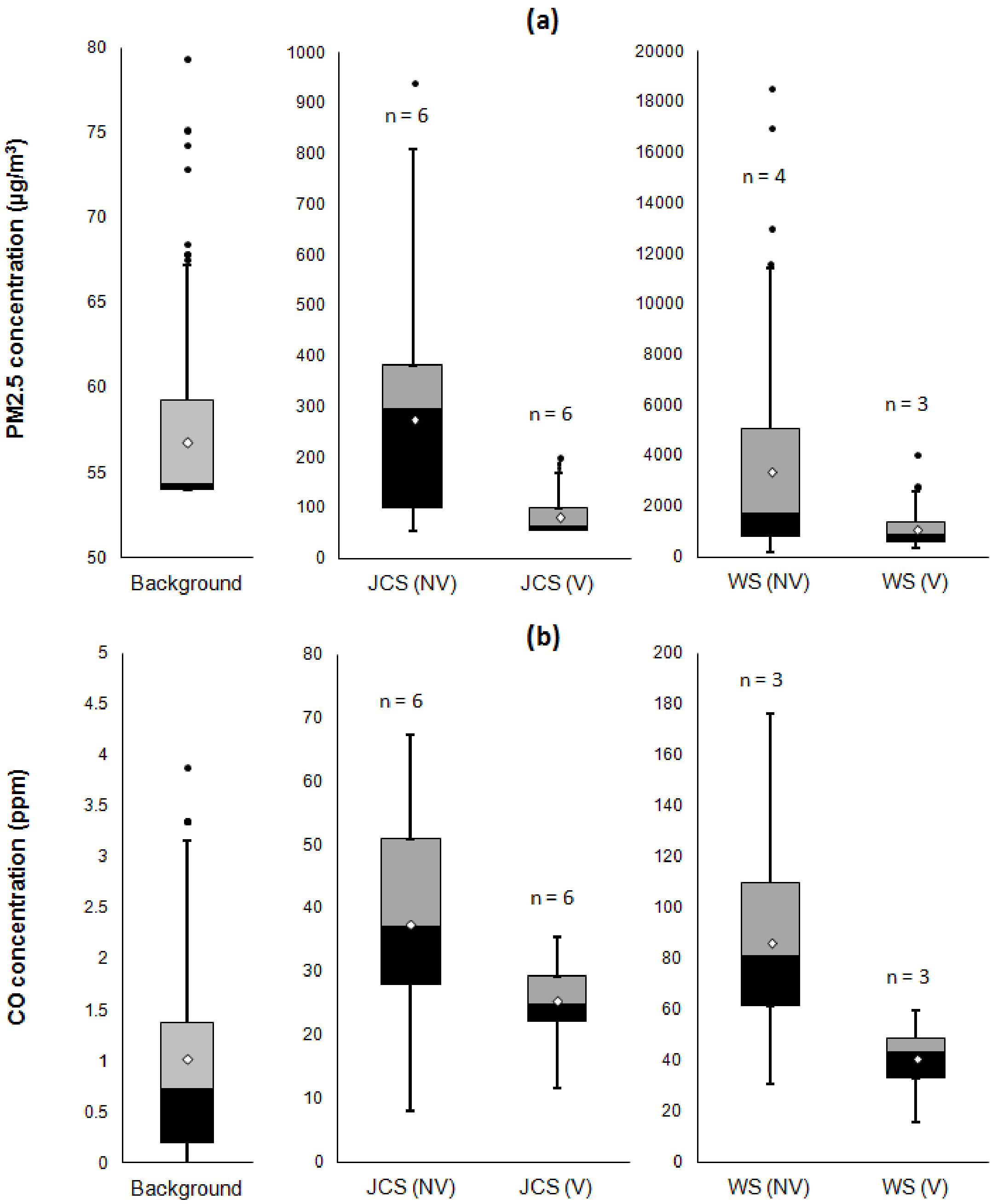


Figure 4.14 Time-averaged indoor (a) $PM_{2.5}$ concentrations and (b) CO concentrations during stove combustion and background concentration

Note: Outliers were defined as the numbers were at >Q_3+1.5*IQR or at <Q_1-1.5*IQR, where Q_1: first quartile, Q_3: third quartile and IQR: inter quartile

This result indicates the potential of the JCS stove to replace the wood stove in rural areas because of the beneficial health impact in ventilated indoor cooking environments.

The average time taken for water to boil using these stoves was approximately 15–20 min. Only the wood stove in non-ventilated conditions would reach the World Health Organization (WHO)'s indoor CO guideline level for 15 min, i.e 87.32 ppm (WHO, 2010) during combustion.

4.2.3.3 Potential exposure

To evaluate probable health impacts to the cooks who spend their time in front of stove, we estimated inhalation dose with simple calculation using the formula as described in Eq. (4-2) as follows:

$$\text{Dose} = \text{inhalation rate (m}^3\text{/min)} \times \sum_i \text{concentration (mg/m}^3\text{)} \quad \ldots\ldots\ldots(4\text{-}2)$$

Where *i* denotes measurement durations (in 1 minute interval), the inhalation rate was approximated with the value of 18 m^3/day (Smith and Peel, 2010) or equivalent to 0.0125 m^3/min. Table 4.6 shows the estimation results of exposure doses of $PM_{2.5}$ and CO during simple WBT tests.

Table 4.6 Estimation of exposure dose to cooks during WBT (±SD)

Parameter	JCS		WS	
	Min	Max	Min	Max
$PM_{2.5}$(μg)	19 ± 3	65 ± 45	221 ± 105	889 ± 564
CO (mg)	6 ± 0.6	10 ± 5	10 ± 2	25 ± 9

Note: Concentrations were derived from cook site concentrations
Minimum exposure was estimated from ventilated condition, while maximum exposure was estimated from non-ventilated condition

The minimum exposure dose of $PM_{2.5}$ during water boiling cooking using a wood stove was more than ten times that using a JCS stove. At the same time, using a JCS stove showed CO exposure dose of about half that using a wood stove. However it should be noted that these doses did not cover contributions of the pollutants under smoky conditions of ignition or the dying phase of biomass combustion. Thus it is expected that the actual dose in the case of a JCS stove will be somewhat higher than these values.

4.2.3.4 Size fractionated $PM_{2.5}$ during WBT

As shown in Figure 4.15, the $PM_{2.5}$ size distribution resulting from the stove burning at cook site is dominated by particles below 0.25 µm. Other studies revealed that the PM distribution emitted from wood burning is unimodal, having a peak at 0.1–0.2 µm (Kleeman et al., 1999), 0.8–0.2 µm (Johansson et al., 2003), and 0.42–1.32 µm (Venkataraman et al., 2008). The background concentration is also almost proportionally distributed throughout the cutoff size. Moreover, we found that by applying ventilation, the fraction of fine particles became higher than that without ventilation.

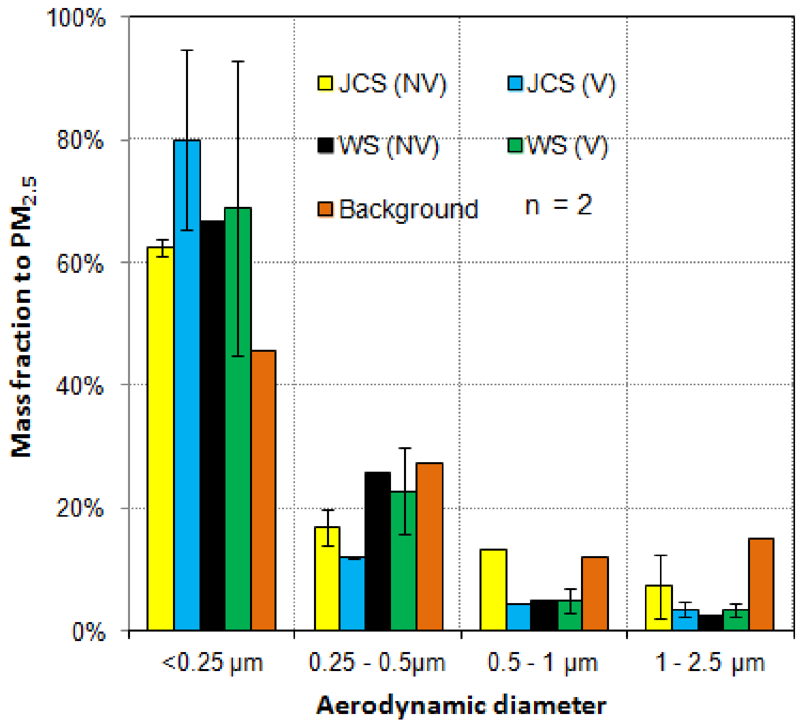


Figure 4.15 Mass percentage of size-segregated $PM_{2.5}$ related to stove emission
Note : bar without SD means unquantified samples due to negative mass occurred. Background was averaged from two-days measurements.

This is in agreement with an earlier study by Johansson et al. (2003) who showed that when high amount of air ventilation is supplied, the number size distribution tends to shift toward smaller particle sizes. Conversely, the opposite will apply in the case of low ventilation or no ventilation. It was also observed that when no ventilation was applied, a lot of smoke was generated, indicating the existence of many larger particles due to coagulation.

4.2.3.5 Carbonaceous and water-soluble inorganic components of $PM_{2.5}$ during WBT

As expected, organic carbon (OC) dominated in the $PM_{2.5}$ fraction, particularly in the fine particles. The ratio of OC to total carbon (TC), OC/TC, (for both JCS and WS) was 0.56–0.81, slightly lower than those in previous studies using wood logs as fuel: 0.72–0.94 in Fine et al. (2004) and 0.57–0.85 in Schmidl et al. (2008). The average of the elemental carbon (EC) fraction of $PM_{2.5}$ in the JCS stove (24%) was higher than that of the wood stove (16%) since, during the process of combustion, the JCS stove flamed more frequently than the wood stove. The JCS stove generated much higher level of condensable organic particles/tar (indicated by OC2/$PM_{2.5}$ ratios of JCS which were 2 – 10 times that of WS at the same range of particle diameter). There was also a lot of oil residue at the bottom of the pot. The health impacts of this emission should be studied further as a high portion of organic fumes were generated. The seed (kernel) of Jatropha itself is quite toxic to living organisms (Gubitz et al., 1999; Gadir et al., 2003, Rakshit et al., 2008). Therefore, the use of a ventilating chimney with the JCS stove is highly recommended. If it is not feasible, then at least the kitchen should be separated from the main household building.

A summary of the chemical composition of collected aerosols is presented in Figure 4.16, where the predominant fraction of OC is obvious. If we assumed the conversion factor of OC to organic matter (OM) was a maximum of 1.8 (Reid et al., 2005) then the percentage of OM in $PM_{2.5}$ was 66.7% in case of wood burning emissions. The total OM fraction in the case of of *Jatropha curcas* seeds was even higher, i.e. 86.3% (wet basis), as studied by Oskoueian et al. (2011). This discrepancy may be attributable to the size dependence of OC to OM conversion factor although we could not evaluate this aspect. Unfortunately in case of JCS (V), the constructed mass of $PM_{2.5}$ was overestimated in the size range of 1.0 – 2.5 µm diameter, perhaps because of overestimation of OC-EC calculation in low $PM_{2.5}$ mass concentration.

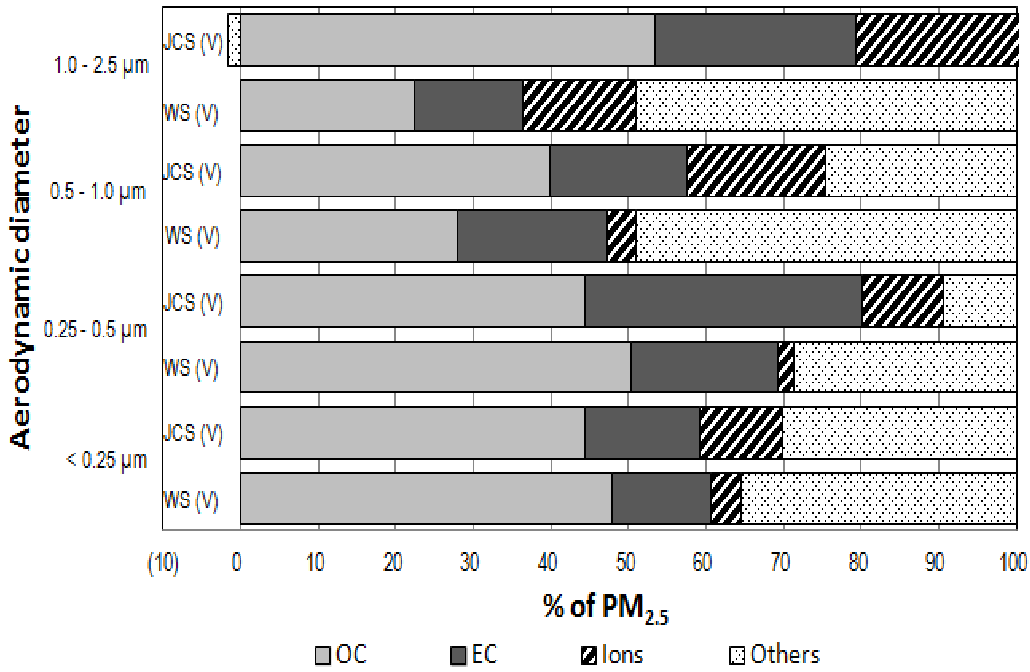


Figure 4.16 Average chemical compositions of $PM_{2.5}$ related to JCS stove and woodstove emission (n =2)
Note : The unit of OC and EC was µgC/m^3

The other interesting point that can be observed in Figure 4.17 is that the ionic composition in the samples related to the JCS stove emission (both in ventilated or non-ventilated scheme) were richer in SO_4^{2-} and NH_4^+ than those of the wood stove. The most probable sources of these water-soluble ions were its crude protein and lipid compound, which are found mostly in the OM component. In general, in each particle size, ionic compositions under ventilated condition were slightly different as compared to those in non-ventilated condition. We assumed that during non-ventilated condition, the chemical characteristics of the captured emission were close to those of original emission in the combustion plume. In most cases, chloride and potassium ions were predominant in the submicron particles, while sodium, nitrate and nitrite appeared more in larger particles. There were no specific characteristics for other ions.

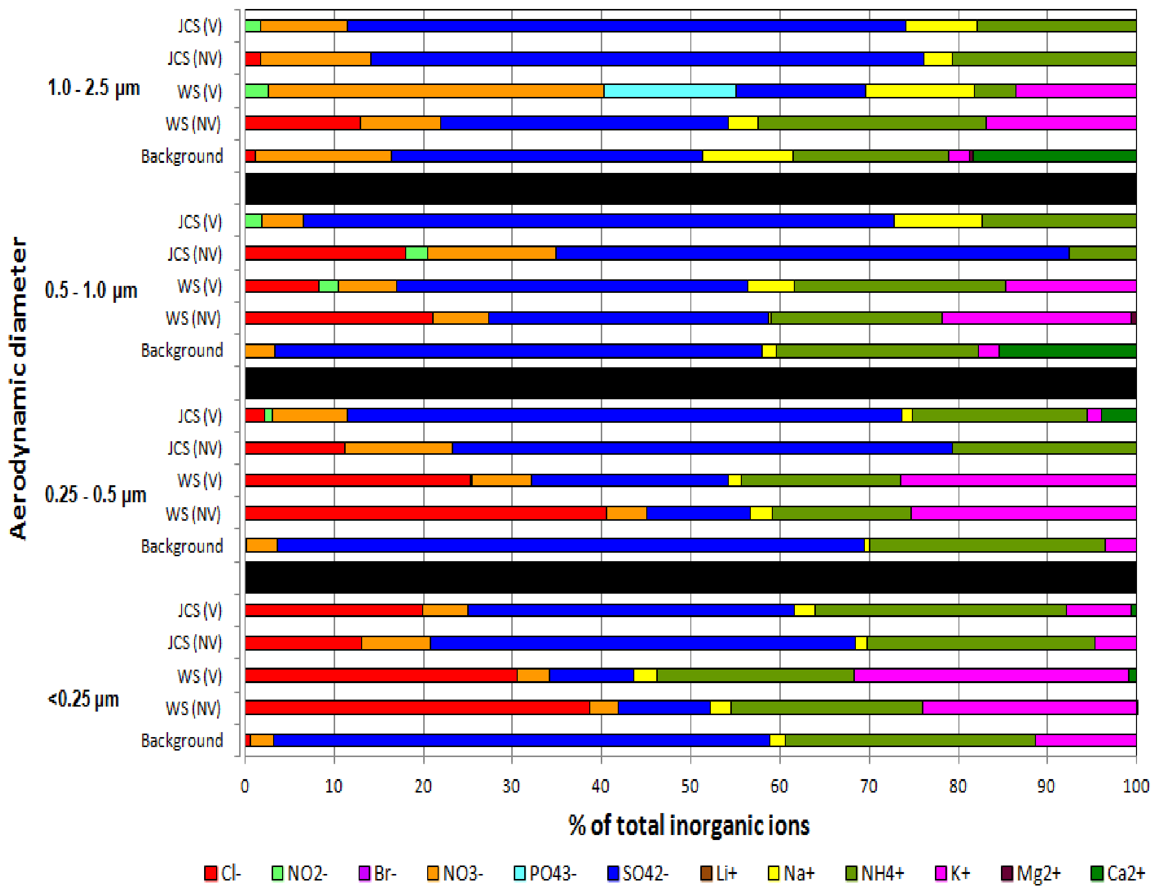


Figure 4.17 Average water soluble inorganic ion compositions of $PM_{2.5}$ related to JCS stove and woodstove emissions (n =2)

The sampling site was surrounded by semi-rural households and about 100 m away from the road line. The site terrain was relatively flat and thus not at downwind position. The outdoor sources may alter mass concentration as well as chemical composition of PM emitted from a stove to some extent in the case of the naturally-ventilated arrangement. On mass concentration basis, contribution of background (outdoor sources) to the increased indoor concentration by JCS emission stood at 6 – 16% while it was nearly 1%, by WS emission. With respect to chemical composition, the outdoor contribution showed comparable results. When assessing inorganic composition other abundant species i.e. NH_4^+ and NO_3^-, the concentration ratio of background to WS-ventilated or JCS-ventilated indoors was in the range of 5 - 23% and 2 - 17% for NH_4^+ and NO_3^-, respectively. Such NH_4^+ was derived from agricultural sources and animal waste (USEPA, 1999) while NO_3^- ions were derived from either mobile or stationary sources through NOx oxidation.

The concentrations of sodium ions under naturally-ventilated conditions were about 10 times higher than those in non-ventilated conditions; nonetheless they were comparable (1-2 times) with those in background measurement. Na^+/Cl^- ratio of $PM_{2.5}$ was close to that of sea water and our site was located around 15 km from the sea. Therefore these incremental sodium ions were derived from aged sea salt aerosols. In contrast, NO_2^- was not detected during background measurement, while under ventilated conditions the NO_2^- made up 0.2 – 0.3% of the mass concentration of total ions. We did not identify the outdoor sources in further detail because source apportionment was beyond the scope of this study.

4.2.4 Conclusion

The JCS stove showed higher thermal efficiency and lower specific fuel consumption (SFC) compared to the wood stove. However, due to its configuration, this JCS stove has a lower capacity than that required in the cooking process. Thus, improving the refueling process is important for enhancing its performance. As the fuel reserves decreased without any refueling, the $PM_{2.5}$ profile related to the emission demonstrated a decreasing trend from the beginning. This feature was somewhat different from that of the wood stove, which exhibited fluctuations throughout the combustion process. The CO concentration of the JCS stove was far below the WHO standard compared to the shortest time standard (87.32 ppm for 15 min) even without ventilation. Using the JCS stove also reduces the exposure of the cooks to $PM_{2.5}$ and CO. The elemental carbon and ionic compounds of the fine particles related to the JCS stove emission were somewhat higher compared to those of the wood stove. This is probably due to the flaming condition of the JCS stove and the chemical composition of the JC seeds. The seeds are rich in crude proteins and lipids which are the sources of SO_4^{2-} and NH_4^+, respectively.

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CHAPTER-5

Characteristics of indoor air pollution in Indonesian rural communities

(Characteristic of indoor air pollution in Indonesian rural communities, submitted to Atmospheric Environment, Elsevier)

(Relative risk and modelling indoor air pollution due to wood fuel use in rural Indonesian households, to be submitted to Journal of Applied Sciences in Environmental Sanitation)

Chapter outline

This chapter evaluates the measurements of indoor air pollution in two different sites. These measurements are combined with gathering information of important factors suggested in the previous chapter in an attempt to reduce the exposure. The parameters of interest are $PM_{2.5}$ and CO, and the places of interest are the kitchen and living room as a control. The findings will be used for constructing related program to reduce the exposure in chapter 6.

5.1 Introduction

Biomass solid fuels such as dung, wood and agricultural residues are continuing to be used as cooking fuel by nearly half of the world population (Smith et al., 2004). Most of these people live in developing countries in Africa and Asia. The use of this low grade cooking energy poses serious health effects as broadly reviewed by Naeher et al. (2007).

In 2004 the World Health Organization (WHO) estimated indoor air pollution from solid fuels ranks 10^{th} in the global risks for mortality in the world (WHO, 2009), while in low income countries this risk goes up to the sixth rank.

Exposure to indoor air pollution is also associated with acute lower respiratory infections (ALRI) such as pneumonia amongst children under the age of five (Bruce et al., 2000). In Indonesia, the ALRI incident pneumonia has been found to be one of the major causes of death in infant and children under 5 years old (Ministry of Health, 2009). The correlation between the pneumonia and the use of biomass solid fuels is suspected, however further study is required to confirm it.

Currently wood fuel users in Indonesia are estimated to be 69% and 15% for rural and urban people, respectively while the Indonesian people with low income mainly reside in rural areas and the percentage is about 17% compared to 9 % in the urban area (BPS 2011a). This figure implies that not all wood fuel users are categorized as poor people.

In Indonesia since mid-2007, the government has launched a National kerosene conversion program which provides each household using kerosene to one package of LPG stove for free. Currently, about 80% of kerosene fuel users have switched to LPG (Pertamina, 2011), including kerosene users in rural area. Wood fuel users in rural areas also got the LPG stove package due to their low income. Irrespective of the provision of subsidized LPG fuel, some rural households still use wood fuel as their primary cooking fuel. Although LPG fuel has been already adopted in the rural region, use of firewood as a primary source of fuel is common and these rural populations face potentially dangerous health impacts. The rationales behind the high number of using wood fuel despite receiving of a gas stove package (according to a pre-survey study) are an economic reason (fuel accessibility), energy security, safety concerns (i.e. fear of explosion/fire with the use of LPG, particularly viewed by the elderly), and less desired taste of the LPG-cooked food. Adopting a dual fuel (wood fuel and LPG), particularly in low income households, is now deemed to be a safe way for household energy security against the incidental increase of subsidized LPG price at the retailer because the stock is sometimes limited. In addition, some rural households believe that the subsidized LPG cylinder (3 kg) stove is not as suitable for heavy cooking as the currently used wood stove.

Rural areas in Indonesia commonly exist in coastal and mountainous/highland areas within the archipelago. There are some examples of the measurements of indoor air pollution levels in each distinctive area of developing countries. For example, research conducted in the mountainous areas in Guatemala revealed that the average levels of particulate matters with a diameter of 2.5 μm or less ($PM_{2.5}$) in the kitchen reached 4.36 to 6.56 mg/m^3 (Naeher et al., 2000), while in Tibet, average $PM_{2.5}$ levels were 134–271 μg/m^3 (Gao et al., 2009). Siddiqui et al. (2009) revealed 8-hour average $PM_{2.5}$ concentration was 2.74 mg/m^3 in Pakistan's coastal areas.

Wood stove emission is the main source of kitchen-related indoor air pollution in many poor households in developing countries. Without applying proper ventilation at the cook site, the $PM_{2.5}$ mass concentration increased to 299% of that with ventilation (Huboyo et al., 2012). The mass size distribution of indoor $PM_{2.5}$ from traditional woodstove was dominant in submicron particle range, i.e. aerodynamic diameter <0.25 μm (Armendriz et al., 2010; Huboyo et al., 2012). Mass size fraction of $PM_{2.5}$ emitted from woodstove combustion, in fact, depends on many parameters. Rau, J.A (1989) stated the composition of residential wood smoke from stoves is strongly dependent on stove operating conditions. While some other significant factors that may affect the emission include the type of wood stove, burning rate, type of wood, stove configuration, and moisture content of wood (Mc.Donald et al., 2000). Due to low burning efficiency, the emission of fine particles emitted from traditional woodstove combustion usually was followed by CO emission. The simultaneous measurements of indoor $PM_{2.5}$ and CO concentrations in developing countries have been conducted extensively elsewhere (Park et al, 2003; Naeher et al., 2000; Fullerton et al., 2009; Armendriz et al, 2008). Due to the simplicity of CO monitoring, many researchers suggest to use CO concentration as a proxy for $PM_{2.5}$ one in the households using wood fuel.

So far, no studies of indoor air pollution in the developing world have been done simultaneously in mountainous and coastal rural areas. It is believed that, the characteristics of indoor air pollution in these two distinct areas are quite different due to their different living environment. The purpose of this study is to simultaneously measure the indoor pollution levels ($PM_{2.5}$ and CO) of the household kitchens in the mountainous and coastal areas in the rural region of Indonesia. In this study, we also measure time-averaged $PM_{2.5}$ in the living rooms for comparison. In addition, the size-segregated $PM_{2.5}$ concentrations at the cook sites are evaluated to characterize the fine particle distributions from wood fuel burning. We will quantify the size-segregated carbonaceous components (OC-EC) as well as inorganic water-soluble ions of indoor $PM_{2.5}$ related to wood fuel combustion. By revealing these characteristics, it is expected to identify appropriate measures to reduce indoor air pollution in rural areas in the immediate and the future government programs.

5.2 Methodology

5.2.1 Study setting

The study was undertaken simultaneously at the locations as described in chapter 2. This study does not represent rural condition at nationwide, since rural household conditions cover a widespread area across the Indonesian Archipelago. Nationwide study would require a much larger sample size than our available resources as Indonesia is a multi-ethnical country. This study gives information on typical kitchen indoor air pollution associated with wood fuel as a main cooking fuel in two distinctive locations.

As surveyed previously in chapter 3, it seems there are large fractions of households using dual fuel (LPG-wood fuel) after the national program on conversion of kerosene to LPG was implemented in this area. We believe the indoor concentrations of air pollutants for dual fuel use are comparable to those for only wood fuel use because the air pollutant emission (in case of particulate matter) of LPG stove burning is far below that of wood stove showing about 1/26 times for cooking with the same meal (Smith et al., 2005). Moreover they used LPG stoves for cooking in a short period or warming the food in the afternoon only, thus it obviously exhibited low indoor air pollutant emission. We sampled 20 dual- fuel users (wood fuel as main cooking fuel) randomly in both sites.

Samplings were conducted during dry season in June–July 2011. Indoor air concentrations were mainly measured in the kitchen and living room (for control) in each household. During sampling, the people were asked to live as usual including freely use or not use the LPG stove and refrain from smoking in the kitchen. In addition to the daily cooking activities in the sampled households, information was gathered on housing characteristics as well as cooking characteristics.

5.2.2 Measurements

In this study, we measured daily temporal variation of $PM_{2.5}$ mass concentration, size distribution of $PM_{2.5}$ mass concentration (during use of wood stove only) and daily CO concentration. Temporal $PM_{2.5}$ samples were collected in the kitchen and living room (as a control) using the inexpensive monitor of UCBs (Berkeley Air Monitoring Group) by photoelectric principle. The setting of the monitor was the same with the measurement in chapter 3. Calibrations of the UCBs were made in the field with a gravimetric mass principle and gave the following results (correspond to Figure 4.11 in chapter 4) :

Table 5.1 Results of UCB calibrations with gravimetric principle

Regression equations (μg/m^3)	R^2	Note
$PM_{2.5}$(grav) = 1.92 UCB-$L_{(K)}$	0.728 (n = 10)	Kitchen Lembang
$PM_{2.5}$(grav) = 2.27 UCB-$L_{(L)}$	0.776 (n = 7)	Living room Lembang
$PM_{2.5}$(grav) = 1.89 UCB-$J_{(K)}$	0.908 (n = 9)	Kitchen Juwana
$PM_{2.5}$(grav) = 1.76 UCB-$J_{(L)}$	0.953 (n = 9)	Living room Juwana

Note: L = Lembang site, J= Juwana site, subscript K = Kitchen, subscript L= Living room

Previous studies of the UCBs calibration in the field conditions also indicated that the results of UCBs were generally underestimated mass concentration compared with the gravimetric mass concentration (Chowdhury et al., 2007; Armendriz et al., 2008).

Indoor air measurements were made for 24 h; however, due to field conditions and data acquisition time for setting and downloading UCB data, samples were obtained only for 22–23 h. Particle-size distributions at the cook site related to wood fuel burning emission were measured using an SKC Sioutas Cascade Impactor/CI) (SKC Inc.) In this case, particles of interest have a cut-off size below 2.5 μm. The flow rates (recorded sampling volumes in the range of 473 L – 2127 L) were calibrated at pre- and post-samplings with a DryCal primary flow meter (Bios International, USA). $PM_{2.5}$ samples were collected on pre-heated (600 °C for 4 h) quartz filters (Pallflex) with a diameter of 25 mm (collection stage) and a 37-mm filter (back-up stage). Prior to being weighed, the filters were conditioned for at least 48 h followed by treatment with zerostat (Milty) to neutralize the static charge in the filters. Each sample was weighed at least five times to ensure a weight consistency using a Sartorius, ME 5-F balance (±1 μg accuracy) in a humidity controlled room (30%– 40%). To account for the uncertainties in handling filters during measurements, field blanks were also provided for each sample. Samples with a mass of more than 3 mg at each stage were discarded due to the distortion of the collection efficiency of the impactor (Sioutas, 2004).

For a background, the outdoor samples (sampling volume 39.4 – 40.9 m^3) were collected using an eight-stage Cascade Impactor (Graseby Andersen) with φ 8.3 cm collection filters. The cut-off diameter of interest was 2.1 μm, an approximate value for indoor cut-off diameter (2.5 μm). This impactor was operated at a 28.7 L/min flow rate.

Indoor CO concentration was measured using a USB-CO data logger (Lascar Co.) with a measurement range of 0–1000 ppm and ±6% accuracy. This CO monitor was calibrated using a span-calibration at 0 and 92.9 ppm using a CO standard gas (Sumitomo Seika Co.). Furthermore, daily average indoor temperature and humidity were measured by a USB thermo hygrometer (Lascar Co.).

A subset of filter samples from cascade impactor were subjected to size-segregated OC-EC mass analysis using thermal optical OC-EC analysis (DRI model 2001) with the Improve A protocol. The detail of the OC-EC calculation contained in the deposited particles on the stage filters (25 mm and 37 mm) was described elsewhere (Huboyo et al., 2011b). We also determined water-soluble inorganic ions of the collected samples (14 samples) using ion chromatography (HIC-10A, Shimadzu Co.) with columns of Shimadzu IC-SA2 and IC-SC1. The eluents were prepared from 12 mM $NaHCO_3$ combined with 0.6 mM Na_2CO_3 (Wako, Japan) and 3.5 mM H_2SO_4 for anions and cations, respectively. The filters were extracted with ultra-pure water of 18.2 MΩ cm (Sartorius Stedim) in an ultrasonic bath. After ultrasonicated for 1 h and centrifugated for 10 min, the extracts were filtered through PTFE filter of 0.45μm pore size (Dismic 13 HP). All sample blanks (25 mm and 37 mm filters) were analyzed with the same procedure and used for the correction of sample concentration. The minimum detection limit (MDL) was calculated as three times of standard deviation of field blanks. The obtained MDLs were summarized below Table 5.3. The recovery efficiencies of the ions analysis were between 83 - 103%. We ignored fluorine ion because it was detected excessively in the blank of pre-heated filter.

5.3 Results and discussion

5.3.1 Socio-economic aspects and cooking characteristics of sampled households

Table 5.2 summarizes the socio-economic aspects and the observed cooking characteristics of the sampled households. In general, the house characteristics were in agreement with description in chapter 3. The kitchens in Juwana are more than thrice the size of those in

Lembang. Thus, it is expected that the indoor air concentration of pollutant in Juwana is diluted higher.

Commonly, they cook at the early time (around 3 – 4 AM in the morning) allowing them sufficient time to go to their works early. Based on our survey, they used wood stove when they practiced "heavy cooking" such as cooked rice and water which need longer cooking time for providing their daily needs. The latest time for cooking in Juwana site was at around 10 AM due to the fact that the householder which is also a food vendor (cooking not only for their meal but for selling their cooked foods).

Table 5.2 Cooking activity and characteristics of the households

	Lembang site	Juwana site
Avg number of person per household	3.5	3.4
Kitchen dimension (m^3)	22.49 ± 10.3	70.3 ± 27.4
Living room dimension (m^3)	34.9 ± 14.9	63.7 ±48.1
Kitchen ventilation area (m^2)	2.3 ± 0.8	3.9 ± 1.9
Cooking time		
- early time	3:02 AM	3:40 AM
- latest time	8:12 AM	10:10 AM
Cooking duration (min/day)	166 ± 46	107 ± 33
Wood moisture content (%)	18.1 ± 5.01	16.07 ± 2.09
Consumed wood (kg/day)	3.09 ± 1.43	3.76 ± 1.6
Wood type	mixed wood	mainly rubber wood
Wood calorific value (kcal/g)	4.0 – 5.02	4.28– 4.33

Note: cooking times and cooking duration denote to cook with wood stove

The consumed biomass in the dry season was almost comparable with those in the wet season (3-4 kg/day). This means the consumed biomass of the household can be averaged throughout the year. The type of wood used at the two locations was quite different. In Lembang, wood is widely available and is easily gathered from the forest or plantation waste or uncultivated gardens; as a result, the wood fuel in this region is mixed. In Lembang households, they used varied wood type for their fuel. In contrast, Juwana is not surrounded by forests, and the households afford to purchase rubber wood (approximately 0.38 USD/4 kg wood) from small wood-supplying stores or assess wood fuel waste (Table 5.3)

Table 5.3 Wood fuel properties in two sites

Wood species	Scientific name	Specific gravity (% moisture)*	Calorific value (cal/g) †	Ash content (%)*	Wood moisture (%) †
Pine	*Pinus merkusii*	0.4-0.75(15)[1]	4479.90	0.26[4]	15.8 ± 3.3
Quina	*Cinchona pubescens*		4304.55		18.2 ± 2.7
Bamboo	*Bambusa spinosa*	0.5 – 0.85(12)[2]	4215.47	1.9 – 4.6[2]	14.7 ± 3.9
Rubber wood	*Hevea brasiliensis*	0.55 -0.7(15)[1]	4285.03 - 4333.95	0.65 – 1.3[6]	16.1 ± 2.1
Avocado	*Persea americana*	0.5-0.7 (12-15)[1]	4625.54	-	14.7 ± 0.5
Jackfruit	*Artocarpus heterophyllus*	0.55 – 0.7 (12)[3]	-	-	24.0 ± 1.9
Gum tree	*Eucalyptus urophylla*	0.54-.57(15)[1]	4609.00	0.25[7]	-
Red cedar	*Toona sureni (Blume)*	0.27-0.67(15)[1]	4000.98	0.79[4]	18.9 ± 6
Albizia	*Paraserianthes falcataria (L.) Nielsen*	0.23 – 0.5(12)[1]	5023.40	0.6[8]	14.9 ± 3.3
Siam weed	*Chromolaena odorata*	-	-	-	22.4 ± 4.5

Note: * based on secondary data
† based on measurement
1. Orwa et al., 2009
2. Meir E, 2013
3. FAO, 2013
4. Pari et al., 2006
5. Setiadi, A, 2009
6. Boerhandy and Agustina DS, 2006.
7. Pratiwi, W, 1984.
8. Martawijaya et al., 1989

This wood fuel type suggested that in Lembang site combination of softwood (pines) and hardwood were utilized, while it was mainly hardwood in Juwana site. Based on questionnaire results, people in Juwana got their new fuel stock every 9.8 days on average. People in Lembang usually collect their wood every 13.9 days on average, thus have longer storage than in Juwana. Based on the cooking characteristics outlined in Table 5.2, we have conducted the two-tailed Mann Whitney U-test (p = 0.05) for parameters of member of householder, room dimension, potential ventilation area, cooking duration and wood humidity. The two tests indicated that there were no significant differences between locations except cooking duration, room dimension and potential ventilation area of the kitchen. The kitchens in two sites normally have 2 doors (to go outside and to go another room), and some have window(s) and definite opening space. However, all of these houses have natural ventilation through spaces between wall and roof.

5.3.2 Indoor $PM_{2.5}$ concentrations

As shown in Figure5.1, there were large variations of the $PM_{2.5}$ concentrations in the kitchens at both sites. Three samples in Lembang and one sample in Juwana were unquantified because several UCBs results showed unusual high baseline values, which may yield erroneous calibration for gravimetric mass. The discrepancies were found between our results (time averaged $PM_{2.5}$) and other studies, because usually they located their devices in the "combustion zone" of the stove to minimize kitchen volume effect in which we addressed in this study. As illustrated in Figure. 5.1, the average concentration in Lembang kitchen was generally higher than that in Juwana sites. The difference was statistically significant (Mann-Whitney U-test, $p < 0.05$).

Several reasons are suggested for the higher pollutant concentrations at the Lembang site than at Juwana site. The first reason is the difference in cooking frequency using wood fuel at both sites. People in Lembang cook using wood fuel twice (morning and evening) compared to only once in Juwana site, then it produced more pollutants than in Juwana site.

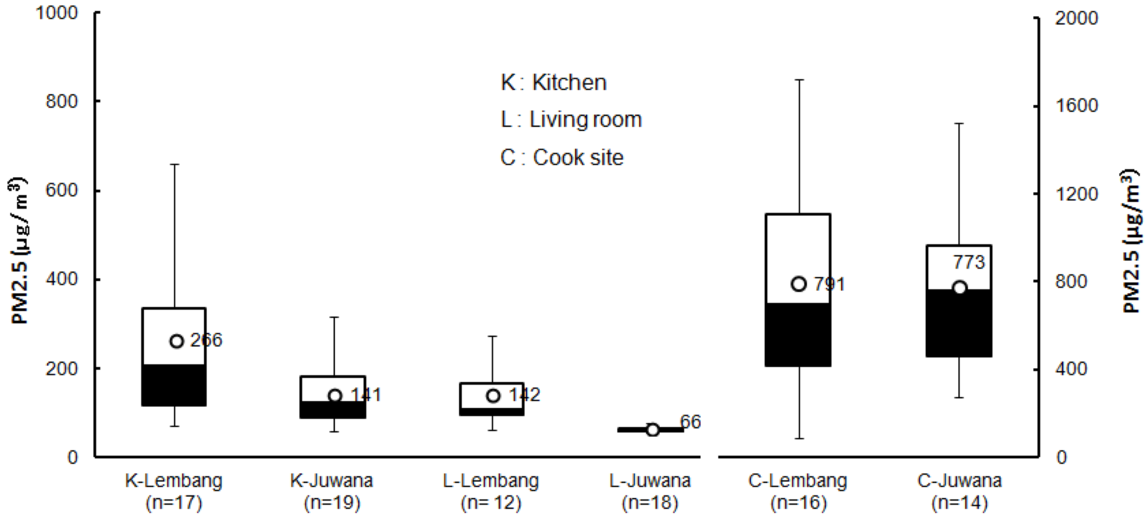


Figure 5.1 The average $PM_{2.5}$ concentrations (22–23 h) in the kitchen, living room, and at cook site (during cooking period only)

Therefore cooking duration per day was longer in Lembang site than that in Juwana site (Table 5.2). Another possible reason is striking difference in room volume and ventilation area, as the kitchen volume in Juwana is almost thrice to that in Lembang. Correlation analysis between $PM_{2.5}$ mass concentrations and room volume, aggregated for two sites indicated moderately negative-correlation (Spearman, ρ (34) = -0.394, p = *0.02*). During the cooking period, only 15% households in Lembang opened the kitchen door to outside. On the contrary, in Juwana, all households opened the doors fully or a half during cooking period. This condition made air pollutants dissipated quicker in Juwana site than in Lembang site.

Another possibility was the wood had somewhat higher moisture content in the Lembang site than in Juwana site (See Table 5.2 and Table 5.3). The wood fuel used in Lembang consists of mixed wood species and type (fresh cut or old twigs) which might have higher humidity rather than stored wood in Juwana site. The ambient humidities in Lembang were higher than that in Juwana. Relative humidities during measurement in the kitchen were 82.4 ± 6.2% in Lembang and 74.4 ± 4.5% in Juwana between 6.00 PM and 03.00 AM.

Outdoor $PM_{2.5}$ concentrations (81 ± 8 μg/m^3) in Juwana were much higher than in Lembang (55 ± 29 μg/m^3) due to its location close to the main trans-Java island highway. Lower outdoor $PM_{2.5}$ at Lembang site implies that the indoor pollution may have an influence on the outdoor pollution. Since the housing configurations of Lembang site were in clusters, the neighboring indoor pollution contributed to elevated indoor air pollution on some occasions. In contrast, higher outdoor $PM_{2.5}$ (at Juwana site) than in indoor site indicated outdoor pollution influenced indoor pollution. This condition seems to be typical in urban area located in the road proximity.

In the living room for a control, as depicted in Figure 5.1, the $PM_{2.5}$ concentrations at Lembang site were higher than those in Juwana site and had much lower concentration than those in the kitchen. Interestingly during cooking period, the $PM_{2.5}$ concentrations in the living room of Lembang site also oscillated, indicating high emission of cooking activities using wood fuel entering the living room through the opened door. Besides of cooking activities, the other contributor of higher $PM_{2.5}$ concentration at the living room of Lembang site was indoor smoking activities according to our record. While in Juwana site, several households burnt the mosquito coil which elevated indoor $PM_{2.5}$ in the living room at some degree in addition to smoking activities.

The $PM_{2.5}$ concentrations at the cook sites were comparable, i.e. around 800 μg/m^3 at both sites. These values were around three to four folds of indoor concentrations of UCB results. Normally, this concentration was used to approximate total exposure for the cook combining with time activity budgets (Ezzati et al., 2000). Comparable values of $PM_{2.5}$ concentrations at the cook site for both sites suggested that even though having significant different volume and different ventilation area, the potential exposure to the cooks may have the same degree. However, in this case, the exposure to the householder should be short-term because they usually cook intermittently and frequently move to the living room.

According to our time activity record, the cooks spent 79% of their time in front of the stove during the cooking period in Lembang and 41% in Juwana.

5.3.3 Size segregated $PM_{2.5}$ concentrations related to cooking with wood fuel

Measured particle size distributions of $PM_{2.5}$, OC and EC (Figure. 5.2) had a similar pattern to those in other studies using the same device (Armendriz et al., 2010). For all samples, they had a peak at less than 0.25 µm in diameter. Park and Lee (2003) found a peak at 0.7 µm for fine particles related to wood burning using APS in Costa Rica. Hays et al., (2002) found the size distribution of wood smoke was unimodal with most of the mass centered at 0.2 µm, while Wardoyo et al.(2006) found the peak based on particles number was around 0.03 – 0.04µm.

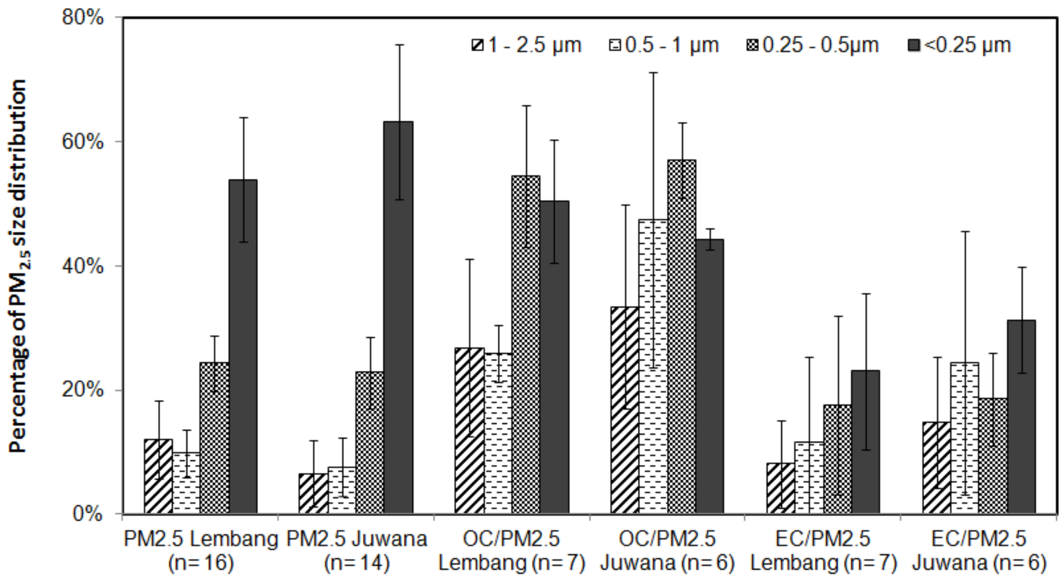


Figure 5.2 Average size distributions of $PM_{2.5}$ concentration at the cook sites during cooking period with wood fuel

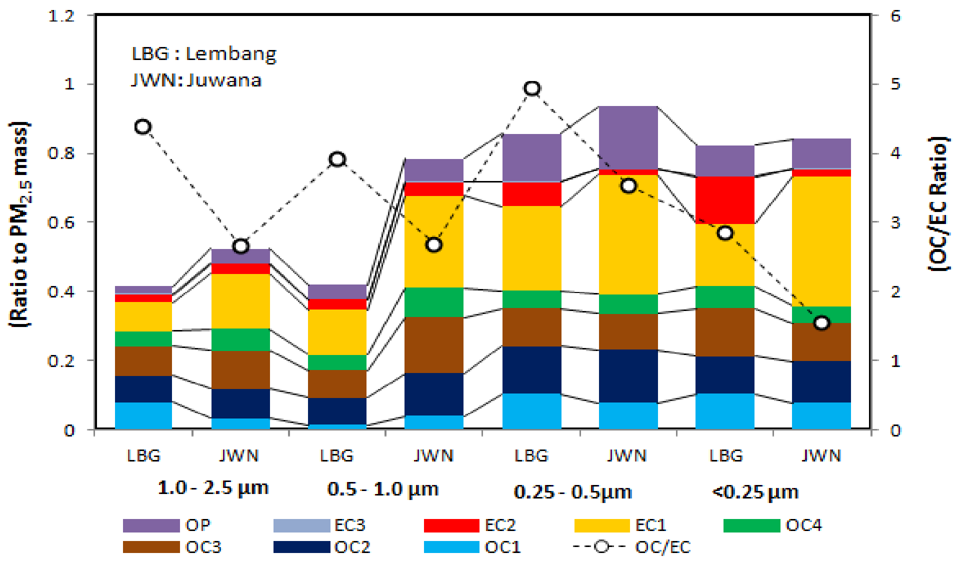
At the cooks sites, mass fractions (%) of four size ranges from 1.0 to 2.5 µm, 0.50 to 1.0 µm, 0.25 to 0.50 µm, and less than 0.25 µm were, respectively, 11.9 ± 6.2, 9.8 ± 3.8, 24.4 ± 4.5 and 53.9 ± 9.9 at Lembang and 6.4 ± 5.3, 7.6 ± 4.7, 22.8 ± 5.7, and 63.2 ± 12.5 at

Juwana. The total OC mass fraction in $PM_{2.5}$ was 23 – 40%, while the EC mass fraction in $PM_{2.5}$ was 4 – 20%. The OC component was comparable with that in Zhang et al. (2012), while the EC tended to be higher. Unlike $PM_{2.5}$ mass size fraction, our OC fraction showed a distribution peak at 0.25 – 0.5μm, this was in agreement with those found by Li et al. (2009) who showed OC of biofuel (including wood fuel) combustion has a single peak at 0.26-0.38 μm.

Mass ratios of EC to $PM_{2.5}$ in each size bin in Juwana site showed higher than those in Lembang site. This indicates more flaming (hot burning) condition occurred in the wood stove burning in Juwana site than in Lembang site. Lower wood moisture contents (see Table 5.2) and more rich air supply to the stove (due to kitchen ventilation) favored hot burning in Juwana site than in Lembang site. The more flaming conditions in Juwana site were also indicated by higher fraction of finest particles (<0.25 μm) than in Lembang site. The average of OC/EC ratios in each size bin ranged from 2.9 to 4.9 in Lembang site and from 1.45 to 3.5 in Juwana site. The ratios of Lembang site were higher than those of Juwana site. These values were comparable with previous studies about 0.9-4.4 (Gonçalves et al., 2010), 2.6 – 5.6 (Schmidl et al., 2008) but lower than 10.7 (Zhang et al., 2012).

The carbon fractions, as illustrated in Figure 5.3(a), relative to $PM_{2.5}$ mass concentration indicate a different pattern of EC1 and EC2 in both sites. Within submicron particles (□0.5μm) range, Juwana site demonstrated higher fraction of EC1 than in Lembang site. On the other hand, the trend was in opposite for EC2. In general, the EC1 represent soot resulted from low temperature burning as in biomass burning or wood stove burning, while EC2 is often used as a marker for anthropogenic soot within higher temperature burning as in vehicles emission. However other studies also confirmed higher fraction of EC2 compared to EC1 emission in biomass burning particularly from pine wood burning compared to other biomass burning such as hardwood and grass (Chow et al.,2004; Chen et al., 2007; Chuang et al, 2012). Wood type used in Lemban g indicated that high EC2 fraction was attributed to burning of pine wood in the mixed wood fuel. Also based on Figure 5.3(b), in general, wood stove in Lembang site emitted larger fraction of OC/TC than in Juwana indicating the dominance of smoldering burning.

(a)



(b)

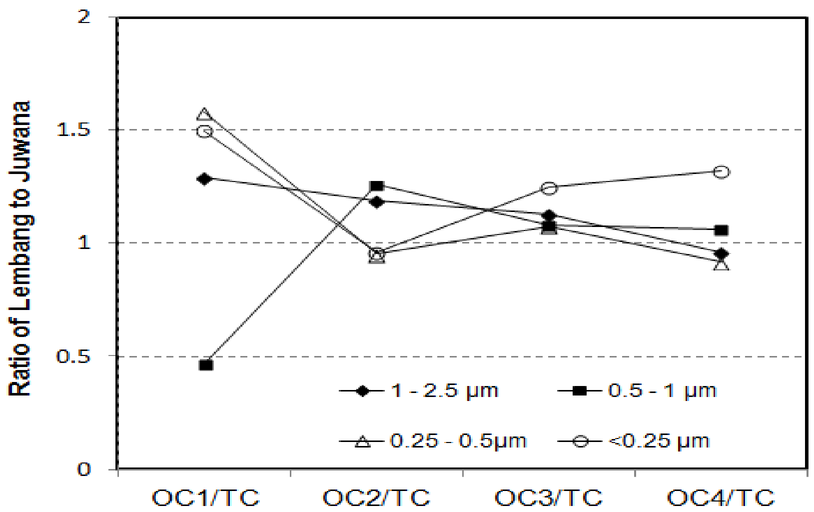


Figure 5.3 (a) Thermally resolved carbon fraction of 4 size ranges and OC/EC ratio; (b) OCn/TC related to woodstove burning

Rau (1989) found during smoldering combustion, the OC contribution to $PM_{2.5}$ emission was 1.9-5.5 times than in flaming combustion of wood stove. Moreover, lower fraction of OC in Juwana site suggests emission of less volatile OC particles compared to those in

Lembang site. This is in accordance with Hossain et al. (2012) description that smoldering combustion emits higher fraction of volatile species than flaming combustion.

The compositions of detected water-soluble inorganic ions (Table 5.4) were comparable with previous work using wood stove on simulated kitchen as described in chapter 4. Major components were Cl^-, NO_3^-, SO_4^{2-}, NH_4^+ and K^+ at both sites. While NO_2^-, PO_4^{3-}, Na^+, Mg^{2+}, and Ca^{2+} were obtained in small fractions. The higher fraction of K^+ and Cl^- in Juwana site than in Lembang site indicates flaming condition dominantly occurred in Juwana site than in Lembang site. This makes sense as the hot burning produces a large fraction of K, Cl and S in the emission of wood burning (Rao, 1989, Johansson et al. 2003). The OC profile describe above also indicate more flaming condition in coastal site than in mountainous site.

The major inorganic compounds during flaming fires of biomass burning were presumed to be potassium chlorides and followed by ammonium chlorides (Alves et al., 2010). PO_4^{3-} ion was detected in three samples at the Lembang site although in small fractions. Indeed, the minor amount of phosphorus was found in the burning of biomass (Johansson et al., 2003). Overall, the quite large uncertainty (54 - 151 %) of the major inorganic ions indicates the chemical fractions in $PM_{2.5}$ may be affected by other factors such as biomass density, elemental composition and moisture content (Alves et al., 2010). Generally, the compositions of anions (NO_3^-, SO_4^{2-}, NH_4^+) and cations (K^+, PO_4^{3-}, Na^+) in the sub-micron size (<1µm) in Lembang had larger variation of the concentrations than in Juwana. This is probably due to the use of mixed wood fuel having more varied moisture content (Table 5.2). Another factor such as cooking method (See and Balasubramanian, 2008, Huboyo et al., 2011a) may affect the compositions of inorganic ions in the collected aerosols. In general cooking methods in Lembang site were more varied (frying, steaming, boiling and sautéing) rather than that in Juwana site i.e. dominated only by frying and boiling..

Table 5.4 The average fractions of water soluble ions to $PM_{2.5}$ (values in % of mass concentrations)

Size bin	Cl^-		NO_2^-		NO_3^-		PO_4^{3-}		SO_4^{2-}		Na^+		NH_4^+		K^+		Mg^{2+}		Ca^{2+}	
	L	J	L	J	L	J	L	J	L	J	L	J	L	J	L	J	L	J	L	J
1.0 - 2.5 µm	0.84	1.89	ND	0.18	0.73	1.32	0.07	ND	2.34	2.81	0.68	1.36	1.41	0.70	0.69	1.26	0.24	0.02	2.09	1.81
0.5 - 1.0 µm	0.87	1.62	ND	ND	0.74	0.66	0.33	ND	3.68	3.12	0.44	0.38	1.97	0.77	0.90	0.92	0.14	ND	1.27	2.40
0.25 - 0.5 µm	0.92	1.87	0.01	0.04	0.44	0.36	0.03	ND	2.73	1.67	0.13	0.13	1.74	0.99	0.80	1.12	ND	ND	0.19	0.11
<0.25 µm	0.75	3.17	ND	ND	0.20	0.29	0.01	ND	1.57	1.39	ND	0.10	0.71	1.07	0.38	1.93	ND	ND	0.07	0.11

Note:

L = Lembang site ; J = Juwana site ; ND = not detected ;

Detection limits ($\mu g/m^3$) : Cl^-= 0.01; NO_2^-= 0.02; Br= 0.01; NO_3^-= 0.02; PO_4^{3-}= 0.02; SO_4^{2-}= 0.02; Li = 0.01; Na^+= 0.06; NH_4^+= 0.02; K^+= 0.12; Mg^{2+}= 0.07; Ca^{2+}= 0.14

Values below detection limits are excluded.

Li and Br are not shown due to no detection for all samples.

5.3.4 CO concentrations and relation with $PM_{2.5}$

The time-averaged CO concentrations for 22-h measurements at the mountainous site showed higher than those in coastal area, though the difference was not statistically significant (Mann-Whitney U-test, $p > 0.05$). Our 22-hr averaged CO concentration was lower than that of other study using a wood log fuel (Edwards et al., 2007). Yet, the average CO concentration of one household sample in Lembang exceeded the indoor CO guidelines for 24-h period (5.68 ppm) of World Health Organization (WHO, 2010). Also the average CO concentration showed relatively lower in comparison with 8-hr average of 13.5 ppm for wood fuel burning in the urban periphery in Indonesia (Huboyo and Budihardjo, 2009b). This is due to the different CO sampling position.

As depicted in Figure 5.4, the time-averaged CO concentrations for 22-h measurements indicated linear relationship with the time-averaged $PM_{2.5}$ concentrations in the kitchen. In Lembang site, it showed a stronger linear relationship (R^2 = 0.93) compared to that in Juwana site. The R^2 of Juwana site (0.57) was comparable to 0.51 of Park and Lee (2003), but lower than 0.61 (Dutta et al., 2007) and another study of 0.74 (Chengappa et al.,2007).. The weaker indoor CO-$PM_{2.5}$ relationship in Juwana site than in Lembang site was likely influenced by two factors. The first factor is more efficient burning conditions in Juwana site which lower CO emission and generate finer particles. Higher stove combustion efficiency due to sufficient air supply (as in Juwana site) will reduce the products of incomplete combustion (PIC) emissions including CO emission (Smith, 1994). The second factor is larger kitchen dimension in Juwana site than in Lembang site and it may cause air dilution and reduce CO concentrations. Owing to larger kitchen room, the sampling point in Juwana site was at farther distance from the combustion source than in Lembang site. Therefore, sampled gas and particles had already dispersed in different rate in this naturally ventilated kitchen. With respect to pollutants emitted from a heated source, Rim and

Novoselac (2008) reported fine particles had more varied concentrations than gaseous pollutants due to buoyancy flow in a naturally ventilated room.

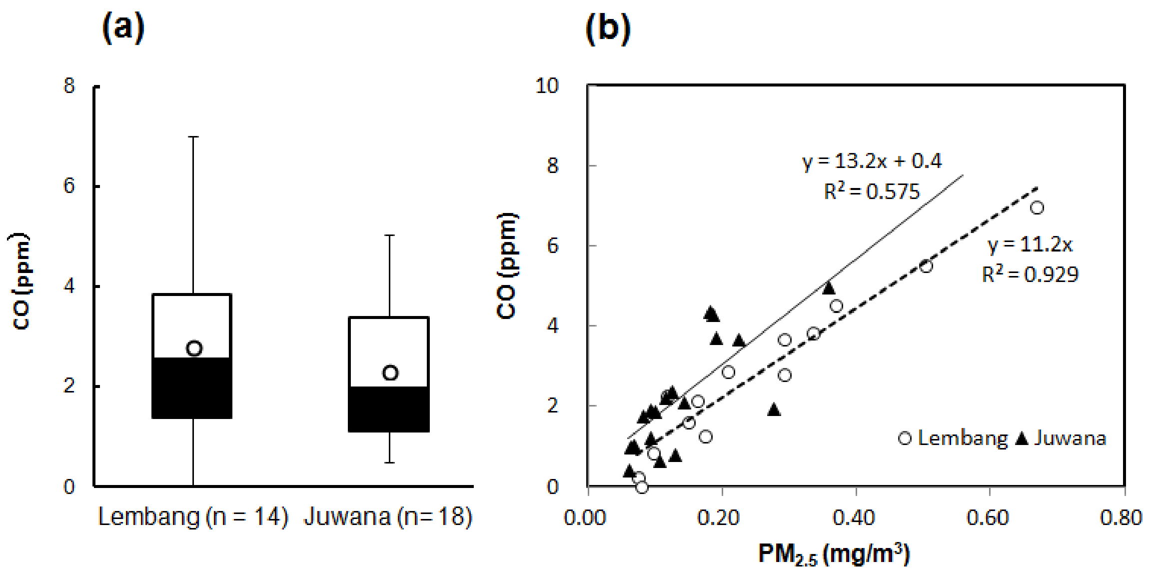


Figure 5.4 (a) Time averaged CO concentrations in the kitchen and (b) the relation between $PM_{2.5}$ and CO concentrations

5.3.5 Estimating exposure to the cooks

We estimated the exposures using $PM_{2.5}$ concentrations in kitchen and living room as well as outdoor ambient concentrations combined with time activity information by season at two sites. The average 24-hour exposure to $PM_{2.5}$ for each person was estimated using modified formula, originally proposed by Balakrishnan et al. (2004) and Mestl et al. (2011). The exposure formula was:

$$E_w = \left(\frac{[Tc*Ckc]+[Tk*Ck]+[Ti*Ci]+[To*Co]}{Tc + Tk + Ti + To}\right)_w \quad (5.1)$$

$$E_d = \left(\frac{[Tc*Ckc]+[Tk*Ck]+[Ti*Ci]+[To*Co]}{Tc + Tk + Ti + To}\right)_d \quad (5.2)$$

$$E_{total} = \text{average}(E_w, E_d) \quad (5.3)$$

where, w : wet season

d : dry season

Tc : time spent in kitchen while cooking, 1.84 h (wet season) and 2.32 h (dry season) in Lembang; 0.84 h (wet season) and 0.74 h (dry season) in Juwana

Ckc : kitchen concentration during cooking.

Tk : time spent in the kitchen when not cooking (we assumed to be 0.5 h/day for wood fuel preparation and other purpose)

Ck : average kitchen concentration other than cooking period

Ti : time spent in the living room (the remaining time after Tc, Tk, and To)

Ci : 24-hour average concentration in the living room

To :time spent outdoors, calculated by estimating the worktime for householders i.e. 7 h and 9 h for Lembang and Juwana respectively

Co : outdoor concentration during wet and dry season.

The equation is divided by Tc+Tk+Ti+To (24 h) to estimate 24 h average concentration exposure. This formula assumes: the kitchen $PM_{2.5}$ concentrations are well mixed; the $PM_{2.5}$ concentrations in the bedroom are comparable to those in the living room; the time spent in the kitchen, living room and outdoor are not changed by season; the cooks also work in the field; the cooking duration in the morning and evening (particularly in Lembang site) are comparable. The data used here are adopted from UCB measurements in chapter 3 and chapter 5. The parameters used in the calculation are summarized in the Table 5.5.

Table 5.5 Parameters for estimating daily exposure of $PM_{2.5}$

Parameters	Wet season		Dry season	
	Lembang	Juwana	Lembang	Juwana
Ckc (mg/m^3)	2.01 (1.78)	1.09 (1.37)	1.16 (1.01)	0.78 (0.76)
Ck (mg/m^3)	0.24 (0.19)	0.12 (0.08)	0.13 (0.1)	0.09 (0.05)
Ci (mg/m^3)	0.12 (0.04)	0.09 (0.02)	0.18 (0.18)	0.07 (0.02)
Co (mg/m^3)	0.06 (0.00)	0.05 (0.00)	0.06 (0.03)	0.08 (0.01)
Tc (h)	1.29	0.84	2.36	0.73
Tk (h)	0.50	0.50	0.50	0.50
To (h)	7.00	9.00	7.00	9.00
Ti (h)	15.21	13.66	14.14	13.77
Daily exposure, E(mg/m^3)	0.21	0.11	0.24	0.10

Note: values in the brackets are standard deviation

The average daily exposures in Lembang and Juwana were 0.24 (mg/m^3) and 0.1 (mg/m^3) respectively. If we assume the inhalation rate is 18 m^3/day for adults (chapter 4) then it corresponds to daily dose (DD) of 4.36 mg and 1.85 mg $PM_{2.5}$ exposure for Lembang and Juwana cooks respectively. This average daily dose of $PM_{2.5}$ is used to get relative risk (RR) for cardiopulmonary and cardiovascular diseases. The logarithmic relationship between RR and daily dose for cardiopulmonary (Cp) diseases and cardiovascular (Cv) diseases suggested by Pope et al., 2009 are:

$$RR(Cp) = 0.1083\times\ln(DD) + 1.37,\ R^2 = 0{:}87 \quad (5.4)$$

Upper and lower 95% confidence limits are

Upper = $0.1014\times\ln(DD) + 1.55$, $R^2 = 0.86$; Lower = $0.1137\times\ln(DD) + 1.22$; $R^2 = 0.80$

$$RR(Cv) = 0.0978\times\ln(DD) + 1.33,\ R^2 = 0.89 \quad (5.5)$$

Upper and lower 95% confidence limits are

Upper = 0.0986×ln(DD) + 1.48, R^2 = 0.86; Lower = 0.0969×ln(DD) + 1.20, R^2 = 0.89

Table 5.6 Estimated relative risk (RR) due to wood fuel use for the cooks in two sites

Sites	24-h average exposure (mg/m^3)	Estimated daily dose (mg)	Adjusted RR [95%CI]	
			Cardiopulmonary diseases	Cardiovascular diseases
Lembang	0.24	4.36	1.52 [1.38 – 1.69]	1.47 [1.33 – 1.62]
Juwana	0.1	1.85	1.44 [1.29 – 1.61]	1.39 [1.26 – 1.54]

Since the Lembang communities cook twice a day and have the worst kitchen environment, they have longer exposure (Tc) and higher pollutant exposure (higher Ckc) compared to Juwana communities. This will ultimately make higher the pollutant daily dose compared to those in Juwana site. The relative risk of cardiopulmonary diseases and cardiovascular diseases due to wood fuel use showed higher values in Lembang site rather than in Juwana site. Since the majority of the cooks are housewife (the result in chapter 3) , the cooks should be women of 30 years or more of age. The relative risk estimate of the cooks for cardiopulmonary diseases was quite lower than those estimated for India (Desai et al., 2004) showing 3.20 [CI:2.30–4.80]. However it was almost comparable with relative risk calculation by Mestl and Edwards (2011) for Chinese wood fuel user i.e 1.51 [1.36–1.69]. In addition, the result for relative risk of cardiovascular disease in Lembang site was also comparable with that of Mestl and Edwards (2011)of 1.48 [1.34–1.64].

The evidence risk of COPD to women older than 30 years due to biomass fuel use are strong, then exposure reduction is indispensable. It is essential therefore to promote good cooking practice and healthy kitchen among wood fuel users which are still persistent in a high proportion of the population across Indonesia.

5.3.6 Indoor air pollution modeling using single box model

The indoor air concentrations during cooking period were predicted using a single-box model. This model assumes a well-mixed room with single constant emission source. It also assumes instantaneous mixing and no backflow to the room. This model considers stove performance and kitchen characteristics. The ventilation, represented by air exchange rate, is the main parameter for pollutant removal and other removal mechanisms were assumed to be negligible. The model is adopted from Johnson et al., 2011 and is described mathematically as:

$$C_t = \frac{G\,f}{AER\,(V)}\left(1 - e^{-AER(t)}\right) + C_0\left(e^{-AER\,(t)}\right) \quad \text{.............(5.6)}$$

where,

Ct	: concentration of $PM_{2.5}$ at time t (mg/m^3)
G	: emission rate (mg $PM_{2.5}$/hr)
AER	: air exchange rate (/hr)
V	: kitchen volume (m^3)
t	: time (hr);
C_0	: $PM_{2.5}$ concentration from preceding time unit (mg/m^3)
f	: fraction of emissions that enters the kitchen environment.

The time interval of iteration was set in 1 minute interval to match with monitored $PM_{2.5}$ in UCB (in 1 minute interval). The AER was estimated using the same formula in chapter 4. This AER did not consider the availability of ventilation area, instead it is estimated by the slope of least-square fit of natural logarithm on decay CO concentration (McCracken, 1998). In this study, the AER`s were in the range of 0.2 – 3.23 hr^{-1}. The fraction of emission entering the kitchen environment was assumed to be 1 at both sites since no chimney was installed. The background concentration before cooking started was set as initial C_0. The emission rate was assumed to be constant throughout cooking period. It depends on the stove power, stove thermal efficiency, and emission factors (fuel based emission factor). The emission rate, G (mg $PM_{2.5}$/min), was calculated as:

$$G = \frac{E_F}{E_D} P(\eta) \quad \text{……………(5.7)}$$

where,

E_F : fuel based emission factor (mg $PM_{2.5}$/kg fuel)

E_D : the energy density of the wood fuel (MJ/kg), 16 MJ/kg as assumed in chapter 4.

P : stove power (MJ/hr), 4,832 W from WBT test in chapter 4.

η : stove efficiency (18% based on the cold test in WBT at chapter 4)

As the PM emission factor , we used 500 mg PM emission/kg wood fuel. This is the lower end of emission factor of simple wood stove as depicted by McCarty (Mc.Carty et al., 2010). The results of simulated concentration compared with actual concentration are illustrated in Figure 5.5.

The ratios of simulated concentration to actual concentration on average are 1.1 and 1.7 for wet season and dry season respectively. However several samples in both sites have large uncertainty i.e. their ratios showed 3 – 5. The actual emission rate was varied widely, depending on the burning condition of the stove. Keeping this emission rate at constant value then if we compare minute by minute results between actual and simulated concentration, the simulation results have large uncertainties (either overestimate or underestimate). For example in L7 sample in wet season, the variability of actual emission rate was very high (the std. deviation of about 7 mg/m^3 while the simulation result showed only 0.7 mg/m^3). This high variability of the emission rate might be due to the cook behavior on blowing air into stove, wood refueling and wood fuel moistures. This model is sensitive to emission rate and kitchen volume, showing about 50% of variance in the kitchen concentration and therefore these parameters greatly influence on model accuracy.

The AER contributes to about 10 – 25% of kitchen concentration variability. It seems that this model has greater accuracy for predicting moderate indoor kitchen concentrations i.e around 1 mg/m^3. The ratio of simulated concentration to actual concentration is better for Lembang site i.e. 0.9 and 1.7 compared to Juwana site i.e. 1.13 and 1.8 for wet season and dry season respectively. Overall, this model is quite useful to preliminary assess the indoor air pollution that might occur if housing parameters are well characterized.

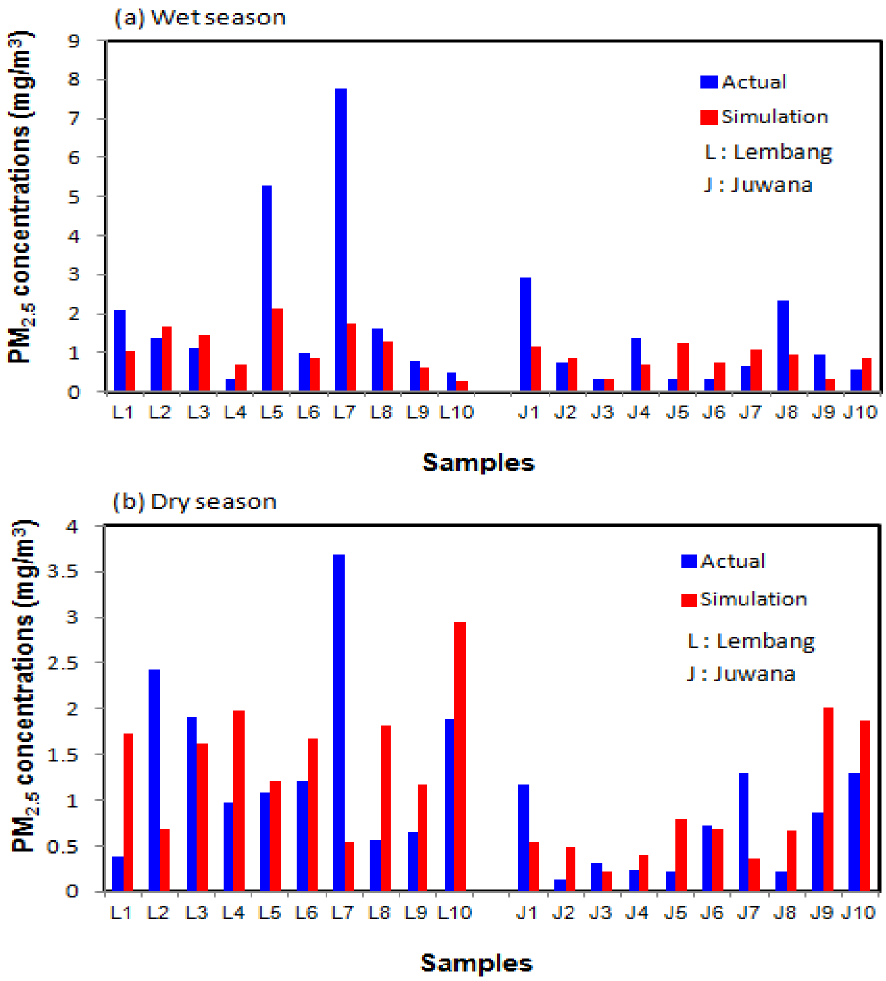


Figure 5.5 Comparison between actual concentration and simulated concentration during cooking period in two seasons

5.4 Conclusion

This study showed that indoor $PM_{2.5}$ concentrations in the mountainous region were almost double than those in the coastal area. This is because of smaller kitchen volume, smaller ventilation area and more frequent cooking with wood fuel in mountainous site than in coastal site. However, during cooking with wood fuel, the indoor $PM_{2.5}$ concentrations at the cook sites showed almost comparable for both sites. The emission from wood stove burning in the kitchen occasionally penetrated into the living room in the mountainous region site. The burning condition of wood stove in coastal area was in flaming combustion than in mountainous region and this can be suggested by higher fraction of the finest particles in $PM_{2.5}$, higher fraction of EC in $PM_{2.5}$ and higher fraction of K^+ and Cl^- ions in $PM_{2.5}$ mass concentration. The time-averaged CO concentrations for 22-h measurements at the mountainous site showed higher than those in coastal area, though the difference was not statistically significant. Relationship between CO and $PM_{2.5}$ concentrations showed higher positive correlation in mountainous site than in coastal area probably due to lower stove burning efficiency and the smaller kitchen volume in mountainous region.

The relative risk for cardiopulmonary as well as cardiovascular diseases was higher in mountainous site than in coastal site. Single box model can be used for estimating indoor air pollution roughly due to wood fuel use during cooking period.

Reflecting from this work, the countermeasures option to mitigate indoor air pollution in these areas will cover three aspects. First is reducing the pollutants at sources by installing improved wood stove and flues to expel the pollutants out of house, secondly by improving quality of living environment by providing or practicing sufficient ventilation and or separating the kitchen with the main building. Lastly exposure of pollutant in the kitchen as well as in the living room for the cooks and householders can be reduced by adopting good cooking practice and quitting of smoking and mosquito coil burning habit. Instead, familiarizing with other method such as a lotion of mosquito repellant or mosquito net might be chosen.

CHAPTER-6

Conclusions and recommendation

Chapter outline

This chapter summarizes the findings related to the objectives outlined in chapter 1. In this chapter, problems were mapped to get roots problem in order to propose mitigation. Based on this causality map, specific programs/actions and general proposals are recommended to be performed in the short term, medium term and long term within rural communities.

6.1 Conclusions

Wood fuel will still dominate in the future energy supply for Indonesian rural households. Adopting modern fuel i.e. subsidized LPG would not necessarily leave wood fuel as household cooking fuel energy. Adoption of dual fuel energy (LPG-wood fuel) in rural areas is mainly driven by economical motive. This will have benefit to rural household cooking energy security in case of the disturbance of subsidized LPG supply. Moreover, the wood fuel is still required for heavy cooking such as boiling water and rice cooking. In fact, the wood fuel users were also not to be targeted of LPG fuel conversion. The average wood fuel unit consumption in the study area was estimated to be 0.88 m^3/cap/year. Across the country, the distribution of wood fuel users was still concentrated in Java island where the wood fuel resources were diminishing.

Local housing characteristics were influenced by local wisdom, culture, climate, and location. In our study, the households in mountainous area using wood fuel were potent to have the indoor air pollution episode than in coastal areas owing to smaller room volumes, longer cooking duration, smaller ventilation area and space heating need. In addition, the improper behavior in a large fraction of the mountainous people (Lembang site) such as keeping close the ventilation during cooking incur harmful pollutant exposure at higher risk. People's awareness of identifying indoor air pollutions in these two investigation sites, however, showed an optimistic view in designing integrated indoor air pollution countermeasures.

Traditional wood stove had the lowest thermal efficiency and high specific fuel consumption compared to charcoal stove, kerosene stove, improved stove using *Jatropha curcas* seed and improved wood stove (SAE stove). Ventilation during cooking is important to reduce the exposure of the cooks. Cooking without proper ventilation, even using a gas stove, obviously produced considerable amounts of $PM_{2.5}$ and CO in an indoor kitchen at cook site. While in the non-ventilated room, the wood stove combustion evidently exposed $PM_{2.5}$ to the cooks 4 folds than that using natural ventilation. Alternative cook stove, i.e *Jatropha curcas* stove may replace traditional wood stove as this stove emitted less indoor $PM_{2.5}$ (about one tenth) than traditional wood stove did.

Indoor air pollution concentrations ($PM_{2.5}$ and CO) in rural mountainous area on average were higher than those in coastal area. Due to bigger volume, sufficient ventilation and less frequent cooking with wood fuel, the coastal site demonstrated lower indoor air pollution. Assuming well mixed concentration in the kitchen, the relative risk of cardiopulmonary and cardiovascular is higher for mountainous communities rather than in coastal communities. In fact, at cook site, the $PM_{2.5}$ concentrations at both sites showed comparable values. This indicated on cook site, the exposure was quite high irrespective of the kitchen volume and ventilation. Hence the cooks should avoid engaging on cooking in front of the stove continuously. Nevertheless, the susceptible household members present in the kitchen were likely more exposed in the Lembang than in Juwana due to smaller volume and inadequate ventilation. It is recommended to minimize activities in the kitchen during cooking period because most of the indoor $PM_{2.5}$ mass size fraction was dominated in sub-micron size range which is respirable and pose a health threat.

6.2 Causality problems identification and recommendation

Indoor air pollution episode in rural areas is rooted by persistent use of wood fuel with traditional wood stove in unhealthy household. As the economic motive was behind this condition, therefore poverty alleviation as mandated in Millennium Development Goal (MDG) is the core to solve the problem. However to eradicate rural poverty requires sustainable rural development in a long-term program. Then it needs, otherwise, immediate action (short term-program) to mitigate indoor air pollution within rural households. Furthermore, medium-term program is also needed to mitigate it to ensure reliable resources for infrastructure development, funding resources and time for socialization. The schematic root problems and probable solutions are illustrated in Figure 6.1

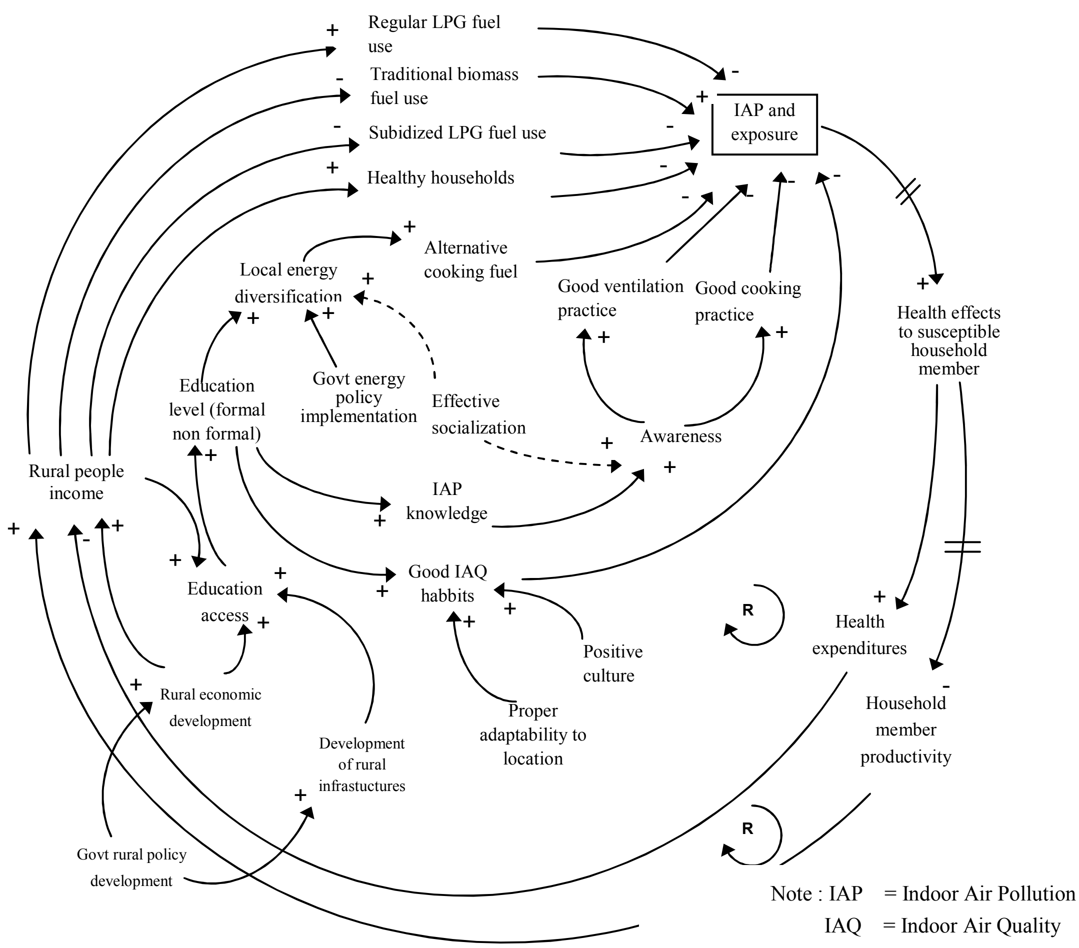


Figure 6.1 Causal diagram of indoor air pollution in Indonesian rural households

There are many ways to improve indoor air quality in rural area households, however, this proposed recommendations are specific based on on-site measurements as well as observations in the area studied.

6.2.1 Short-term program

The proposed program based on current ventilation area availability to minimize the cost of changing ventilation scheme. This action includes opening up the ventilation to dissipate the combustion pollutants as quickly as possible from the inner households. Implement good practice in cooking which should be familiarized by the cooks. The stove should be put near the ventilation to allow smoke exit, moving intermittently to neighboring rooms during cooking, keep closing the interconnecting door between kitchen and living room, avoid putting plastic/waste garbage to include in the burning, prolong for keeping the wood stock/other biomass for cooking and minimize the time of non-cooks to be in the kitchen during cooking.

6.2.2 Medium-term program

In this proposed program, several physical and non-physical resources are needed. First is the installment of an improved (efficient) wood stove with chimney. These stoves should be provided by external funding scheme because most of rural people are poor. Secondly, diversification of cooking energy with adopting local resources such as biogas, biofuel or other renewable energy. This program already exists under self-sufficient energy village program (Ministry of Energy and Mineral Resources). However, this should be fostered to reach as many as rural villages and emphasize on providing cooking energy, too (not only for providing electricity). Third, reorganize the kitchen households by enlarging the kitchen to get a reasonable volume if sufficient ventilation could not be afforded or if possible separation from the dwelling room. Promoting sustainable harvesting of wood fuel by only harvesting the branches of trees (not the trunk) to prevent biomass resource depletion. Lastly, giving socialization on healthy cooking, healthy living and wise use of cooking energy.

6.2.3 Long-term program

Alleviate the poverty by giving access of rural people on education, developing adequate basic infrastructures, providing health services and secure clean energy as well as electricity. Healthy living will be achieved if there are enough opportunities for rural people to be empowered people. Empowering rural people to sustain their livelihood, raise their incomes that do not depend on subsidized fuel will establish the balance of urban-rural growth. Other issue is the change of persistent habits which should be broken. Change the inappropriate habits leading to deteriorating indoor air quality such as smoking, using mosquito coil burning (using a lotion or electric mosquito repellant instead), burning the garbage and applying space heating with wood stove combustion.

Acknowledgements

I would like to express my appreciation to the Directorate General of Higher Education Republic of Indonesia for providing financial support during my doctoral education. This dissertation work was financially supported by Global Centre of Excellence (GCOE) Program of the Graduate School of Energy Science, Kyoto University and Environmental Management Leader Program (EML) of Kyoto University.

I would first like to thank my advisor, Prof. Susumu Tohno, for giving me the opportunity to join this lab and facilitate the resources to conduct my doctoral research and to complete this dissertation. I appreciate his guidance, support, and facilitation throughout the years. I would also like to thank my dissertation committee, Prof. Shiro Saka and Prof. Minoru Yoneda. I appreciate their input to my dissertation research. Their insights and valuable suggestions strengthened the quality of this work.

I would like to express my special thanks to Ir.Puji Lestari, Ph.D for giving the recommendation to study at Kyoto University. She also assisted me guidance in the field measurements and contributed to paper writing.

Sincere appreciation and thanks is due to Dr. Kouhei Yamamoto for his valuable assistance during study at Kyoto University. Dr. Motonori Okumura deserves a special recognition for helping me in establishing chemical analysis in the laboratory as well as facilitating to purchase articles for my research. Also thanks to Dr. Kameda for the friendship. The help of the staff of Kyoto University and also Ms. Tomoko Kamada have also been most helpful.

The informal support of laboratory friends is also acknowledged. Special thanks to Kinoshita-san, Fujii-san and Kasuga-san for their help in administration matters here in Kyoto.

Our team mates in the field at Bandung area: Windy, Tisa, Nuhe, Dina and Titis and at Pati area: Mega, Pamella, Fajar, Zaza and Dona are greatly appreciated for their collaborative and hard work during “dark silent sampling”. I also in debt for help from YDD colleagues: Ms.Prianti Utami and Mr. E.Jara for their supports on stove testing.

My deepest thanks, of course, go to my parents, my wife and my daughter and son for their unconditional support, patience, and encouragement. It was quite tough time to be separated many times due to this study.

Kyoto, April 2013

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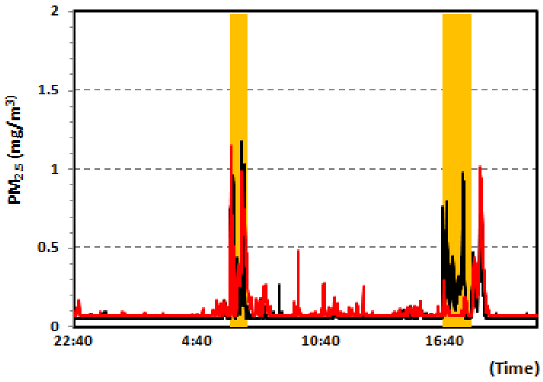
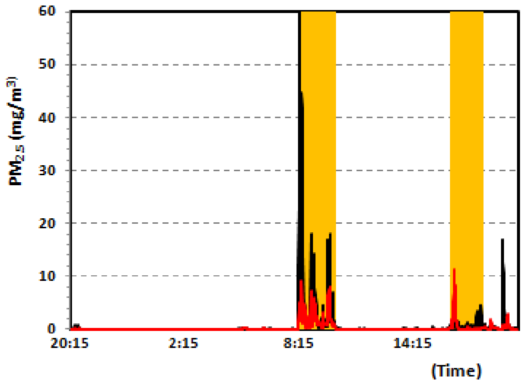
Appendices

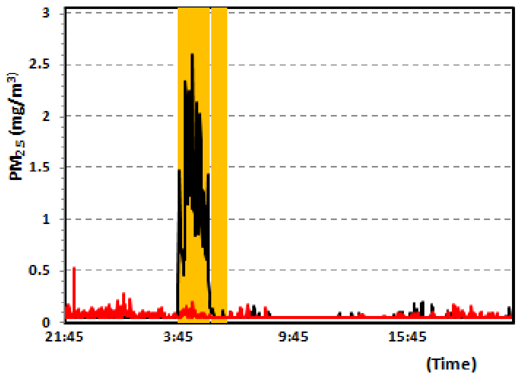
Example of measurement graphs (output of UCB`s):



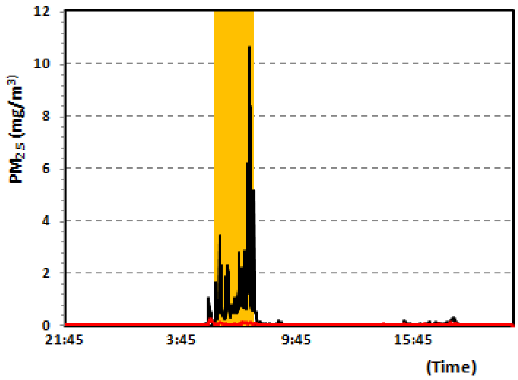
HH-2 Lembang



HH-13 Lembang



HH-4 Juwana



HH-5 Juwana

cooking time Kitchen Living room

Lembang site

The Sunten Jaya village is in the highland

Household sample_1

Household sample_2

Measurement in the kitchen_1

Measurement in the kitchen_2

Juwana site

Brackish water pond

Wood fuel supplier

Household sample

Household sample

Measurement in the kitchen_1

Measurement in the kitchen_2

QUESTIONNAIRE

MODULE A

No	BASIC HOUSEHOLD INFORMATION
1.	Household ID : S- Sub village: District:
2.	Family members :
3.	Latest education level of household head: a. Elementary school b. Junior high school c. Secondary high school d. College
4.	Latest education level of housewife: a. Elementary school b. Junior high school c. Secondary high school d. College
5	Daily in charge for cooks: a. Housewife b. Householder head c. Children d. Others …………….

MODULE B

No	HOUSEHOLDER PARAMETERS
1	Living room : length : m, width: m height: m
2	Kitchen room : length : m, width: m height: m
3	Area of specific ventilation: Living room : m^2 Kitchen room : m^2
4	Are there any non-specific ventilation in the kitchen : a. yes b. no
5	Wall materials: Living room : a. brick b. concrete block c. bamboo d. plank e. others………….. Kitchen: a. brick b. concrete block c. bamboo d. plank e. others …………….
6	Floor type: Living room : a. tile b. cemented c. plank d. con block e. earthen f. others………….. Kitchen: a. tile b. cemented c. plank d. con block e. earthen f. others…………..

Note : Specific ventilation : door, window, regular wind path and draft fan
Unspecified ventilation: eaves, irregular wind path, wall orifices etc.

MODULE C

No	HOUSEHOLDER ACTIVITIES
1	Primary cooking fuel: a. LPG b. wood c. others…………….
2	Secondary cooking fuel: a. LPG b. wood c. others…………….
3	Cooking frequencies Primary cooking fuel a. once /day b. twice/day c. three times/day e. > three times/day Secondary cooking fuel : a. once /day b. twice/day c. three times/day e. > three times/day
4	Cooking duration estimates : Primary fuel: a. □30 min b. 30 min - 1 hour c.1 - 1.5 hours d.1-5 – 2 hours e.>2 hours. Secondary fuel : a. □30 min b. 30 min - 1 hour c.1 - 1.5 hours d.1-5 – 2 hours e.>2 hours

5	Cooking practice behavior : a. the doors are kept open b. the windows are kept open c. both door and window are kept open d. both door and window remain closed d. others …………………………………….
6	Monthly fuel consumption estimate: LPG =….. cylinders, wood fuel = ……. kg or …….m^3
7	Are there smoker at home: a. yes (who?................................) b.no If the above answer is yes, how many cigarettes are smoked at home (on average)? :………………cigarettes.
8	When do the smokers do smoke at home : …………………………….
9	Using mosquito repellant? a. yes b. no If the answer is yes, what sort of mosquito repellant is being used: a. electric b. spray c. coil burning d. liquid e. others………
10.	Household lightning type: a. electricity means b. non electricity means (……………………………………..)
11.	Household cleaning: a. once/day b. twice/day c. three times/day d. others (……………………………………..)
12.	Are there any other outdoor sources of pollution? a. yes b. no If the answer is yes, then mention the source (might be more than one). a. transportation b. solid waste burning c. factory smoke d. neighbour cooking smoke e others……………
13.	Which is the bigger polluter? a. inside the house b. outside the house c. both pollution are comparable

Note : The LPG fuel refer to subsidized 3kg LPG. Wood fuel amount might be substituted by wood volume. The daily habit for smoking could be noted by time based i.e in the morning/day time/afternoon only or every after meal or uncertain
Non electricity lightning for instance kerosene lamp, pressurized lamps etc.
Point 13 emphasizes on comparing which is the bigger pollutant (between indoor and outdoor) based on subjective respondent knowledge

MODULE D

Based on your knowledge and observation, please give the rank (from the highest to the lowest) among these variables below which affect the indoor air quality.

These variables are arranged in alphabetical order.

VARIABLES	RANK
Mosquito coil burning	
Non electricity lamp	
Smoking	
Type of cooking fuel	
Ventilation factor	

MODULE E

No	OTHERS
1	Perceived of physical disorder related to unhealthy indoor air quality: - respiratory system : a. cough b. wheezing c. phlegm d. breathing problem e. none - eye irritation: a. watering of eyes b. eye redness c. other………… d. none - others: ……………………………..
2	When the above symptom usually appears? (notify)……………………. a. continuous b .hourly c. daily d. monthly e. not specified f. others……………….
3	Family income per month : a. □ Rp. 250.000 b. Rp 250.001 – 700.000 c. Rp. 700.001 – 1.000.000 d. Rp. 1.000.001 – 1.500.000 e. 1.500.001 – 2.000.000 f. > Rp. 2.000.000
4	Expenses per month (on average) for health care? Rp………………………….
5.	The preferable media for acquiring up-to-date information: a. TV b. radio c. newspaper/magazine d. internet e. neighbor/community meeting f. others…………………

List of Publications

1. Huboyo HS, Tohno S, Lestari P. Woodfuel utilization for cooking in Indonesian household: Assessment of indoor PM_{10} pollution and wood consumption at national level, In: Yao T (ed) Zero-Carbon Energy Kyoto 2012, Green Energy and Technology, Springer pp.123 - 131, 2013. (Chapter 2)

2. Huboyo HS, Lestari P, Tohno S. Household characteristics and potential indoor air pollution issues in rural Indonesian communities using wood fuel energy (Submitted to Indoor and Built Environment, SAGE Journal, 2013) (Chapter 3)

3. Huboyo HS, Tohno S, Cao R. Indoor $PM_{2.5}$ Characteristics and CO Concentration Related to Water-Based and Oil-Based Cooking Emissions Using a Gas Stove. *Aerosol Air Qual Res*, 11: 401–411, 2011. (Chapter 4A)

4. Huboyo HS, Tohno S, Lestari P, Mizohata A, Okumura M, Utami P, Jara E. Comparison between Jatropha curcas seed stove and woodstove: Performance and effect on indoor air quality, *Energy Sustainable Development*, Elsevier, (in press, http://dx.doi.org/10.1016/j.esd.2013.03.008). (Chapter 4B)

5. Huboyo HS, Tohno S, Lestari P. Characteristic of indoor air pollution in Indonesian rural communities (Submitted to Atmospheric Environment, 2013) (Chapter 5)

6. Huboyo HS, Tohno S. Relative risk and modelling indoor air pollution due to wood fuel use in rural Indonesian households (to be submitted to Journal of Applied Sciences in Environmental Sanitation) (Chapter 5)

List of Presentations

1. Huboyo HS, Budihardjo MA. Carbon monoxide concentration in the kitchen using solid fuel, kerosene and LPG, International Symposium on Sustainable Energy & Environmental Protection 2009, Yogyakarta Indonesia, November 23 – 26, CD proceeding ISBN 978-602-95934-0-2, oral presentation (WTEP12), p.16.

2. Huboyo HS, Tohno S. Characterization of indoor fine particles associated with cooking method based on the measurement of mass size distribution and number concentration. Abstracts of 2nd GCOE International Symposium "Zero-Carbon Energy Kyoto 2010", August 19-20, 2010, Kyoto, Japan, p.88.

3. Huboyo HS, Tohno S. Characteristic of carbon monoxide and fine particles in indoor

air related to cooking method, Better Air Quality (BAQ) 2010 Conference, Singapore, 2010 November 9 – 11, poster,p.33.

4. Huboyo HS, Tohno S, Lestari P. Comparison of traditional and alternative fuels for cooking in Indonesian rural households in term of nergy use and indoor air pollution. Abstracts of 3rd GCOE International Symposium "Zero-Carbon Energy Kyoto 2011" (Specially Jointed with BK21 Program at Ajou University), August 18-19, 2011, Suwon, Korea, p. 62.

5. Huboyo HS, Lestari P, Tohno S. The basic performance of jatropha seed stove and its indoor air pollution over traditional wood stoves. Abstract of European Aerosol Conference 2011, September 4 – 9 2011, Manchester, UK (poster, with review).p.116.

6. Huboyo HS, Lestari P, Mizohata A, Tohno S. Method for determinating size segregated carbonaceous indoor aerosol of $PM_{2.5}$ related to jatropha curcas seed stove and traditional woodstove emission through water boiling test, SUSTAIN 2011 The 186th Symposium on Sustainable Humanosphere, Kyoto, Japan, 8-10 October 2011, Proceeding 884-8850, oral presentation (EnE-028), p.415-420.

7. Huboyo HS, Lestari P, Tohno S. Biomass fuel use in Indonesian rural households: the indoor aerosol of ultrafine (and its BC), fine, coarse particles related to cooking emission and a rough estimate of its biomass fuel consumption at nationwide. Abstracts of 4th GCOE International Symposium "Zero-Carbon Energy Kyoto 2012" (Specially Jointed with JGSEE King Mongkut's University of Technology Thonbury), May 22-23, 2012, Bangkok, Thailand, p 93.