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# Indoor Respirable Particulate Matter Concentrations from an Open Fire, Improved Cookstove, and LPG/Open Fire Combination in a Rural Guatemalan Community

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Improved biomass cookstoves have the potential to reduce pollutant emissions and thereby reduce pollution exposure among populations in developing countries who cook daily with biomass fuels. However, evaluation of such interventions has been very limited. This article presents results from a study carried out in 30 households in rural Guatemala. Twenty-four hour $PM_{3.5}$ concentrations were compared over 8 months for three fuel/cookstove conditions ($n = 10$ households for each condition): a traditional open fire cookstove, an improved cookstove called the *plancha mejorada*, and a liquefied petroleum gas (LPG) stove/open fire combination. Twenty-four hour geometric mean $PM_{3.5}$ concentrations were 1560 $\mu g/m^3$ ($n = 58$; 95% C.I. 1310, 1850), 280 $\mu g/m^3$ ($n = 59$; 95% C.I. 240−320), and 850 $\mu g/m^3$ ($n = 60$; 95% C.I. 680−1050) for the open fire, *plancha*, and LPG/open fire combination, respectively. A generalized estimating equation model showed a 45% reduction in $PM_{3.5}$ concentrations for the LPG/open fire combination as compared to the open fire alone. The difference approached significance ($p < 0.0737$). The plancha showed an 85% reduction in $PM_{3.5}$ concentrations as compared to the open fire ($p < 0.0001$). An analysis of the interaction of time with stove type showed that the temporal trend in pollution did not significantly differ among the three stove types. The reduced $PM_{3.5}$ concentrations were maintained over time. Season did not affect pollutant concentrations. Of the two interventions, the plancha appears to offer the best prospects for achieving substantial reductions in indoor air pollution levels, although issues of cost and stove maintenance remain to be addressed.

## Introduction

More than 40% of the world's population relies on unprocessed solid biomass and other solid fuels for their daily household cooking needs (*1*, *2*). The fuels are typically used on unvented, simple stoves leading to levels of indoor air pollution that are among the highest ever measured (*3*). Studies from developing countries report average particulate concentrations that are 10 or more times higher than the U.S. Environmental Protection Agency Standards (*4*, *5*). Exposure to these high levels of pollution has been consistently associated with acute respiratory infections (ARI) (*6*), the largest single-category cause of morbidity and mortality worldwide (*7*). It accounts for approximately 9% of the global burden of disease, 80% of which is in developing country children <5 years of age (*8*). There is also evidence linking exposure to biomass fuel combustion with chronic obstructive lung disease (*9*, *10*), tuberculosis (*11*), cataracts (*12*), and adverse pregnancy outcomes (*13*). The World Health Organization (WHO) has estimated that as many as 2 million people in developing countries die prematurely every year from exposure to the combustion products of household solid fuels (*14*).

Despite the magnitude of the problem, few resources have been allocated to the development and evaluation of interventions aimed at substantially reducing exposures to pollution in these populations. In developed countries, modernization has without exception been accompanied by what has been termed the "post-biofuel transition". This has involved a shift from biofuel use to use of petroleum products (e.g., kerosene, gas) and electric stoves (*15*). In developing countries, on the other hand, even where cleaner more sophisticated fuels are available, households continue to rely on biomass fuels for cooking and heating mainly due to the cost of fuel and appliances. The transition to cleaner fuels is further hindered by a number of socio-cultural factors and practical considerations. The flavor of foods cooked with biomass is sometimes preferred to that cooked with commercial fuels. Biomass fuel cookstoves are also often used for spaceheating and drying of food, fuel, and house building materials (*15*).

Although the transition to cleaner fuels tends to occur naturally with development (movement up the "energy ladder"), the economic situation in the world today suggests that indoor air pollution from biomass fuel combustion will remain a substantial public health problem among a large proportion of the world's population for many decades to come. It is critical, therefore, to find an alternative to the open fire in the interim that not only significantly reduces pollutant concentrations but is economically feasible and culturally acceptable. A number of programs have attempted to do this by introducing improved cookstoves with reduced indoor emissions that are based upon the design of the traditional open fires. This has often been done either by addition of a flue or chimney or by making improvements to the stove's combustion efficiency. Only a handful of studies, however, have evaluated the reductions in pollution achieved by these cookstoves (*16*−*24*).

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In this paper, we present results from an eight-month study carried out in a rural community in the western highlands of Guatemala. Twenty-four hour $PM_{3.5}$ concentrations were compared in households with three common fuel/cookstove conditions: a traditional open fire cookstove, an improved cookstove with flue called the *plancha mejorada* (or improved *plancha*) hereafter referred to as the plancha, and an LPG/open fire combination. Previous studies in the area have shown that the plancha significantly reduces pollutant concentrations under semi-experimental conditions in three test households (*24*). The objective of this study was to determine if these reductions would be observed under real life cooking conditions and whether, with proper maintenance of the planchas, the reductions would be maintained over time. A second objective was to examine the emission reductions achieved by an LPG/open fire combination since recent survey data have shown that LPG stoves are being used increasingly at the study site and that these stoves are rarely used alone, but rather in combination with the open fire (*25*). We discuss which, if any, of these interventions is a viable alternative to the traditional open fire cookstove. This is addressed with regard to its use as a sustainable intervention in rural Guatemala and similar settings and also for a randomized trial being developed in collaboration with the World Health Organization (WHO) designed to measure the effect of a measured reduction in pollution on incidence of acute lower respiratory infections (ALRI) in young children (*26*).

## Methods

**Study Site and Study Population.** The study was carried out in La Victoria, a rural community in the district of San Juan Ostuncalco (pop. 32 000) in the western highlands of Guatemala. The area is mountainous, lying at an altitude between 2000 and 2300 m. The Mam speaking native American people are the main ethnic group living in the area. Households in La Victoria, like those in other rural communities of San Juan, are largely dependent on wood fuel. As of September 1998, 49% of the 867 households in La Victoria used a traditional open fire wood cookstove for all their cooking needs (*25*). Thirty-one percent use the plancha exclusively, and 10% use an LPG/open fire combination. Children in La Victoria and the surrounding communities are typically carried on their mothers' backs at least up to the age of 2 years even while she is cooking. Engle et al. found that in a Kiché-speaking village neighboring La Victoria, women spend on average 5 h a day in the same room with a lit fire (*27*). As a result, women and young children receive substantial exposure on a daily basis. The main source of income for families in the area is from agriculture. Fewer than 2% of women in the area smoke tobacco, and the men who smoke generally do so away from the home. Infant mortality rates are estimated to be approximately 55 per 1000 live births, and acute respiratory infections are the leading cause of infant mortality. Typical homes are made of simple adobe walls, dirt floors, and tile or metal roofs. Few homes have straw roofs, which would hinder the installation of improved stoves with chimneys (*28*). Over the past 20 years, a locally produced improved cookstove called a plancha has been developed in the district of San Juan and other parts of Guatemala. The body of the plancha is made of cinder blocks and bricks. The iron surface has 3−4 potholes filled with several concentric rings that can be removed for placement of pots of different sizes. The plancha, like the open fire, uses wood for fuel, but also has a flue made of metal or cement pipe sections, which allows for removal of most of the smoke from the kitchen (*21*). The plancha mejorada or improved plancha has an improved combustion chamber, as compared to the original plancha, with a baffle to direct the heat toward the second and third potholes at the back of the combustion chamber. Use of the plancha is easy and requires no special manual dexterity. Women accustomed to cooking with an open fire have quickly adapted their cooking skills to the plancha. In addition, by storing heat in its large metal top plate and brick stove body, the plancha provides longer duration space heating than the open fire.

**Measurements and Analysis.** Data for this study were collected between December 1998 and July 1999 covering the dry season and part of the rainy season. A household survey that included information on stove type, stove condition, socio-economic and demographic characteristics was carried out in 184 households in three contiguous hamlets of La Victoria: Los Romeros, Los López, and Centro II. Forty-five percent of these households were found to have existing planchas. Ten households with planchas that did not have noticeable construction flaws and for which two open-fire households could be matched were selected for the study. The households were matched on variables that might confound the relationship between stove type and kitchen pollution levels including home characteristics (used as a proxy for socio-economic status), education level, and household composition. LPG stoves were then offered to (and accepted by) 10 of the 20 open fire households. The LPG stove used, called *El comal*, is an innovative gas stove design based on the traditional *comal*, a large round cooking surface used to cook tortillas. *El comal* has been less tested among the study population than the plancha. However, anecdotal evidence suggests a demand for this type of LPG stove because it has a high-powered burner useful for cooking large quantities of nixtamal (corn for tortillas and tamales). The commonly available LPG stove has low-powered burners that are only useful for preparing small dishes.

Twenty-four hour $PM_{3.5}$ measurements were collected six times in each of the 30 households on a rotation schedule at approximately 1-month intervals using battery operated SKC Aircheck samplers (model 224-PCXR8) and SKC Personal Exposure monitors (PEM model 200) using Zeflour $8 \times 10$ 2 $\mu$m filters. The model 200 SKC PEM was designed for a cut-point of 2.5 $\mu$m at 4 L/min. The pumps were run every third minute for 24 h at a flow rate of approximately 2 L/min to avoid equipment failure due to filter saturation. Using a flow rate of 2 L/min, the approximate cut-point is calculated by dividing 2.5 $\mu$m by the square root of 2. The result is approximately 3.5 $\mu$m (*29*). Field blanks and collocated samples were used to estimate the limit of detection and precision, respectively, of the sampling method.

The samplers were placed at a height of 1.25 m, roughly at the breathing zone of the women (and of the young children carried on their mothers' backs) and at a distance of 1 m from the outside perimeter of the stoves. Where possible, they were placed at least 1.5 m from the doors and windows. Flows were measured before and after sampling using a 1-L buret bubble tube connected upstream of the PEM inlet. Sample durations were recorded by the SKC pumps. To adjust the concentrations to standard temperature and pressure conditions, daily average ambient temperature and atmospheric pressure data were collected from the national meteorological institute (INSEVUMEH). The air pollution filters were analyzed gravimetrically using a micro-balance at the University of San Carlos air quality laboratory in Guatemala City. The fieldwork was carried out by local Mam bilingual fieldworkers who were trained by the fieldwork supervisor.

The air pollution filters were analyzed gravimetrically using a micro-balance (0.00001 precision) at the University of San Carlos air quality laboratory in Guatemala City. The filters were first placed in a constant temperature oven (25 °C) for 24 h and then in a desiccation chamber for 24 h prior to both on and off weighing. Filters were placed in sealed Petri dishes during transport and storage.

Stove users in the LPG intervention households were given a brief training (about 1 h) on the safe and effective use of the gas stoves. An expert stove mason inspected the integrity of each plancha three times during the study and when a problem was observed, the stove was repaired. The field staff also briefly inspected the condition of the stoves in conjunction with air sampling visits.

The association of $PM_{3.5}$ concentrations with stove type (open fire was the reference), time (coded 0−5 and treated as continuous), ventilation (low, medium, high), season, and kitchen volume was evaluated using generalized estimating equations (GEE) to account for correlations between $PM_{3.5}$ measurements taken in the same households. Two- and three-way interactions were also included in the model, specifically to examine any differences in pollution over time among the three stove types. We controlled for potential confounding by the matching variables by including them as fixed effects in the analysis. The analysis was carried out using the SAS procedure GENMOD. To improve normality and variance homogeneity, log-transformed $PM_{3.5}$ concentrations were used. Time period was included as a continuous variable to examine temporal changes in concentrations. The matching variables, with the exception of kitchen volume, season, and ventilation were not significant and therefore not included in the final model. The interaction of time period and stove type, while not significant, was included in the final model because these were the primary variables of interest. P-values <0.05 were considered significant. The highest measurement of 16 561 $\mu g/m^3$ was for an open fire household and was not included in any of the analyses. Although we believe this value may potentially be an influential observation rather than an outlier, it is not representative of the values observed for the other 57 open fire measurements. The interpretation of the results, however, was the same with and without this value.

## Results and Discussion

Table 1 presents the key matching characteristics for households in the three cookstove conditions: open fire, plancha, and LPG/open fire combination. Socio-economic status, as proxied by floor type, wall material, and roof material, was essentially the same in each of the three groups. Level of maternal education was also similar. The percent of fathers with no education was slightly higher among the plancha households as compared to the other two groups. The biggest difference among the groups was in kitchen volume, which was controlled for in the GEE model.

During the plancha maintenance surveys, several signs of stove deterioration were observed. The repairs performed as a result of these problems included replacement of six chimneys due to corrosion and deformation, replacement of two plancha disks due to cracking, and repair of four stove bodies.

Table 2 presents descriptive statistics for $PM_{3.5}$ concentrations for the three cookstove conditions. The geometric mean concentrations were 1560 (95% CI: 1310, 1850), 280 (95% CI: 240, 320), and 850 (95% CI: 680, 1050) for the open fire, plancha, and LPG/open fire combination, respectively. As shown in Figure 1, geometric mean concentrations did not show any clear trend across the six time periods for any of the stove types and the relative levels for the three types were consistent across time periods. Table 3 presents the GEE model for the association of concentration with stove type and time period (i.e., time), controlling for kitchen volume. The model shows a 45% ($1 - \exp^{\text{estimate}}$) reduction in $PM_{3.5}$ concentrations for the LPG/open fire combination as compared to the open fire alone. The difference approached significance ($p < 0.0737$). The plancha shows an 85% ($1 - \exp^{\text{estimate}}$) reduction in $PM_{3.5}$ concentrations as compared to the open fire. This difference was highly significant ($p < 0.0001$). The interaction of time period with stove type, used to look at temporal changes in stove type concentrations, showed that the trend in cookstove emissions did not significantly differ among the three cookstove combinations. On average, the emissions increased slightly from one time period to the next for the open fire and plancha (average unit time increase of 3 and 7%, respectively), but the increase was not significant. For the LPG/open fire combination, emissions slightly decreased (average logarithm decrease of 0.04), but this was also not significant. Volume showed a highly significant negative association with $PM_{3.5}$ concentrations ($p < 0.0003$) with an approximately 1% decrease in pollutant concentrations for every unit increase in volume.

Results from this study build upon previous work on the plancha at the study site (*19, 21, 22, 24*). The motivation for evaluating the plancha as a potential exposure reduction technology has been 2-fold: first, as a potential long-term sustainable alternative to the open fire for the people of the western highlands of Guatemala, most of whom cannot afford

**TABLE 1. Household Matching Characteristics for the Open Fire, Improved Cookstove, and Gas/Open Fire Combination**

| variable | open fire ($n = 10$) | improved cookstove ($n = 10$) | LPG ($n = 10$) |
|---|---|---|---|
| | | (%) | |
| floor type | | | |
| dirt | 70 | 70 | 70 |
| cement | 30 | 30 | 30 |
| mother's education | | | |
| none | 90 | 90 | 70 |
| 0−3 yrs | 10 | 10 | 30 |
| 4−6 | | | |
| father's education | | | |
| none | 60 | 80 | 50 |
| 1−3 yrs | 30 | 10 | 30 |
| 4−6 | | | 10 |
| no father | 10 | 10 | 10 |
| wall materials | | | |
| adobe | 90 | 90 | 90 |
| block | 10 | 10 | 10 |
| roof material | | | |
| corrugated tin | 100 | 80 | 100 |
| tile | | 10 | |
| thatched | | 10 | |
| | | Mean ± SD | |
| kitchen volume ($m^3$) | 37.0 ± 20.7 | 29.0 ± 15.3 | 25.9 ± 13.1 |
| household size | 6.5 ± 2.5 | 6.6 ± 1.7 | 6.9 ± 1.9 |
| crowding[a] | 4.8 ± 2.6 | 5.6 ± 2.3 | 5.5 ± 1.1 |

[a] Defined as the number of people living in the household divided by the total number of rooms in the home (including the kitchen).

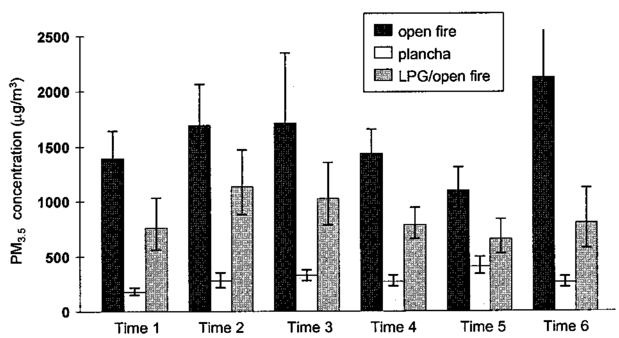


**FIGURE 1. Geometric mean $PM_{3.5}$ concentrations ($\mu g/m^3$) and 95% confidence intervals for the open fire, plancha, and LPG/open fire combination by time period.**

**TABLE 2. Twenty-four hour $PM_{3.5}$ ($\mu$g/m$^3$) Concentrations for the Open Fire, *Plancha*, and Gas/Open Fire Combination**

| stove type | $N$[a] | mean ± SD | geometric mean (95% CI) | median | range |
|---|---|---|---|---|---|
| open fire | 58 | 1930 ± 1280 | 1560 (1310, 1850) | 1630 | 300−6750 |
| plancha | 59 | 330 ± 220 | 280 (240, 320) | 270 | 50−1130 |
| LPG/open fire | 60 | 1200 ± 1080 | 850 (680, 1050) | 780 | 125−5510 |

[a] *N* refers to the total number of observations for the 10 households in each cookstove condition.

**TABLE 3. Generalized Estimating Equation Model for the Effect of Stove Type (Open Fire Is the Reference), Time Period (Treated as Continuous), and Kitchen Volume on $PM_{3.5}$ ($\mu$g/m$^3$) Concentrations[a]**

| variable | estimate | 95% CI | p-value |
|---|---|---|---|
| intercept | 7.68 | (7.15,8.22) | 0.0000 |
| stove | | | |
| LPG/open fire | −0.60 | (−1.26,0.06) | 0.0737 |
| plancha | −1.92 | (−2.49,−1.36) | 0.0001 |
| time period | 0.03 | (−0.03,0.10) | 0.3578 |
| stove/time period interactions | | | |
| time period*LPG | −0.07 | (−0.18,0.04) | 0.2075 |
| time period**plancha* | 0.04 | (−0.04,0.13) | 0.3353 |
| volume | −0.01 | (−0.02,−0.00) | 0.0003 |

[a] Estimates are based on log-transformed $PM_{3.5}$ concentrations to improve normality and variance homogeneity.

cleaner fuels; second, as a potential intervention for a randomized trial on the relationship between ARI and pollution exposure. There are a number of criteria the improved cookstove must fulfill for it to be suitable for either purpose.

First, since stoves and cooking habits have such an important place in a culture, the improved cookstove must be culturally acceptable so that it is actually used. In 1994, an improved cookstove initiative was begun in San Juan by the national Social Investment Fund (FIS) of Guatemala to promote the use of the plancha. As part of the program, FIS paid contractors to build the planchas. A focused ethnographic study (FES) carried out in the same population where the FIS program was active showed that the plancha is culturally appropriate and highly valued by families (*30*). The women easily accepted and had no difficulty using the plancha. It was better accepted than the LPG stoves because it is more practical than the LPG stove for carrying out the full range of cooking tasks and space heating.

In addition to being acceptable, the cookstove must significantly reduce pollutant concentrations. Three prior studies carried out in the same area provide additional evidence on the reductions achieved with the planchas in everyday and experimental conditions. These studies are summarized in Table 4.

Mean concentrations for the plancha in the present study and in the first cross sectional study were relatively high as compared to those observed in the study of the three test households (*19*, *24*). Concentrations were also higher than the second cross sectional study. The higher concentrations in the first cross sectional study may be because $PM_{10}$ was measured rather than $PM_{2.5}$ or $PM_{3.5}$. Another possible explanation is that only stoves in relatively good condition were chosen for the current study, while in the first cross sectional study, a high proportion of planchas were in a functionally inadequate state having been poorly made, installed, and maintained. The fact that concentrations in this study were higher than in the second cross-sectional study may be due in part to the fact that almost half of the data collection period for the current study took place during the coldest winter months. Data for the second cross-sectional study were collected during the summer months (March−August) when homes tend to be better ventilated resulting possibly in lower indoor concentrations. Despite the differences in pollutant concentrations among studies, all showed substantial reductions in pollutant concentrations with the plancha as compared to the open fire. Even with the substantial reductions observed, there is a wide range of pollution levels, the lower end comparable to levels experienced in the developed country setting and the high end overlapping with levels seen for the open fire.

In the current study, homes using gas had mean levels of pollution between those for the plancha and the open fire, although they did not significantly differ from concentrations in the open fire households. This is because households supplement gas stove use with the open fires for space heating and some cooking tasks. The main reason reported is that it takes too long to cook certain items on the gas stove. In addition, many of the older women do not feel comfortable with the technology. The gas stove is often used for the quick cooking tasks such as frying eggs or heating water for coffee or *atol* (a thick grain beverage). The longer cooking tasks such as cooking *nixtamal* (corn for tortillas and tamales) are

**TABLE 4. Summary of Previous *Plancha* Studies in Study Area: 24-h Mean Particulate Concentrations and Key Characteristics of Studies[a]**

| | mean ± SD [$N$][b] | | | |
|---|---|---|---|---|
| | open fire | plancha | LPG | key characteristics of previous pilot studies |
| $PM_{10}$ ($\mu$g/m$^3$) (*19*) | 1210 ± 726 [23] | 520 ± 572 [25] | 140 ± 56 [12] | 60 household cross-sectional study of emissions from in situ open fires, *planchas*, and gas stoves (gas stove not used in combination with open fire as in current study) |
| $PM_{2.5}$ ($\mu$g/m$^3$) (*24*) | 520 ± 260 [3 × 3] | 88 ± 62 [3 × 3] | 45 ± 23 [3 × 3] | three test households under carefully managed experimental conditions − measured emissions from in situ open fires, newly installed *planchas*, and in situ gas stoves (gas stove not used in combination with open fire as in current study) |
| $PM_{2.5}$ ($\mu$g/m$^3$) (*22*) | 868 ± 520 [17] | 152 ± 120 26] | | 50 household cross-sectional study of emissions from in situ open fires and *planchas* |

[a] Modified from Naeher et al., 2000 (*24*). [b] *N* is the number of households. For the test household study, there were three households with three measurements taken in each household.

done on the open fire, and pollutant concentrations are extremely high. The fact that the first cross sectional study showed the lowest concentrations among gas stove users and intermediate concentrations for plancha users is because the objective of that study was to assess emissions from the gas stoves alone, and households were instructed not to use the open fire during the measurements.

The study in the three test households (*24*) showed that the plancha can reduce emissions to low levels, lower than those observed in the cross sectional studies and the current study, but only under semi-experimental conditions with newly installed stoves, careful supervision, and over a short time period in a small number of households. It remained unclear whether the stoves would work as well under less controlled, real life conditions and whether, with proper training in maintenance, the reduced pollutant concentrations would be maintained over time. In fact, none of the three previous pilot studies examined whether the plancha has the capacity to maintain low pollution emissions. The present study has shown that under real life, nonexperimental conditions, and with proper maintenance, concentrations remained low over 8 months. While on average there was a slight increase in concentrations from one time period to the next, it was not significant and did not differ significantly from the trend seen for the open fire or LPG/open fire combination, neither of which showed significant changes over time.

Given the current socio-economic circumstances of these rural households, the LPG option does not appear to offer these communities a substantial pollution advantage over the traditional open fire due to the continued supplemental use of the fire. It is possible that further development work with the communities on both stove technology and patterns of use could yield greater reductions in air pollution, but it seems unlikely that LPG can meet all cooking and heating needs while remaining affordable. LPG thus does not seem to offer a suitable option for an intervention study, since continued use of the open fire may not yield large enough reductions in exposure.

The plancha, on the other hand, appears to offer a practical option for both routine longer-term use in these rural areas as well as a discrete and effective means of reducing pollution for the proposed randomized intervention. It shows significant and substantial reductions in pollutant concentrations as compared to the open fire. The findings suggest that with proper maintenance and supervision, these reductions are maintained over time. With new, well-designed and properly maintained stoves, we would expect pollutant concentrations to remain within the range observed in the test household study, levels that are appreciably lower than those observed in the current study in which already existing planchas were used. The plancha thus would seem to be appropriate as a long-term sustainable alternative to the open fire. However, cost and availability of the plancha must also be considered.

The materials to build planchas are easily available in San Juan and the surrounding districts. In addition, there are a large number of masons experienced in stove construction in the San Juan area. At about US$200, however, it remains prohibitively expensive for most people in this area. Indeed cost has been reported to be the main reason that most families have not made the change. When the FIS program was helping families purchase the stove, it was quickly adopted by many households in the community even though it required a large time commitment for gathering materials, attending training, and doing the construction. While many in the communities value the plancha and would be willing to contribute toward its purchase, it seems that some form of financial assistance and/or credit arrangement will be required to achieve wide coverage in poor areas.

Before subsidies for the plancha could be recommended, a number of issues require further investigation. The current study has shown that with proper maintenance, pollutant concentrations remain low over time. The stove inspections and repairs required during this study, however, suggest that the planchas deteriorate both because they are not properly maintained and because of material and construction flaws. Cost may be one reason households seem not to properly maintain stoves, but more study is needed. Economic analysis of costs and benefits (including health, environment, social, and women's well-being, etc.) is also required to assess the relative benefits of investment in stoves as compared with other possible health and development initiatives. Issues of sustainable development and involvement of communities, households, and women in particular and the development of a sense of ownership among plancha users need to be considered as well.

There were a number of limitations to this study. It would have been useful to extend it beyond eight months to examine whether the plancha can maintain the reduced levels of pollution over a longer time period. It would also be valuable to follow newly installed planchas since this would allow control over construction and materials. Finally, although we measured pollutant concentrations, we did not examine actual human exposures. To fully understand the health implications of using the plancha, it is important to also examine patterns of exposure.

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## Literature Cited

(1) Reddy, A. K. N.; Williams, R. H.; Johansson, T. B. *Energy after Rio: Prospects and Challenges*; United Nations Publications: New York, 1997.

(2) World Resources Institute; UNEP; UNDP; World Bank. *1998–99 World Resources: A Guide to the Global Environment*. Oxford University Press: 1998.

(3) Smith, K. *Annu. Rev. Energy Environ.* **1993**, *18*, 529–566.

(4) Smith, K. R.; Aggarwal, A. L.; Dave, R. M. *Atmos. Environ.* **1983**, *17*, 2343–2362.

(5) Albalak, R.; Keeler G. J.; Frisancho A. R.; Haber, M. J. *Environ. Sci. Technol.* **1999**, *33*, 2505–2509 1999.

(6) Smith, K. R.; Samet, J. M.; Romieu, I.; Bruce, N. *Thorax* **2000**, *6*, 518–532.

(7) Smith, K. R.; Corvalán, C. F.; Kjellström, T. *Epidemiology* **1999**, *10*, 573–584.

(8) Murray, C. J.; Lopez, A. D. *Global Burden of Disease*. Harvard School of Public Health: Cambridge, 1996.

(9) Albalak, R.; Frisancho, A. R.; Keeler, G. J. *Thorax* **1999**, *54*, 11, 1104–1108.

(10) Perez-Padilla, J. R.; Regalado, J.; Vedal, S.; Pare, P.; Chapela, R.; Selman, M. *Am. J. Resp. Crit. Care Med.* **1996**, *154*, 701–706.

(11) Mishra V. K.; et al. *Int. J. Infect. Dis.* **1999**, *3*, 3, 119–129.

(12) Mohan, M.; et al. *Arch. Opthalmol.* **1989**, *107*, 670–676.

(13) Mavlankar, D. V.; Trivedi, C. R.; Gray, R. H. *Bull. WHO* **1991**, *69*, 435–442.

(14) World Health Organization. *Health and Environment in Sustainable Development*, Geneva, World Health Organization, 1997.

(15) Smith, K. R. *Biofuels, Air Pollution and Health: A Global Review*. Plenum Publishing Corporation: New York, 1987.

(16) Reid, H. F.; Smith, K. R.; Sherchand, B. *Mountain Res. Dev.* **1986**, *6*, 4, 293–304.

(17) Pandey, M. R.; Sharma, P. R.; Gubhaju, B. B.; Shakya, G. M.; Neupane, R. P.; Gautam, A.; Shrestha, I. B. *Ann. Trop. Paediatr.* **1989**, *9*, 4, 212–220.

(18) Ramakrishna, J.; Durgaprasad, M. B.; Smith, K. R. *Environ. Int.* **1989**, *15*, 341−352.
(19) Smith, K. R.; Liu, Y.; Rivera, J.; Boy, E.; Leaderer, B. P.; Johnston, C. S.; Yanagisawa, Y.; Lee, K. *The Proceedings of Indoor Air '93: The 6th International Conference on Indoor Air Quality and Climate*, Helsinki, Finland, 1993; Vol 1, pp 441−446.
(20) Ballard-Tremeer, G. Jawurek, H. H. *Biomass Bioenergy* **1996**, *11*, 5, 419−430.
(21) McCracken, J. P.; Smith, K. R. *Environment Intl.* **1998**, *24*, 739−747.
(22) Naeher, L. P.; Smith, K. R.; Leaderer, B. P.; Mage, D.; Grajeda, R. Proceedings of Indoor Air '99: The 8th International Conference on Indoor Air Quality and Climate, Edinburgh, Scotland, 1999; Vol. 3, pp 124−129.
(23) Ezzati, M.; Mbinda, B. M.; Kammen, D. M. *Environ. Sci. Technol.* **2000**, *34*, 578−583.
(24) Naeher, L. P.; Leaderer, B. P.; Smith, K. R. *Indoor Air* **2000**, *10*, 200−205.
(25) Unpublished data collected concurrently with this study.
(26) Bruce, N.; Neufeld, L.; Boy, E.; West, C. *Int. J. Epidemiol.* **1998**, *27*, 454−458.
(27) Engle, P. L.; Hurtado, E.; Ruel, M. *Hum. Organization* **1997**, *56*, 4, 408−417.
(28) Hostnig, R. Monografia del Municipio de Ostuncalco: Quatzaltenango. Centro de Capacitación e Investigación Campesina, 1991.
(29) Hinds, W. C. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*. John Wiley & Sons: New York, 1982.
(30) Grajeda, R.; de la Roca, P.; Ruel, M. T.; Hurtado, E. Institute of Nutrition of Central America and Panama: Guatemala, 1994.
(31) Boy, E.; Bruce, N.; Smith, K.; Hernandez, R. *Energy Sustainable Dev.* **2000**, *2*, 2, 21−29.

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