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A pilot study of traditional indoor biomass cooking and heating in rural Bhutan: gas and particle concentrations and emission rates

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Abstract

Although many studies have reported the health effects of biomass fuels in developing countries, relatively few have quantitatively characterized emissions from biomass stoves during cooking and heating. The aim of this pilot study was to characterize the emission characteristics of different biomass stoves in four rural houses in Bhutan during heating (metal chimney stove), rice cooking (traditional mud stove), fodder preparation (stone tripod stove) and liquor distillation (traditional mud stove). Three stage measurements (before, during and after the activity had ceased) were conducted for $PM_{2.5}$, particle number (PN), CO and CO_2. When stoves were operated, the pollutant concentrations were significantly

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elevated above background levels, by an average of 40 and 18 times for $PM_{2.5}$ and CO, respectively. Emission rates (mg/min) ranged from 1.07×10^{2} ($PM_{2.5}$) and 3.50×10^{2} (CO) for the stone tripod stove during fodder preparation to 6.20×10^{2} ($PM_{2.5}$) and 2.22×10^{3} (CO) for the traditional mud stove during liquor distillation. Usable PN data was only available for one house, during heating using a metal chimney stove, which presented an emission rate of 3.24×10^{13} particles/min. Interventions to control household air pollution in Bhutan, in order to reduce the health risks associated with cooking and heating are recommended.

Keywords: Bhutan, rural, emission rate, firewood, cooking, heating

Practical Implications

Household air pollution resulting from the use of solid fuels for cooking and heating is the leading cause of premature death in many developing countries. In order to assess the health risks, quantitative characterization of the emissions from stoves and cooking activities under real-world conditions is crucial. Our study adds to a small number of studies that estimated emission rates from biomass stoves under real-world operating conditions, the findings of which will be useful for agencies responsible for public health care system and those working towards the improvement of indoor environments.

1. Introduction

Although there has been a 21% decrease globally in the number of households relying on solid fuels for cooking between 1980 and 2010, the number of people exposed to emissions has remained the same (around 2.8 billion) due to population growth (Bonjour et al., 2013). Household air pollution (HAP) is the single most significant global environmental risk factor, accounting for nearly 5% of the global burden of disease (expressed as disability adjusted life-years (DALYs)) (Smith et al., 2014). This presents significant health risks in developing countries (Balakrishnan et al., 2004), with an estimated 2.6 billion people depending on biomass fuels (i.e. wood, crop residues and cattle dung) for cooking (Legros et al., 2011). In rural areas, traditional stoves are often used in poorly ventilated kitchens (Rehfuess et al., 2006), and for relatively long durations (Rumchev et al., 2007). Unlike gas and electric stoves, the fuel combustion process in traditional stoves is very difficult to control and leads to different emission profiles during different stages of the combustion cycle. Women and children spend the greatest amount of time inside kitchens and therefore incur the highest pollutant exposures (Andresen et al., 2005, Barnes et al., 2005, Li et al., 2012). Particles emitted from cooking also readily infiltrate into living rooms, thereby extending the risks to all occupants (Dasgupta et al., 2009, Wan et al., 2011). Studies in developing countries have consistently demonstrated the adverse health effects of particulate matter (PM) and gaseous pollutants emitted during the combustion of biomass fuels (Rumchev et al., 2007, Kulshreshtha et al., 2008, Kumar et al., 2008a, Lakshmi et al., 2010, Verma et al., 2010, Mengersen et al., 2011, Murray et al., 2012). A recent World Health Organization (WHO) report has attributed 4.3 million premature deaths in 2012 to HAP, with the majority in low and middle income countries (WHO, 2014b).

Despite the large number of studies highlighting the effects of biomass fuels on health in developing countries, relatively few studies have quantitatively characterized biomass stove emissions during cooking and heating within indoor environments. Most studies relied on measurements that provided time integrated average concentrations from which time resolved peak concentrations could not be obtained. Therefore, detailed quantification of emission rates, which are crucial for exposure assessment and for identifying the major contributors to emissions, cannot be determined. The high intensity peak emissions during cooking can account for 31 –61% of the total exposure to particles, and neglecting the contribution of peak emissions, can lead to underestimation of exposure (Ezzati et al., 2000, Mazaheri et al., 2014). Good quality emission rate data collected under real-world conditions are important inputs for health impact assessment, and when comparing the effects of different stoves and cooking practices.

Bhutan (population ~700,000) is a small eastern Himalayan country with an area of 38,394 km^2, and is bordered by India and China. In general, the environmental conditions, as well as social characteristics of Bhutan, are largely comparable with the rest of the Himalayan region. Nearly 70% of the population live in rural villages and are subsistence farmers. Although most villages have access to electricity, the use of firewood in traditional stoves is very common for cooking and heating. Rural areas accounted for 96% of the total firewood consumption in Bhutan, and rural households with electricity consumed only 25% less firewood than those without (DoE, 2005). This is largely because cooking activities, such as fodder preparation for cattle (usually a mix of vegetable wastes, rice husk and corn flour) and distilling home liquor (the primary cooking activities in village homes), cannot be done using standard electric or gas stoves due to the size of the pots needed for such activities. Also, refined fuels (e.g., liquefied petroleum gas (LPG) and kerosene) are expensive and in short supply in the villages, while wood is plentiful and can be collected freely. Bhutan has one of the world's highest rates of firewood consumption per capita (DoE, 2009). This large-scale use of firewood for cooking and heating in Bhutan is likely to result in poor indoor air quality (Bruce et al., 2013). Moreover, the burden of respiratory disease in Bhutan is substantial (MoH, 2007). However, there have been no studies on household air pollution exposure in Bhutan, which has made it difficult to estimate the health impacts of household biomass combustion.

As a part of a larger study investigating air quality in different microenvironments in rural villages in Bhutan, we sought to perform measurements of indoor biomass combustion products in a representative selection of rural village houses during cooking and space heating. The primary objectives were to estimate emission rates from biomass stoves, to compare the results with those derived from other studies and to determine if pollutant levels and emission rates in Bhutan differ from those reported in other economically developing countries.

2. Materials and Methods

2.1 Study design

The study was conducted in the rural villages of Kanglung within the Trashigang district in eastern Bhutan, which is one of the largest and the most densely populated districts in the country. Four houses (H1-H4) located in different villages 5-10 km apart were selected to represent the most common stove types and cooking activities. The general characteristics of the four houses investigated are presented in Table 1. All houses were traditional structures built from mud, wood and stone, except for the walls of the H1, which were strengthened with concrete. H1 was occupied by a family of a government employee stationed in the village and used LPG and electricity for cooking meals in an indoor kitchen. H1 had a metal chimney stove (locally called bukhari) for space heating in the living room (Figure 1 (a)). This stove had a combustion chamber with a door through which wood is added and a separate chamber with a drawer for ash collection and removal. H2-H4 belonged to farmers and cooking was mostly done using traditional stoves in a separately structured kitchen outside the main house. H2 and H4 had traditional stoves, built mostly from mud (Figure 1 (b) and (d)). H3 had a stone tripod stove, the simplest open fire stove, where firewood can be fed from more than one direction (Figure 1 (c)).

This study involved no direct human participation. The Trashigang District Administration, Royal Government of Bhutan, provided approval of the study through letter no DAT/ADM(3)2012/6990 and a verbal consent was obtained from the head of the family for conducting measurements in the selected houses.

Table 1: General characteristics of the houses investigated

House	Stove	Activity investigated	Location of the measurement setup	Ventilation status	Volume (m^3)
H1	Metal chimney stove	Heating	Living room	Windows and door closed	80
H2	Traditional mud stove	Rice cooking	Kitchen	Windows and door opened	82
H3	Stone tripod stove	Fodder preparation	Kitchen	Windows and door opened	21
H4	Traditional mud stove	Liquor distillation	Kitchen	Windows closed, door opened	42

Figure 1: Stove types and cooking activities: (a) chimney stove/heating in H1, (b) traditional mud stove/rice cooking in H2, (c) stone tripod stove/fodder preparation in H3, and (d) traditional mud stove/liquor distillation in H4.

2.2 Measurements

$PM_{2.5}$, PN, CO and CO_2 measurements were done in January 2013 for H1, H2 and H3 (during winter) and in April 2013 for H4 (during spring). The measurements were conducted in three stages, with 45 to 60 minutes of background measurement before the activity, followed by the activity, and at least an hour after the activity has ceased. A single measurement per activity was conducted in each house on different days. Instruments were placed 1.5 meters above the floor and at least 3 meters away from the stoves, depending on the size of the space. The standardization of instrument location with respect to combustion source is important given the potential for spatial gradients in concentration. However, for the real-world measurements performed in homes, we did not want to unduly inconvenience the occupants. Therefore, the location of the instrumentation setup, while mostly consistent, was not standardized in the present study. As is common with all traditional structures in rural villages in Bhutan, all houses used natural ventilation by opening doors or windows, and all the houses had substantial gaps in their structure that would aid ventilation. Measurements were conducted under normal ventilation conditions.

Except for H1, where sampling was done during heating in the family's living room, the sampling for other houses was done inside kitchens. At the time of measurements, the stove in H2 was used for cooking rice, fodder preparation in H3, and liquor distillation in H4 (see Figure 1). It should be noted that while stove types differed, all houses used firewood during the measurements, as they always do. The chimney of the heating stove was projected outside through the window in H1, while no venting system was present in the other houses. Also, during the measurements, any potential outdoor source of pollution, which could result in emission infiltration, was noted.

The duration of activities was 5 hours for heating in H1 (from 17:00 to 22:00, until occupants went to bed), 34 minutes for cooking in H2 (cooking rice for a family of 5), 50 minutes for fodder preparation in H3, and 2 hours for liquor distillation in H4. All the cooking activities involved boiling and steaming, and no frying or grilling was involved.

Additionally, we conducted outdoor background CO_2 measurements for five consecutive days (on different days from measurement in houses) to account for the air exchange rate (AER) estimation (see Section 2.4) at the Sherubtse College campus. The background site was located at a distance ranging from 2 km from H1 to 7 km from H4.

2.3 Instrumentation

Details of the instrumentation used were reported in our previous paper from Bhutan (Wangchuk et al., 2015). But briefly, $PM_{2.5}$ was measured by using a DustTrak aerosol photometer (TSI Model 8520, TSI Inc., St. Paul, MN, USA), that operates based on a light scattering technique, where the amount of scattered light is proportional to the mass concentration of the aerosol. PN was measured by using a NanoTracer (NT, Philips Aerasense, Netherlands), which works by diffusion charging and measures PN concentrations up to 1×10^6 particles/cm^3 in the size range of 10-300 nm. Temperature, relative humidity, CO and CO_2 concentrations were measured using indoor air quality (IAQ)-CALC (Model 7545, TSI Incorporated, St. Paul, MN, USA).

All the instruments were shipped to Bhutan from the International Laboratory for Air Quality and Health (ILAQH), Queensland University of Technology, Brisbane, Australia. Prior to shipment, all of the instruments were tested and calibrated at ILAQH.

DustTrak was tested and calibrated for ambient urban concentrations against Tapered Element Oscillating Microbalance (TEOM 1405-DF, Thermo Fisher Scientific Inc.), which is a robust reference instrument for $PM_{2.5}$ measurements and uses gravimetric detection technique. DustTrak was not calibrated for the biomass emissions, therefore, the measured $PM_{2.5}$ concentrations represent approximations of the actual values. The DustTrak data were considered relevant for the scope of this study, as the recorded $PM_{2.5}$ concentrations were used to analyze the relative differences in the three monitoring scenarios. For simplicity, the DustTrak results discussed in this paper are referred to as $PM_{2.5}$ from now on (omitting the term 'approximation'). A correction factor for NT measurements of PN concentrations is described in the Supporting Information (SI) file.

All the instruments were set to a 10 second averaging interval. The DustTrak was zero calibrated and the flow rate checked prior to each sampling trip. Instrument time stamps were synchronized with the local time.

2.4 Estimation of air exchange rate

An estimate of air exchange rates (AER) in each house was obtained based on CO_2 decay, once the stove was ceased, as demonstrated in equation (1) (Thatcher and Layton, 1995, He et al., 2004):

$$\alpha = \frac{1}{t} ln \frac{C_t}{C_0} \qquad (1)$$

Where α = air exchange rate, t = duration of CO_2 decay, C_t = CO_2 concentration at time t, and C_0 = CO_2 concentration when the source was discontinued. It should be noted that outdoor CO_2 can influence the indoor CO_2 concentration variations through penetration indoors. Thus, the estimated AER by equation (1) will be lower than the true value if the outdoor or background CO_2 value was not subtracted from the indoor value before taking the natural log of the data and plotting it against time. In order to account for this we have subtracted the outdoor background CO_2 concentration from the measured indoor concentrations.

2.5 Estimation of emission rates

The main factors influencing indoor particle concentrations are indoor and outdoor sources, particle loss due to deposition on indoor surfaces, penetration of outdoor particles, and air exchange rates (Morawska and Salthammer, 2003). The equation used to relate these parameters has been reported in previous studies (Koutrakis et al., 1992, Thatcher and Layton, 1995, Chen et al., 2000):

$$\frac{dC_{in}}{dt} = P * \alpha * C_{out} + \frac{Q_s}{V} - (\alpha + k) * C_{in} \qquad (2)$$

Where C_{in} and C_{out} are indoor and outdoor particle concentrations, respectively, P is the penetration efficiency, k is the deposition rate, α is the air exchange rate, Q_s is the indoor particle generation rate, t is time and V is the effective volume of the space. The average emission rate can be estimated by simplifying equation (2), using average values and assuming that the effects of particle dynamics such as condensation, evaporation and coagulation are negligible under the conditions usually encountered in residences, as described in He et al. (2004). The average emission rate, Q_s, is therefore given by equation (3):

$$\overline{Q_s} = V\left[\frac{C_{int} - C_{in0}}{\Delta T} + \overline{(\alpha + k)} * \overline{C_{in}} - \bar{\alpha} * C_{in0}\right] \qquad (3)$$

Where C_{int} and C_{in0} are the peak and initial indoor particle concentrations respectively, $\overline{(\alpha + k)}$ is the average total removal rate (which can be calculated using average decay rate after the source ceased), $\bar{\alpha}$ is the average air exchange rate, and ΔT is time difference between the initial and peak concentrations.

2.6 Data processing and analysis

Statistical analyses were performed using SPSS version 21 (SPSS Inc.). A 5% level of significance was used for all analyses ($p < 0.05$). The Mann-Whitney U test (a non-parametric equivalent of the student's t-test) was used to test the mean differences.

Extremely high PN concentrations, exceeding 1×10^6 particles/cm^3 (which was beyond the upper detection limit of the NT) were observed when the stoves were operated. This resulted in a failure of the instrument during measurements in H2. There was no way to deal with this issue in the field, as the instrument required manufacturer servicing. Therefore, no usable PN data were available for H2, H3 and H4. For heating in H1, concentrations exceeding the upper limit of the instrument were left as 1×10^6 particles/cm^3 and the analysis involving this data represents a lower bound.

3. Results

The results of temperature and relative humidity in the houses during the measurements are presented in the SI file.

3.1 $PM_{2.5}$, PN and CO concentrations

Figures 2 and 3 present the mean $PM_{2.5}$, PN and CO concentrations for the background, during and after the activities have ceased. In all the houses, concentrations of all the pollutants were significantly higher during the activity than the background levels (on average by a factor 40 and 18 for $PM_{2.5}$ and CO, respectively) and after activities have ceased ($p < 0.001$). It should be noted that background concentrations were, at times, influenced by neighborhood activities. For example, before the measurements in H1, smoke from the next-door neighbor had already infiltrated into the house, leading to a high background level. The measurements in H4 were started in the early morning hours, which was associated with a relatively low background level. Further descriptions of concentration variations are presented in the SI file.

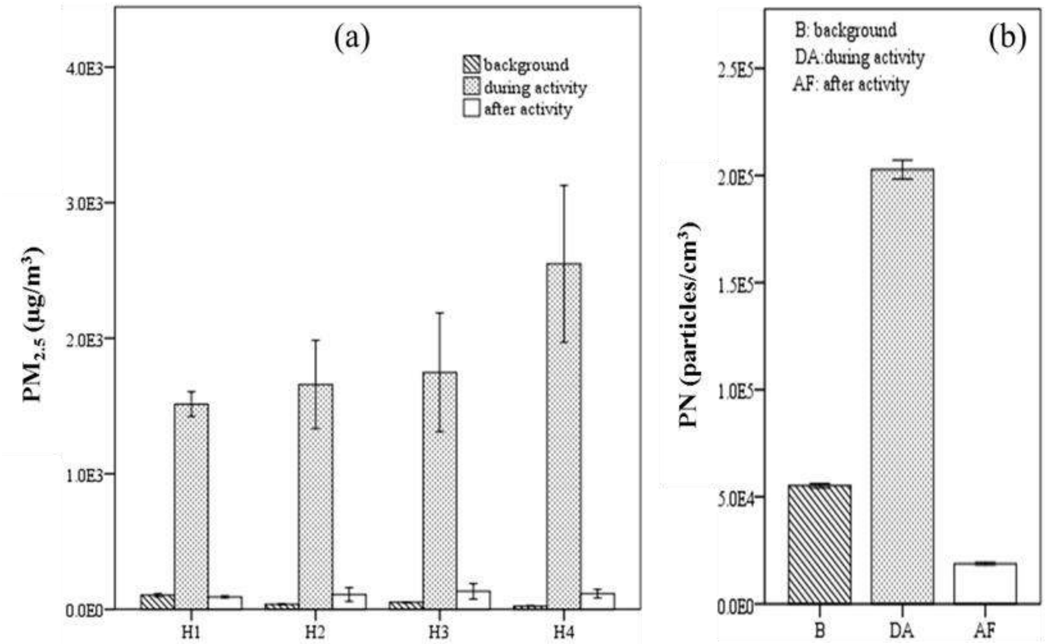

Figure 2: (a) $PM_{2.5}$ concentrations for all the studied houses (H1-H4) and (b) PN concentrations for H1 only during the 3 stages of the measurements: prior to activity (background), during and after the activity. Error bars show 95% confidence interval. (Note: H1- heating/metal chimney stove, H2- cooking rice/traditional mud stove, H3- fodder preparation/stone tripod stove, H4- liquor distillation /traditional mud stove).

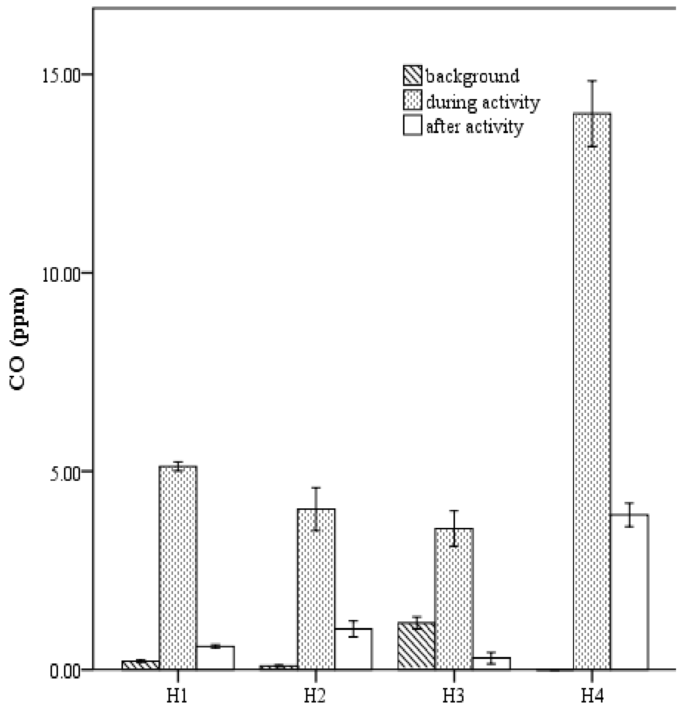

Figure 3: CO concentrations prior to the activity (background), during and after the activity (H1-H4). Error bars show 95% confidence interval.

3.2 Emission rates from stoves

The CO_2 decay after the heating and cooking activities have ceased presented a mean (sd) air exchange rate of 1.75 ± 0.50 h^{-1}. Figure 4 and SI Table S.2 show the summary statistics of emission rates for $PM_{2.5}$, PN and CO. The $PM_{2.5}$ emission rates during startup lighting ranged from 1.13×10^2 mg/min for the stone tripod stove during fodder preparation in H3, to 1.67×10^3 mg/min for the chimney stove during heating in H1. The CO emission rates during startup lighting ranged from 3.76×10^2 mg/min for the stone tripod stove in H3 to 3.09×10^3 mg/min for the traditional mud stove during liquor distillation in H4. The PN emission rate during startup lighting of the chimney stove in H1 was 7.71×10^{13} particles/min. As explained before, PN data were not available for other houses due to the instrument malfunction. However, based on the measurements in H1, it is expected that emission rates would be extreme in other houses, with peak concentrations exceeding 1×10^6 particles/cm^3, as observed in H1. Overall, the highest mean (arithmetic) $PM_{2.5}$ emission rate was observed during liquor distillation (traditional mud stove) in H4, followed by heating (metal chimney stove) in H1, rice cooking (traditional mud stove) in H2, and fodder preparation (stone tripod stove) in H3. Likewise, the highest mean CO emission rate was during liquor distillation in H4 and the lowest during fodder preparation in H3. Heating in H1 presented a mean (sd) PN emission rate of 3.24×10^{13} (2.48×10^{13}) particles/min.

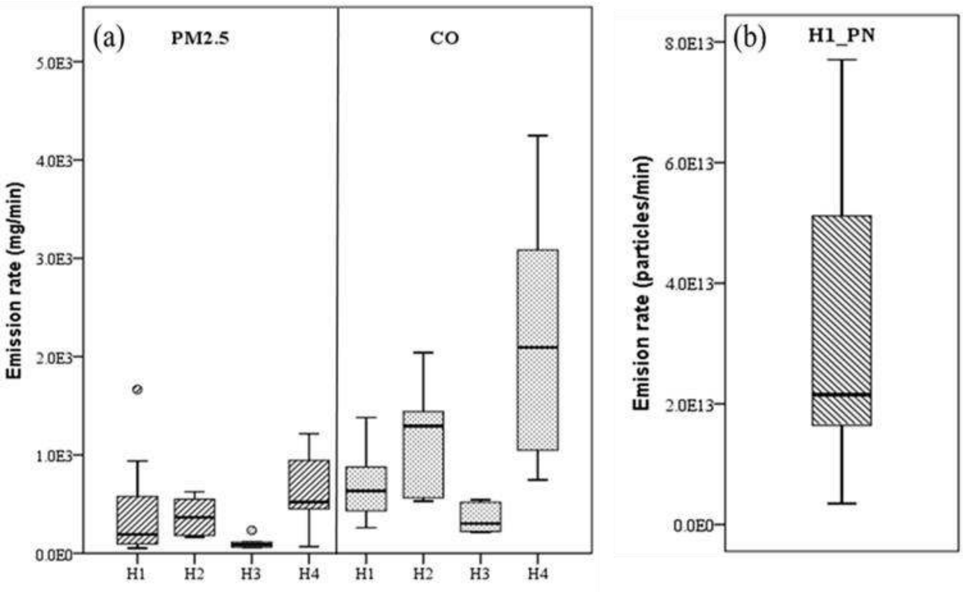

Figure 4: Emission rates (a) $PM_{2.5}$ (mg/min) and CO (mg/min) for H1-4, (b) PN (particles/min) for H1 only. The boxplot presents minimum, first quartile, median (middle dark line), third quartile and maximum values.

3.3 Discussion

While our study was a pilot investigation performed in a limited number of houses, it is one of only a small number of studies to estimate pollutant emission rates from biomass stoves during cooking and heating under real-world operating conditions. Moreover, despite the limited number of measurements, our group had extensive local knowledge regarding typical heating and cooking practices in the study region. This allowed us to specifically target activities that were representative of those occurring among the wider population.

Among the activities we found that liquor distillation resulted in the highest emission rates for both $PM_{2.5}$ and CO than other activities. This is because liquor distillation requires a longer time, more fuel and intense heat in comparison to other cooking types, which is reflected in the high pollutant concentrations during this process. Therefore, emission rates were more influenced by the cooking activities than the type of biomass stoves used. Despite H2 and H4 using a similar stove (traditional mud stove), both $PM_{2.5}$ and CO emission rates were two times higher during liquor distillation in H4 than rice cooking in H2. Also among the houses/activities, the mean $PM_{2.5}$ and CO emission rates were the lowest for H3 during fodder preparation, using a stone tripod stove. Unlike liquor distillation, fodder preparation did not require intense heat and proper cooking. However, it should be noted that our results are based on limited data with single measurement per activity. Future studies should conduct multiple measurements and by recruiting more houses. Additionally, it is possible that our estimated emission rates may have been influenced by the type of wood used, as households had access to different wood species for fuels.

Several studies have investigated emission rates when cooking was done using gas and electricity. The comparison of our results with these studies showed that emission rates from biomass stoves were orders of magnitude higher. For example, He et al. (2004) reported the highest median $PM_{2.5}$ and PN emission rates of 2.68 and 2.78 mg/min, and 4.57×10^{11} and 7.34×10^{11} particles/min, respectively during frying and grilling using gas and electric stoves. Similarly, Wallace and Ott (2011) reported mean PN emission rate of 5.11×10^{12} particles/min during cooking using gas stoves. A cooking test conducted in a simulated kitchen using a gas stove reported the highest $PM_{2.5}$ and PN emission rates ranging from 5.2×10^{2} to 1.0×10^{4} µg/min and 2.6×10^{12} to 3.5×10^{12} particles/min, respectively (Buonanno et al., 2009). As expected, these values were 1-2 orders of magnitude lower than the $PM_{2.5}$ and PN emission rates obtained for biomass stoves in the present study.

The recent WHO guidelines for household fuel combustion recommend emission rate targets (ERT) in order to assess how well various interventions can help meet the guidelines (WHO, 2014a). The ERT are based on stove types: for unvented stoves ($PM_{2.5}$ = 0.23 mg/min, CO = 0.16 g/min) and for vented stoves ($PM_{2.5}$ = 0.80 mg/min, CO = 0.59 g/min), respectively, to meet annual and interim target-1 (IT-1) for $PM_{2.5}$, and 24-hour guideline for CO. Our estimated $PM_{2.5}$ and CO emission rates during heating (which constituted emissions from the stove only) exceeded the WHO recommended ERT by several orders of magnitude. The degree of exceedance is likely to be even higher during cooking activities due to contributions from cooking emissions. Improvements are clearly required in both stove efficiency and emission reduction technologies in order to increase the likelihood of these targets being met. Alternatively, a large shift in energy sources towards cleaner fuels may offer the greatest benefit, albeit with many associated logistical and economic challenges.

The WHO guidelines for household fuel combustion also provides practical recommendations for countries to minimize HAP (WHO, 2014a). Recommendations range from the promotion of improved stove design, shifting to clean fuels, improved ventilation, behaviour change, and user education and training. Although improved stove design does not consistently bring down emission levels to the recommended WHO guidelines (for example, $PM_{2.5}$ and CO), past studies in the Himalayan region have shown that it results in a significant reduction of HAP (Li et al., 2012, Singh et al., 2012). This means that the promotion of improved stove design will result in substantial health benefits. For a rural community in Bhutan, shifting to clean fuels (LPG or electricity) will remain a challenge. The prevalence of customary cooking practices, such as liquor distillation and fodder preparation, limit their use as a primary fuel. More importantly, costs associated with electricity and LPG will force people to continue using firewood, which is in abundance and can be collected freely.

Since cooking and heating using firewood are primary indoor activities among rural homes in Bhutan, residents are chronically exposed to extremely high concentrations of combustion products. Concentrations remain elevated above the background levels even after the activities have ceased. Moreover, it was observed that after the cooking, unburnt woods were withdrawn from the combustion chamber and buried in ash within the hearth to save the ember for subsequent cooking. While this procedure sustains the fire source in the kitchen and saves the residents from buying matches, it extends the source emission time after the activity. This is one of the major differences between the use of traditional wood stoves, and gas or electric stoves. Cooking tests in houses in Hong Kong using gas stoves found that one hour after the cooking was sufficient for $PM_{2.5}$ and PN to decay to background levels (Sze-To et al., 2012). Similarly, cooking tests conducted in Brisbane houses using gas and electricity found that $PM_{2.5}$ and PN concentrations declined to background levels within 15 minutes of the conclusion of the activity under normal ventilation and 45 minutes under minimum ventilation conditions (He et al., 2004).

Further, during the investigation, it was observed that women and children who were at home spent their time close to stoves during cooking. Further, the person cooking had to position themselves directly over the fire to access the stove top. This point towards a need for systematic interventions to reduce HAP in Bhutan. The development of improved stoves will need to be backed by adequate training and education for sustained adoption of the device, and to change peoples' behaviour and perceptions. In the past, the promotion of mud chimney stoves in Bhutan was not successful, among other reasons, due to poor maintenance, perceived fire risks, and because traditionally, smoke is needed to dry chilli and grains in the kitchen (DoE, 2005). In Nepal and China, it was found that improved stove design was an appropriate intervention to reduce HAP, but proper education in relation to their operation and maintenance by users was also necessary (Baumgartner et al., 2011, Singh et al., 2012). Additionally, interventions should target the larger community rather than isolated households.

4. Conclusion

As a part of larger air quality investigation in different microenvironments in Bhutan, this study quantitatively characterized biomass stove emissions during cooking and heating in four rural homes during real-world operations. Emission rates of both $PM_{2.5}$ and CO were highest during liquor distillation and lowest during fodder preparation. Notwithstanding the limited data, we found that emission rates were more dependent on the type of activity than on stove type. Despite H2 and H4 using a similar stove, estimated emission rates for both $PM_{2.5}$ and CO were two times lower during rice cooking in H2 than liquor distillation in H4. Compared with gas and electric stoves, emission rates from biomass stoves were a few orders of magnitude higher.

The results of this study highlight a serious public health issue for people living in the villages in Bhutan, and the need for interventions to reduce health risks. Making a shift to clean energy sources in rural areas in developing countries present a significant challenge due to its associated costs and accessibility. Improved stove design, supported by proper education on maintenance and adaption with traditional household practices, would offer substantial reduction in exposure levels.

Further research should ideally: (1) investigate more houses and contributions from other indoor activities, such as incense combustion and lighting oil lamps as a part of religious ceremonies; (2) assess personal exposure for cooks and other family members; and (3) assess short- and long-term health outcomes associated with exposure to combustion products in such indoor environments.

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