Impact of "Patsari" improved cookstoves on Indoor Air Quality in Michoacan, Mexico

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Abstract

Little quantitative monitoring and evaluation of the impacts of improved stoves has been performed in Mexico. GIRA has recently disseminated 4,000 improved Patsari cookstoves, most of them in the Purepecha region of Michoacan state, Mexico. In paired comparisons in a sub-set of kitchens in a single community before and after installation of an improved Patsari cookstove, 48-hour average kitchen concentrations of carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) were reduced by 66% (n=32) and 67% (n=33), respectively. Kitchens that had more elevated concentrations during the baseline measurements demonstrated more dramatic reductions, as the overall variability was reduced when the improved stove was used. Thus the Patsari stove provides an effective means of reducing kitchen air pollution and potential benefits of installing these stoves are considerable. Although requiring significant additional resources, the HEH project catalyzed a much broader investigation into

health, climate, environment and societal impacts of Patsari stoves, which has had a greater impact on public policy than the direct impact of the number of improved stoves installed in these communities.

1.0 Introduction

There is strong evidence for the role of biomass smoke from unvented household stoves in developing nations in acute lower respiratory infections including pneumonia in children aged under 5 years and chronic obstructive pulmonary disease in adult women (Bruce, et al., 2000; Smith, Mehta et al., 2004). The prevalence of these health impacts reinforces the critical need for well received interventions that effectively reduce exposures in rural populations. Although a number of improved cookstove technologies have the potential to significantly reduce emissions to the indoor environment, exposure reductions have often not been realized in practice due to barriers of cost, suitability for cooking tasks, and acceptance by local populations.

Although Mexico has experienced considerable economic growth and development, almost 80% of the rural population, or about 27 million people, depend on wood for cooking, heating and other domestic tasks (Masera et al., 2005) resulting in significant exposure of the rural population to pollutants in wood smoke. Fuelwood still provides approximately 80% of energy used by rural households and 50% of total energy use in rural communities (Diaz 2000), representing a considerable expenditure accounting for on average 15-20% of household income in rural Mexican communities (Masera and Navia, 1997). As with many other rural communities worldwide, women are most exposed to pollutants from wood smoke during cooking. In Mexican rural homes making tortillas represents more than half of daily fuelwood consumption, and women spend between two and four hours per day on this task in close proximity to the stove, breathing smoke. Women that have home industries making tortillas to sell, which can be up to 20% of women in some communities, may spend as many as eight hours per day in these conditions (Masera, 1995).

Although installing a vented cookstove is often assumed to mitigate air pollution exposures associated with open fires, in practice the situation is often more complicated, especially during transitional phases of technology adoption, where households frequently retain traditional stoves for specific cooking tasks, or use multiple fuels and stoves depending on prices, seasons and availability (Edwards et al., 2007). The need to monitor the actual improvements in indoor air quality in homes in rural communities as a result of installation of improved stoves is therefore critical in assessment of the benefits of the improved stove. Although improved stoves have been promoted in Mexico for 15 years primarily for wood saving and reduction in deforestation (Masera et al 2000), there has been little systematic evaluation of the improvements in air quality in rural homes as a result of improved stoves. The current study begins to address this shortfall as part of the Household Energy and Health project.[1]

1.1 Traditional Stoves in Michoacan

Cooking in this region of Mexico is typically performed on open fires surrounded by three stones (TSF) and open fires with U-shaped surrounds usually built by the users out of mud or clay. Although these devices take the form of an "U" or horseshoe, and "enclose" the fire to a certain extent in what might be considered a combustion chamber, they do not possess a flue or chimney to transport the smoke that is generated from the kitchen. Although highly polluting and often fuel inefficient, the versatility of the open fire is much appreciated. It can be made easily, anywhere, anytime, by anyone, at nearly zero cost; uses fuel of nearly any size; and requires no long-term maintenance (Troncoso et al., 2007).

1.2 The "Patsari" improved wood burning stove[2]

The Patsari was developped by GIRA A.C, a Mexican NGO working with local groups and communities in the development, adaptation, and dissemination of biomass energy, agroecology, and community (social) forest management technologies and micro-enterprises since 1987.[3] GIRA is the leading Mexican NGO focused on wood-burning cookstove development and dissemination and has received several awards including a national forest conservation prize in 2001 and the Ashden Award on Health and Welfare in 2006[4]. At the policy level, GIRA has advised more than 50 other NGOs and government agencies on biomass energy and cookstove dissemination.

The Patsari stove was developed with a participatory approach to meet cooking needs, reduce wood consumption, vent smoke outdoors and to be acceptable and affordable to local populations. The Patsari departs from a modified Lorena cookstove that was previously disseminated in Mexico and has the following improvements: (1) optimized design of the combustion chamber and tunnels, (b) custom-designed parts for durability, including a metal chimney support and a ceramic stove entrance; and (3) reduction in construction time and standardized inner dimensions. The cookstove is made in approximately 2 hours with the aid of a metallic mould that ensures that critical dimensions are maintained. Two models were originally disseminated, with one or two entrances to feed fuelwood, respectively. The former has one combustion chamber and uses a metal ''comal'' of 52 cm diameter[5] for cooking tortillas and is preferred by mixed fuelwood-LPG users. The second Patsari model has two combustion chambers. The main one usually supports a ceramic comal (preferred by other users) for making tortillas. The smaller chamber has a metal comal of 35 cm diameter designed for cooking other dishes, such as beans, and other tasks, such as boiling water. Both Patsari models include tunnels that conduct the combustion gases to secondary chambers used for ''low power'' cooking tasks, such as keeping food warm or warming water. Each chamber includes baffles to improve heat transfer between the comal and the gases, but does not have a grate.

The body of these two original Patsari models is made of a mixture of sand and mud and a small amount of cement. Two new stove models have been recently developed, which are intended to cover on the one hand, the needs of tortilla-making vendors (Patsari-tortillera) and to provide more durability and less maintenance (Patsari-brick). All the materials for the four models are available locally; the custom-made stove parts are also manufactured by local small industries.

1.3 Dissemination Program in the Purepecha region

A total of 4,000 stoves have been disseminated by GIRA, mainly in the Purepecha Region of Michoacan, Central Mexico, but also in eight other Mexican States. Figure 1 shows a conceptual diagram of the integrated stove development and dissemination approach used for the Patsari, which relies on a user-centered approach that seeks sustainable market-based operation at the regional level. GIRA acts as a facilitating agent and also conducts the overall monitoring and quality assurance of the dissemination process.

Stove monitoring and evaluation has been a critical component of the stove dissemination process since inception of GIRA's rural energy program fifteen years ago, as this was recognized as an integral element within a dynamic process of stove innovation, development, and dissemination. More recently monitoring and evaluation was recognized by both funding and government agencies as critical in evaluating the benefits of stove projects in a scientifically acceptable manner and took an even more prominent role within the Patsari project. Schematically, laboratory tests, field trials and pilot tests of prototypes through participation of user's groups provided direct feedback to stove design. Subsequently field trials and field monitoring within communities provide direct feedback in a cyclic process to both the stove design and the stove dissemination process through communities. To monitor the adoption process in communities, GIRA records all Patsari stoves installed in an electronic database including relevant data on stove construction as well as aspects related to stove adoption such as actual stove and fuel usage patterns, and maintenance and repair actions.

In the Patsari project, five monitoring and evaluation areas were identified to document both the major impacts of the Patsari stove and to inform on the stove innovation-dissemination chain. Table 1 presents summary information on the areas monitored and sampling procedure (GIRA, 2006).This represents a unique effort to have a broad understanding of rural dynamics and potential benefits of the technology dissemination and adoption process and included monitoring health impacts in a 600 household study (Riojas et al., 2007), an indoor air pollution survey (Amendariz Arnez et al., 2007), a stove performance study (Berrueta et al., 2007; Bailis et al., in this volume), a social perceptions study (Magallanes, 2006), and studies on fuelwood renewability (Ghilardi et al., 2007) and GHG emissions (Johnson et al., 2007).

2.0 Data and Methods

2.1 Study Site Description

In the Purepecha region of the central Mexican highlands in Micahoacan, 15 municipalities were selected where reliance on biomass fuels for primary energy provision was over 80% (Masera et al 2005). From these municipalities, 600 homes were randomly selected in 6 Purepecha communities for participation in a community intervention trial of the effects of the improved Patsari stove on respiratory health effects where families were randomly selected into intervention and control groups. The study sample for investigation of the effects of the Patsari stove on indoor air quality (IAQ) was selected from the intervention group in the health study in one municipality, Comachuen, a remote indigenous agricultural community of 4,300 habitants located 2,600 meters above sea level. Comachuen was selected as a large percentage of families rely on TCS and wood for cooking (98%) and there has been relatively little technology penetration in the community.

2.2 Study Design

Investigation of the IAQ effects of the Patsari used a paired before and after study design in which baseline monitoring was performed for 48-hours with the traditional stove, and repeated later in the same season 1 month after installation of the Patsari and later (Edwards et al., 2007 in this issue). Sample size was estimated based on a 10-home pilot assuming a coefficient of variation of 0.7 and a desire to detect at least a 40% change in $PM_{2.5}$ and CO concentrations after installation of the Patsari. Although a sample size of approximately 40 would have been sufficient to observe such differences, a sample size of 60 was selected to account for drop outs, those that did not install or were delayed in installing the improved stove, were unable to be located, migrated for work, or modified or otherwise had trouble with the normal functioning of the stove.

2.3 Household Selection

As with many rural areas where housing is not standardized, a wide range of different stove and kitchen configurations were encountered in the Purepecha region. Since measurements of all kitchen types and stove arrangements were not feasible given the sample sizes required to adequately represent all arrangements, a household screening survey was used to restrict kitchens to the more common arrangements in the region with the following criteria: enclosed by four walls, not shared between families, cooking used wood in TCS, families contained between 5-9 members and participating women stated a desire to use Patsari stove after intervention. Most kitchens in Comachuen have wooden walls, a laminated roof and around half have electric lighting. Human subject approvals were obtained from the University of California, Irvine and from participating institutes in Mexico.

2.4 Indoor Air Pollution Monitoring

Particulate mass ($PM_{2.5}$)[1] and carbon monoxide (CO) was assessed in the kitchen, both before and after the introduction of the Patsari stove, at 1-minute intervals over 48 hours at a standardized height of 1.25 m above ground, 1 m distant horizontally from the central combustion zone, and at least 1.5 m from windows and doors.

Particulate matter was monitored using the UCB particle monitor (UC Berkeley, Berkeley, CA), a light scattering nephelometer developed for use in rural biomass burning households (Edwards et al 2006). While the UCB does not select a traditional cutoff point, the photoelectric sensor is most sensitive to particles less than 2.5 µm in aerodynamic diameter ($PM_{2.5}$) (Litton 2004), and has demonstrated good agreement with gravimetric $PM_{2.5}$ samples in field validation studies in rural homes (Chowdhury et al 2007). UCB were adjusted for inter-instrument sensitivity through controlled tests in a combustion chamber at the field office in Mexico (Chowdhury et al., 2007), and calibrated for mass response to aerosols using co-located $PM_{2.5}$ gravimetric filter samples collected in kitchens (Amendariz-Arnez et al., 2007). Average percentage difference in mass estimates between duplicate UCB samples was 14%, with good agreement between different UCB monitors (Amendariz-Arnez et al., 2007).

Carbon monoxide was monitored using electrochemical CO sensors (HOBO® Onset Corporation Inc., Bourne, MA). CO sensors were calibrated for inter-instrument sensitivity using gas calibration standards (0.5, 10, 25, and 60 ppm) prior to use in the study, and checked for response during 4 controlled combustion chamber co-locations during the course of the study (collocated with UCB particle monitors).

[1] $PM_{2.5}$ refers to particles that have a settling velocity less than a spherical particle with a diameter of 2.5 microns (aerodynamic diameter). In general the vast majority of combustion particles are less than 1 micron in diameter, and smaller particles are thought to have greater health impacts.

Both instruments contain dataloggers, which store the minute-by-minute data over the entire measurement period in their memories. These data are downloaded into a personal computer after monitoring.

2.5 Household Post-Monitoring Questionnaires

Structured interviews with the cook in the household were conducted in Spanish at the end of the monitoring period to collect information on home and kitchen characteristics, stove use, fuel type, and other potential sources of PM and CO.

3.0 Results

3.1 Household Characteristics

Most homes had between 3-5 rooms and almost all had electricity and piped water for kitchens and bathrooms. Although kitchens with 4 walls were selected there was still considerable variability in housing construction in houses that participated in this indoor air quality study, although the kitchens were more similar. The vast majority of kitchens had roofs of corrugated compressed particle board (approximately1/4 in thick, laminated on the outside to seal against water) with wooden walls and 68% had earthen floors, 19% concrete floors and 12 % wood floors. 75% of homes had no windows in the kitchen and 25% had a single window, although most left the door open while in the kitchen. Approximately 76% of kitchens originally had the u-shaped traditional stove with the remaining 20% with 3-stone fires.

Similar to many rural areas worldwide, cooking is invariably done by women, and typically women, who are not cooking items to sell, reported spending 4 hours per day cooking, which was reduced on average to 3.5 hours after installation of the Patsari. Although those that prepare tortillas to sell may spend 8 hours or more per day cooking, these homes were not included in the current study. As the women in these homes are exposed to high concentrations for long periods, however, a type of Patsari stove has been developed specifically to mitigate these exposures. Time spent cooking does not appear to be correlated to family size within this sample, although recall activity diaries may not have sufficient resolution to observe such differences. Rather, hours of cookstove use per day appears to be more influenced by frequency of meals and specific dishes cooked. For example, 71% reported cooking foods 3 times a day, with 25% cooking 2 times a day, and 25% reported making tortillas once per day, 64% twice per day and 11% three times per day, leading to large variability in hours spent cooking. On average 43% of the time was spent cooking food with the traditional stove, 34% was spent making tortillas and 23 % was spent frying food. In addition when *nixtamal*, the maize meal base for making tortillas, is prepared approximately once a week, or beans and stews are prepared, cooking would be longer, and all homes reported using stoves to heat water. Gas usage even if the homes had gas stoves was infrequent and a single cylinder usually lasted more than 3 months. Although rural families spend a considerable fraction of their income on cooking in rural Mexico, these families in Comachuen did not purchase woodfuel but collected it from nearby areas. In the vast majority of homes, wood was collected from local areas principally by the husband once or twice each week taking between 1-4 hours. Trash was not burned and automobile traffic was relatively infrequent for most homes.

3.2 CO & PM Monitoring

Figures 4a and b demonstrate typical reductions in PM2.5 and CO in kitchens during a 48-hour monitoring period before and after Patsari installation. Times that the stove was lit during the day are clearly identifiable, and start at 9.30 am with the preparation of morning meal. The evening meal is typically the large meal as the husbands are away at work during the day. The cooking fires generally stay lit through 11pm when they are left to die down. For both PM2.5 and CO dramatic reductions are seen with the installation of the Patsari stove.

Further reasonably good agreement can be seen between CO and PM2.5 peaks during the 48-hour period. The CO and PM peaks occur together, as would be expected since both pollutants are produced during combustion. Since CO and PM are produced to different degrees during flaming and smoldering combustion, the relationship between the two on a short time frame is not exact, although they correlate well over 48-hour periods (Figure 5).

Table 2 shows the reductions in CO and $PM_{2.5}$ concentrations from paired comparisons before and after installation of the Patsari in 33 homes. Although some women continued to use a traditional stove in the same room, or in the yard, CO and $PM_{2.5}$ concentrations were still significantly reduced by 66% and 67% respectively compared to the traditional TCSs. In addition figure 6 shows boxplots of the distributions of kitchen CO and $PM_{2.5}$ concentrations for homes before and after installation of the Patsari. In these paired comparisons in the same homes, there was no overlap of values between the 25^{th} and 75^{th} percentiles before and after installation of the Patsari, showing reductions across the range as a result of the Patsari stove. In order to look at individual differences across houses Figure 7 shows a comparison of the individual kitchen reductions in relation to the average 48-hour concentrations measured with the traditional open fire stove types. Figure 7 shows clearly that the magnitude of the reduction in each kitchen was closely related to the initial baseline levels with the TCS, with greater reductions in homes that had higher initial concentrations.

4.0 Discussion

In paired comparisons the overall average $PM_{2.5}$ and CO reductions observed as a result of installing the Patsari were 66% ($p<0.001$) and 67% ($p<0.001$) respectively (Table 2). Perhaps more importantly, however, the Patsari stove reduced kitchen concentrations across the distribution of homes to fairly consistent levels, and increasing reductions were seen in homes with higher initial concentrations with the open fire stoves. Although these homes and communities relied predominantly on wood as the most important cooking fuel, gas, "olotes" (maize husks) and sawmill/carpentry residues were also used as secondary fuels in some homes. From an IAP perspective this complicates sampling designs, but multiple fuel usage is probably the most common situation in rural communities depending on season, agricultural products etc, as demonstrated in homes in China (Edwards et al 2007). Since evaluating every combination of fuel usage is not feasible due the large numbers of homes that would be required in order to maintain statistical power for such stratification, careful planning and preliminary surveys should be conducted in this regard before undertaking indoor air quality studies.

Evaluation of the impact of the Patsari on kitchen concentrations should not be adversely affected due to the paired before and after design, and would reflect the actual adoption process of the stove.

Although because of resource constraints our sampling design did not include a control group in which no Patsari was installed to control for seasonal effects, in practice the use of a control group would have been limited even controlling for housing type and family size given a) the diverse cooking patterns and cooking times between houses b) differences in fuel usage between homes, and c) the different transitional stove adoption patterns where traditional stoves were still used to some degree in homes. Controlling for these factors would have entailed monitoring a prohibitively large number of control homes. Instead the approach used in this study was to monitor the homes relatively soon after installation during similar climatic conditions to those when the traditional open fire stoves were monitored. It is possible a seasonal/temporal bias exists in the reductions seen here, but is unlikely given the relatively small changes in climatic conditions and the consistent linear relationship between the reductions in kitchen concentrations with the Patsari stove in relation to the initial concentrations with the open fire stoves.

A disadvantage of the variability seen due to transitional stove adoption patterns, cooking patterns and fuel usage is that the reductions seen here as a result of the Patsari stove do not necessarily represent those in other communities. This community is likely to be on the lower end of potential reductions as technology penetration in the community is low, which reduces the number of rapid adopter groups and would tend to increase the amount of transitional stove adoption where the open fire stove is retained for some cooking tasks. In addition, in these homes the husband habitually collected firewood. The issue of stove promotion as a time-saving technology is more complicated, therefore, as increased time spent cooking due to lower power output of stoves with covered combustion chambers would be perceived by the women of the home as being an increase in time taken to perform daily activities, as the principal time saving would be for the husband in collecting firewood. Conversely, for houses that buy fuelwood, the benefits in reduced expenditures would be more apparent. Since success and adoption of the stove ultimately depend on user's perceptions, more targeted promotion matching stove benefits to user's priorities would ultimately result in a program with greater numbers of stoves in use. Although these homes may not necessarily be the homes where the greatest individual air pollution reductions are possible, the overall reductions of air pollution across the community would be greater as a result of more stoves in use. GIRA employs this approach in the analysis of adoption in communities, and the current focus is to identify characteristics of such adopter groups in longer-term monitoring of homes.

The coefficient of variation of average 48-hour kitchen $PM_{2.5}$ concentrations remained at approximately 0.7 in both traditional TCS and Patsari homes, presumably due to continued use of a traditional stove in many homes as they transitioned to the new technology. In spite of efforts to constrain the variability through selection criteria of homes, therefore, the variability remained high due to differences in daily cooking habits. Initial statistical power analysis was conducted from a pilot study to estimate appropriate sample size to observe 40% difference in kitchen concentrations using standard statistical criteria. The 40% criteria was a subjective valuation determined on the basis of the high concentrations in homes using traditional open fire stoves, which if not reduced by 40%, would not warrant the time, expense and effort of installing the improved stove as a technology to reduce air pollution in kitchens (although there may be other reasons for installing it such as reduced fuel use).

Although 30% more homes were selected than would be determined by sample size calculations, in practice 7 participants withdrew after installation of the stove due to the monitoring requirements of the health and indoor air studies, with a further 2 unable to be located. 17 were not monitored for a variety of reasons including 4 that planned to build a new kitchen in which to house the new stove, a positive and not uncommon response to the new stove, although complicating monitoring designs. Two had decided to move to another house and the husbands of 2 had migrated for work resulting in moving to live with relations. 8 participants were not monitored as they requested additional training in the use of the stoves and the remaining participant had modified his stove so that it no longer represented the use of a Patsari. If the households of all of the original participants had been monitored the average reductions in kitchen concentrations would probably have been lower, but would not have reflected the potential benefits of use of the Patsari stove since the stove was not used as designed.

The potential benefits are shown by the systematic reductions made across all households with increasing reductions in kitchen concentrations in relation to the average 48-hour concentrations measured with the traditional open fire stove types (Figure 7). Thus, provided that sufficient training is given, and in spite of transitional adoption patterns in some homes where the traditional stove is retained for some tasks, reductions in kitchen concentrations would be expected across communities with the Patsari stove, proportional to the amount they used the stove.

Benefits of the monitoring and evaluation conceptual approach

The monitoring and evaluation approach followed by GIRA resulted in a continual process of stove innovation-adaptation-monitoring-dissemination. As a result, the stove models tested in this paper have been further improved and the "Patsari brick" is currently the stove model more commonly disseminated by the project. Although changes in stove models present difficulties for policy makers and funders wishing to put a single value on the potential benefits achievable through improved cook stoves, the improvement of stove models represents a positive and valuable outcome of the monitoring and evaluation approach, showing the evolution of the technology through feedback on design.

In addition to the direct benefit of understanding the potential reduction in air pollution concentrations that would result in kitchens, a major largely unrecognized outcome of the HEH projects and the monitoring and evaluation approach was in the bringing together of both national and international collaborators to focus their efforts in understanding the social, environmental, health, indoor air, and greenhouse-gas implications of the Patsari stove in a unique effort to monitor and assess all outcomes within the same communities. Although requiring significant additional resources, such efforts have generated new valuable data that allows an integrated evaluation of improved cookstove benefits. The monitoring studies have increased awareness in the Mexican Government of indoor air pollution from biomass burning as a problem requiring immediate action.

In addition, the Patsari project is the first project to our knowledge from the rural residential sector to demonstrate in-field emissions of greenhouse gases and among the first to market greenhouse-gas carbon credits in the private sector. The current and future impact of the results of this monitoring and evaluation approach on public policy is much larger, therefore, than the direct impact of the number of improved stoves installed in these communities, as they may benefit many rural communities throughout Mexico and possibly further a field.

Although there has been a tendency of government and funding agencies to focus on numbers of stoves disseminated, health benefits are dependent on consistent reductions in exposures, which implies continued acceptance and adoption by local communities, since the health effects of most concern as a result of exposure to biomass smoke occur after chronic exposure, rather than acute short term effects. The success of a stove program ultimately is defined, therefore, by the numbers of stoves being used as intended in communities, rather than simply the number of stoves that are disseminated or built. Unfortunately, due to the long-term nature of follow-up in communities in order to assess chronic health endpoints, evaluations of the full impacts of these interventions are currently under funded and researched. Thus, although this paper addresses the first stage in this process in monitoring the indoor air reductions achieved by the intervention, more resources should be allocated to monitoring usage of the stoves and health impacts over time. Further, more resources should be allocated to identification of rapid adopter subgroups in communities where the benefits of the stoves are better perceived. This strategy will not only maximize the number of stoves in usage in communities and the time and resources involved in the process, but will also aid in further dissemination of the stove through other adopter groups in the community.

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Tables

Table 1 Areas of evaluation in the Patsari Project

Study	Design	Sample groups	Evaluation endpoints
Health	Cross sectional	300 control group homes 300 intervention homes with Patsari stoves	spirometry, blood samples, and health symptoms
IAP	Before and after	60 households in one village; 40 households in a second village	personal exposures, kitchen concentrations and ambient.
Social perception	Qualitative	23 focus groups 26 interviews with key informants	
Stove Performance	Before and after	40 households for KPT 4 cookstoves using tortilla making in CCT 4 cookstoves compared for WBT	Both exclusive fuelwood and mixed fuelwood and LPG
GHG Measurement	Cross sectional	14 Laboratory based WBT 22 field based WBT 14 Patsari households for KPT 8 open fire households for KPT	emissions of CO_2, CO, CH_4, N_2O, black carbon, and non-methane hydrocarbons

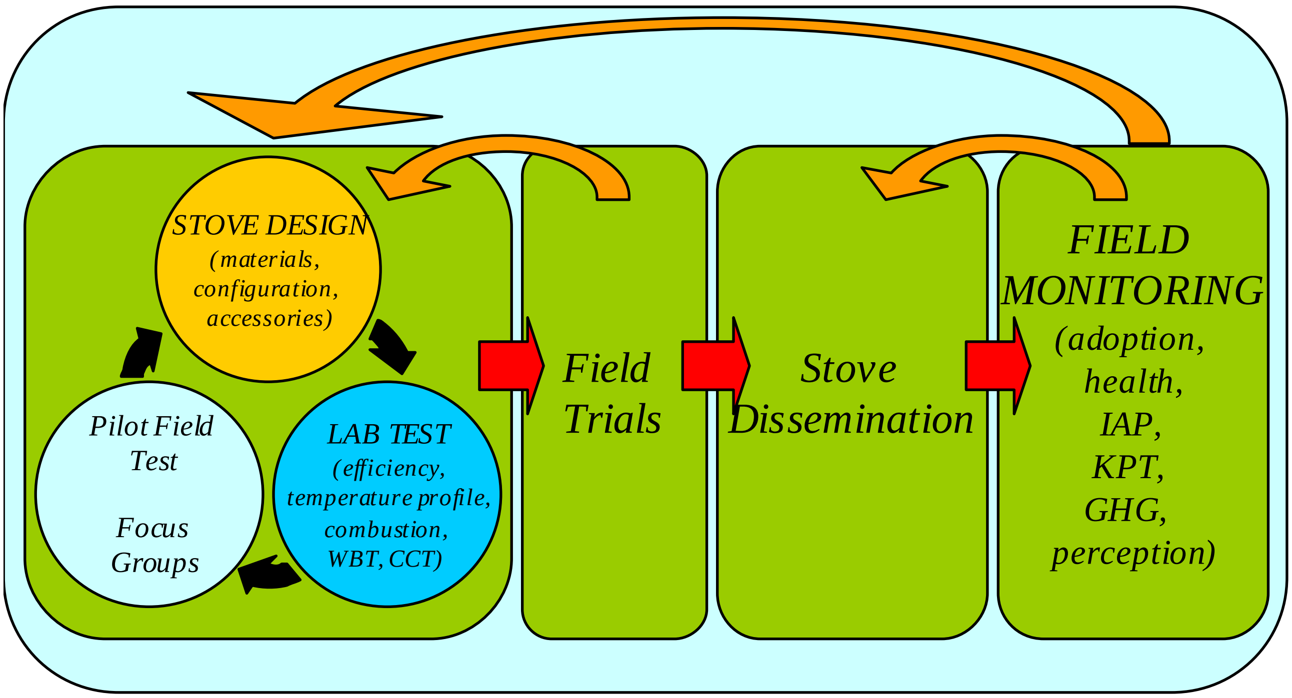
Notes: WBT: water boiling test; CCT: controlled cooking test, where a fixed amount of food is cooked by the same cook; KPT: kitchen performance test, involving typical cooking under normal conditions.

Table 2. GIRA: *Patsari* Stove – paired before and after comparisons of 48-hour averages

	BEFORE				AFTER			Percent Change	
	N	**Average**	**Std Dev**	**Maximum**	**Average**	**Std Dev**	**Maximum**	**Wilcoxon SRT***	
PM: (mg/m^3)	33	1.02	0.79	4.23	0.34	0.27	1.16	<0.001	67%
CO: (ppm)	32	8.88	4.44	22.61	3.02	2.66	12.09	<0.001	66%

*Wilcoxon signed ranks test (SRT) is a non-parametric (the underlying shape of the distribution of concentrations is not assumed) test for before and after samples based on the statistical probability of observing the ranked differences in the before and after measurements

Figures



Notes: WBT: water boiling test; CCT: controlled cooking test; KPT: Kitchen performance test; IAP: indoor air pollution; GHG: greenhouse gas emissions

Figure 1. Conceptual diagram of integrated stove development and dissemination.

Figure 2a) Traditional wood burning cookstoves

Figure 2b) Patsari wood burning cookstove decorated by the user

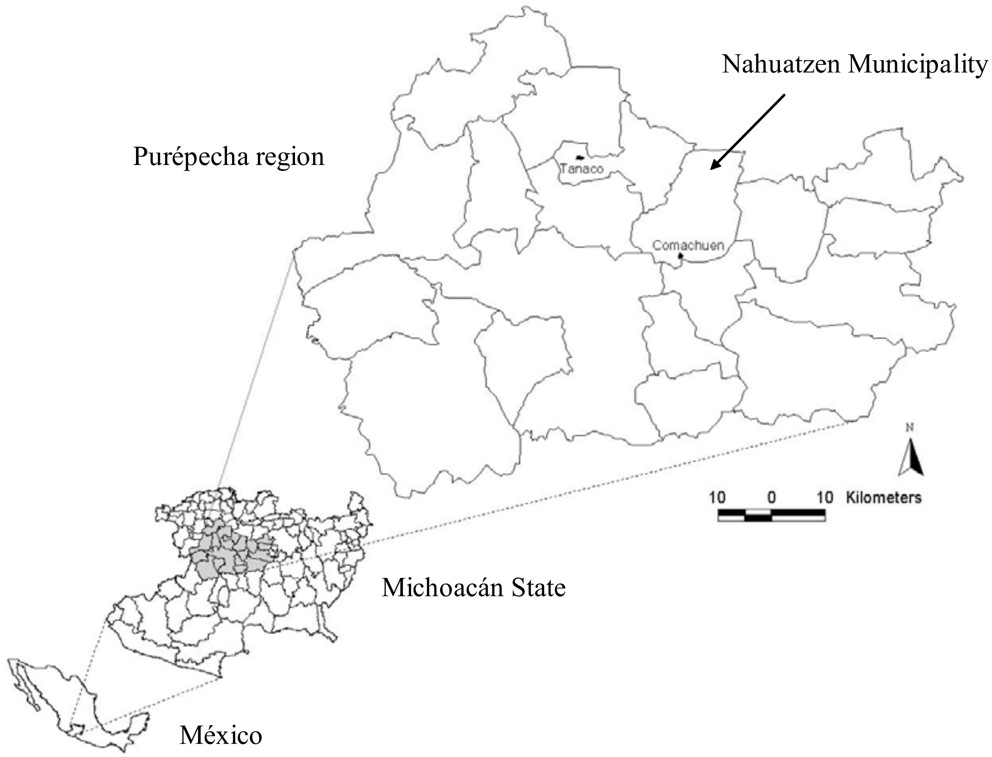


Figure 3. Map of the Purepecha region in Michoacán Mexico

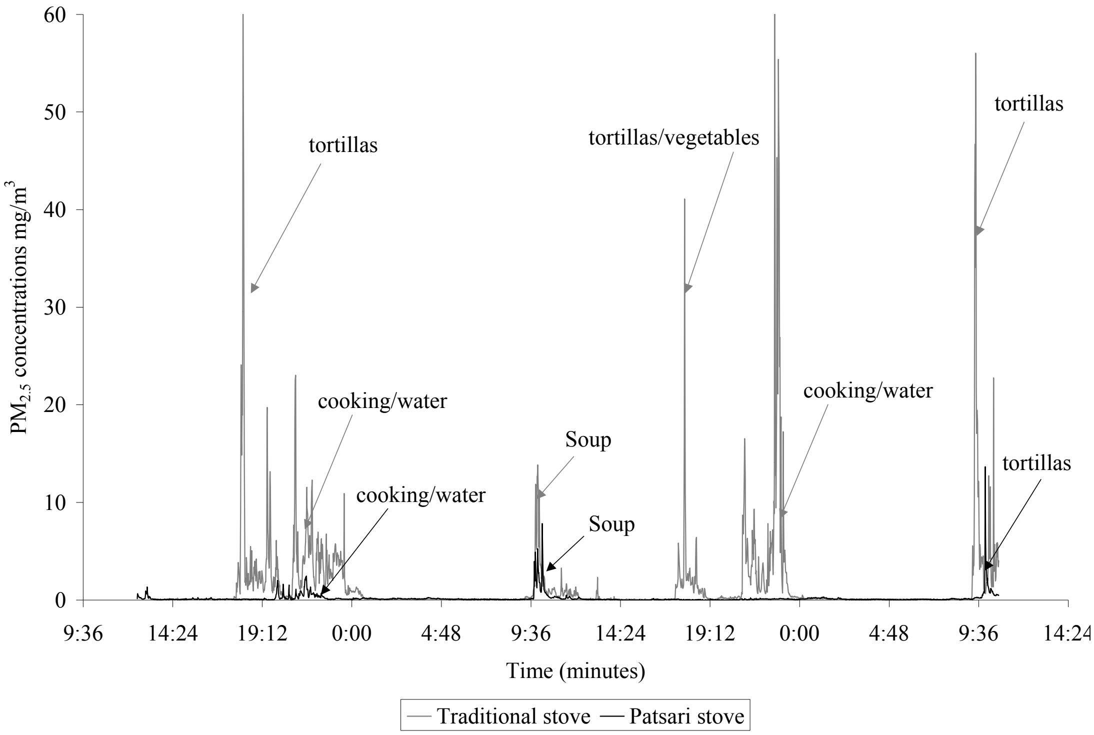


Figure 4a) Typical 48-hour 1-minute kitchen $PM_{2.5}$ concentrations before and after installation of the improved stove

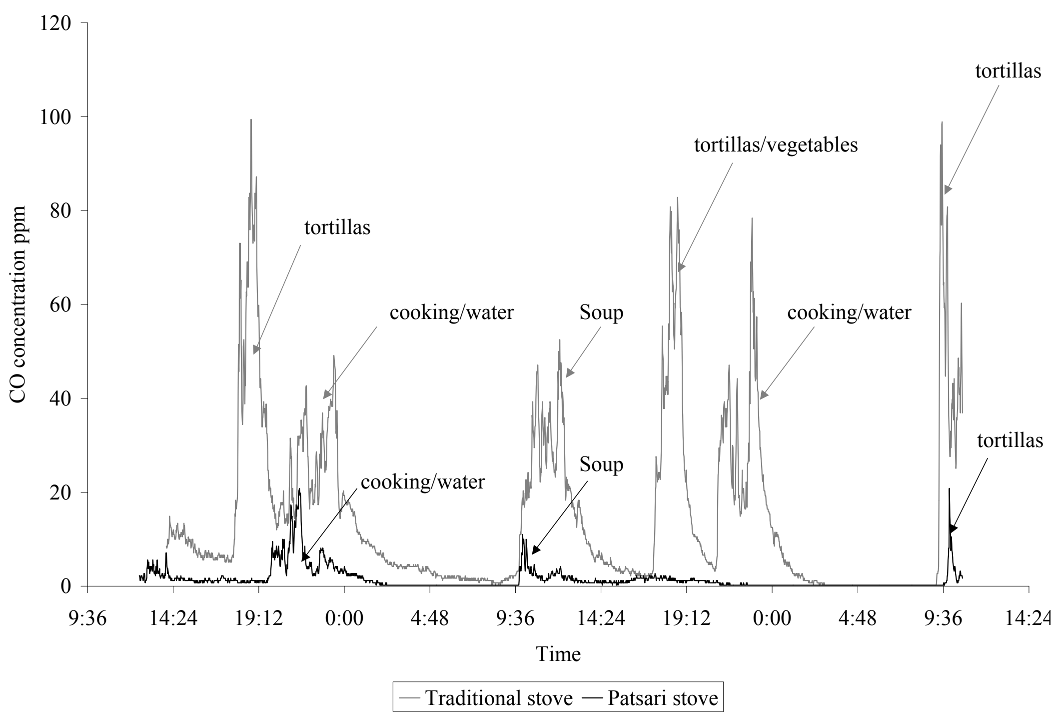


Figure 4b) Typical 48-hour 1-minute kitchen CO concentrations before and after installation of the improved stove

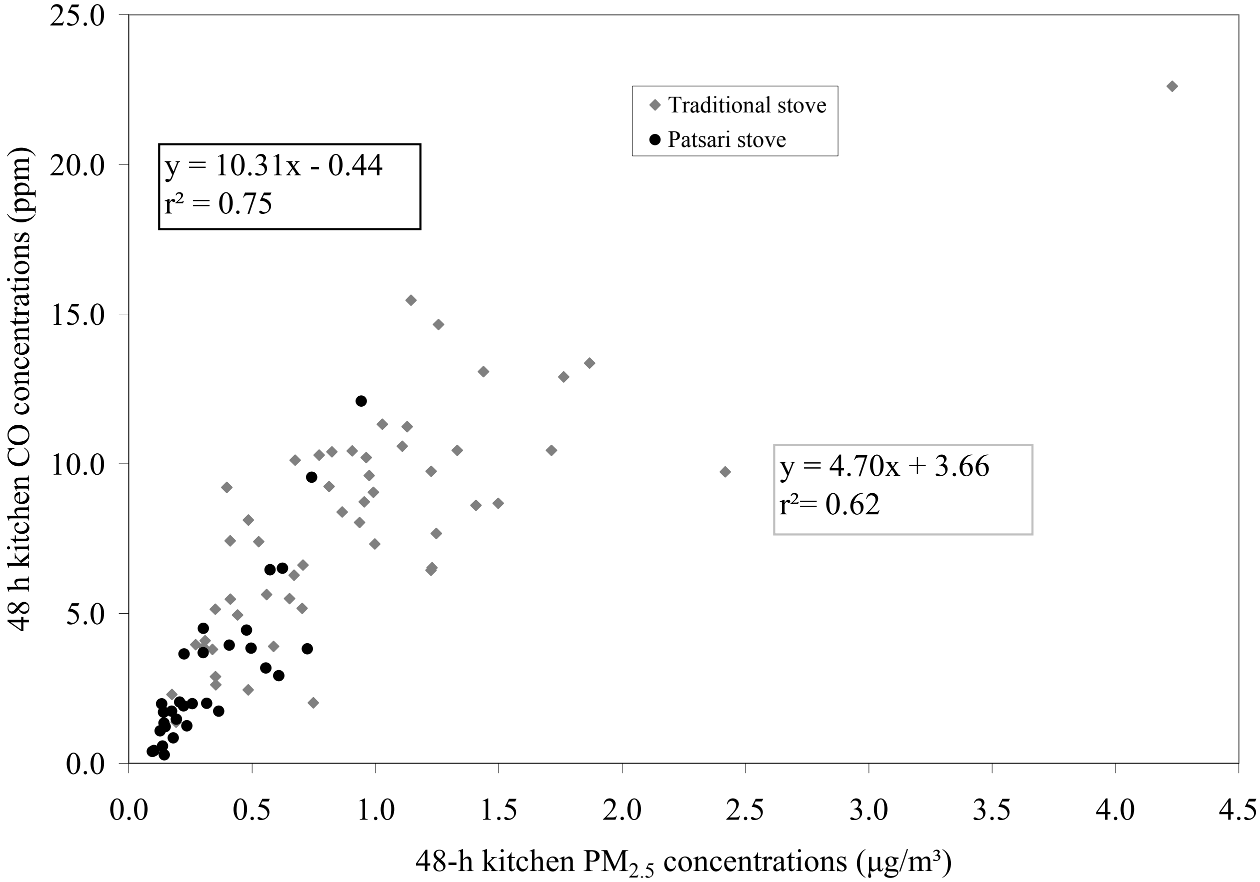
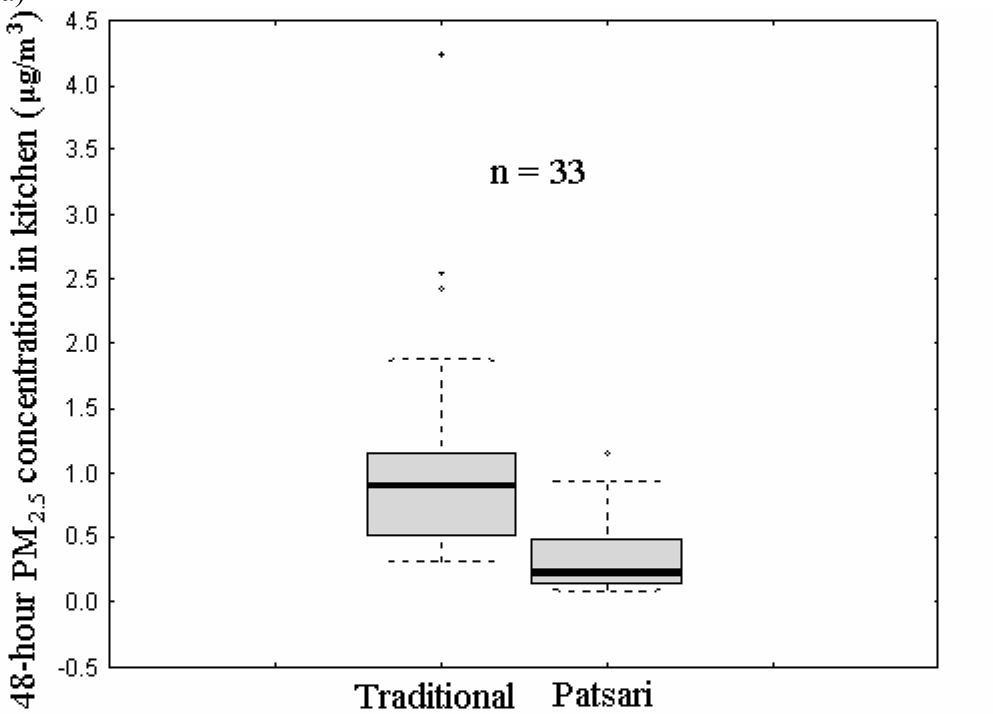


Figure 5. Correlation between average 48-hour PM and CO for both traditional and Patsari stoves.

a)



b)

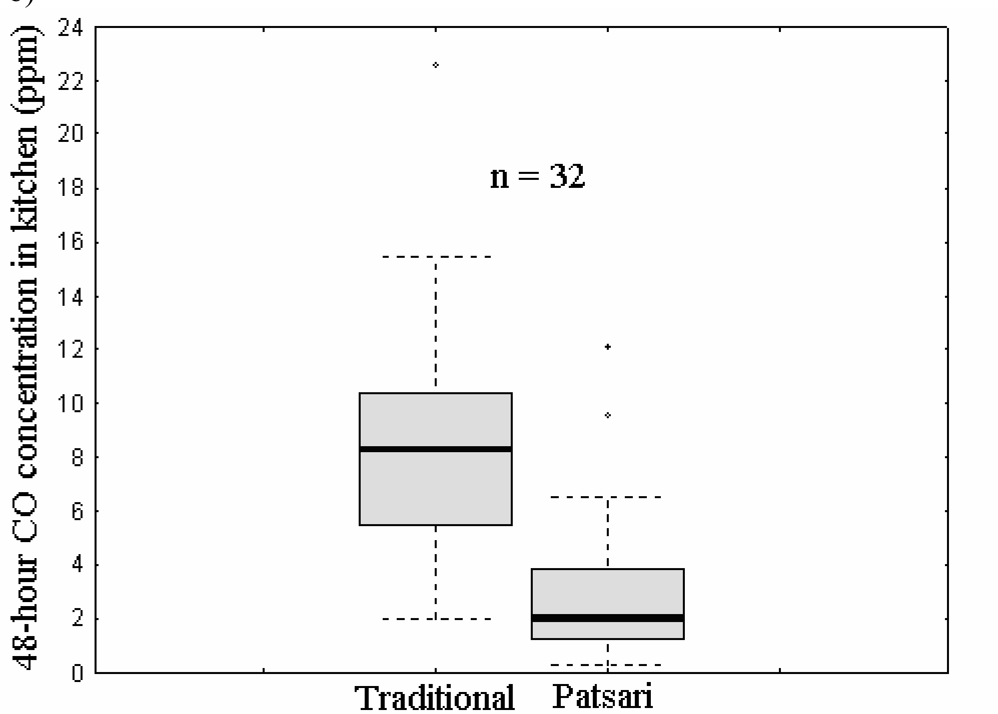
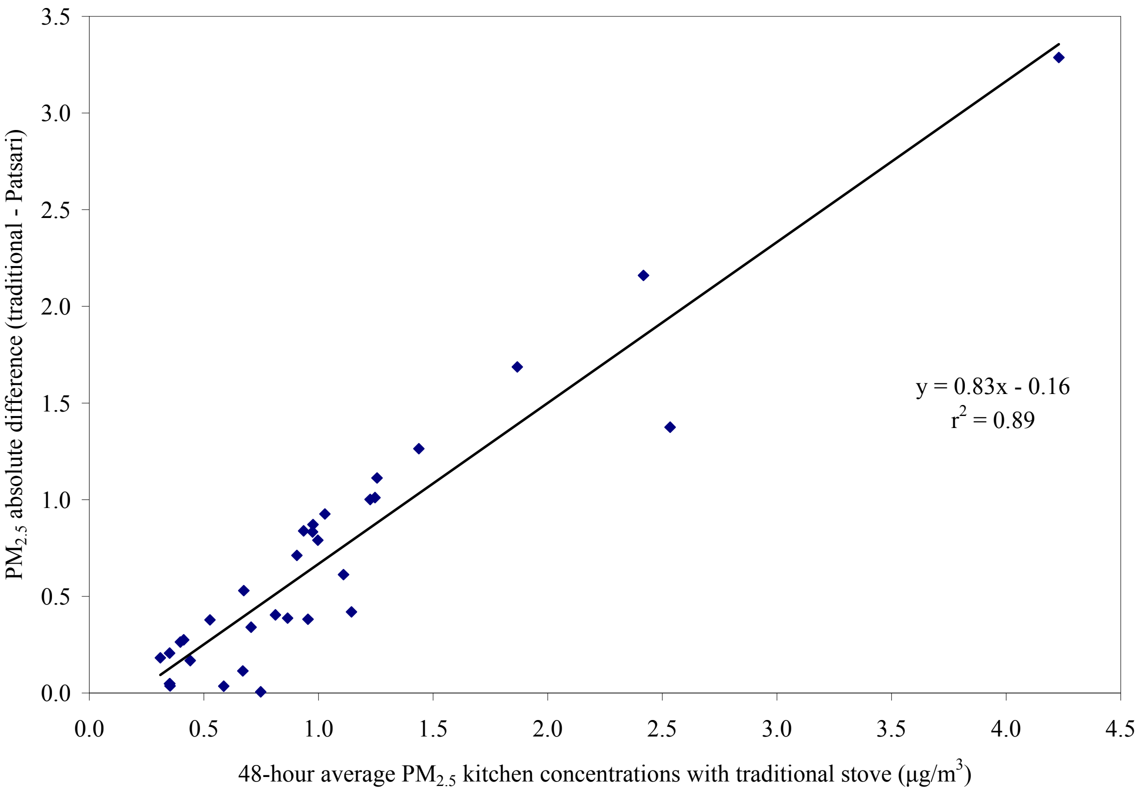


Figure 6. Average 48-hour kitchen $PM_{2.5}$ (a) and CO (b) concentrations before and after installation of the Patsari stove. Here the darker central line in the box represents the median concentration, the lower

and upper boundaries of the box represent the 25th and 75th percentiles respectively, and the dashed lines above and below represent the range of values with extreme values and statistical outliers appearing as individual points.

a)



b)

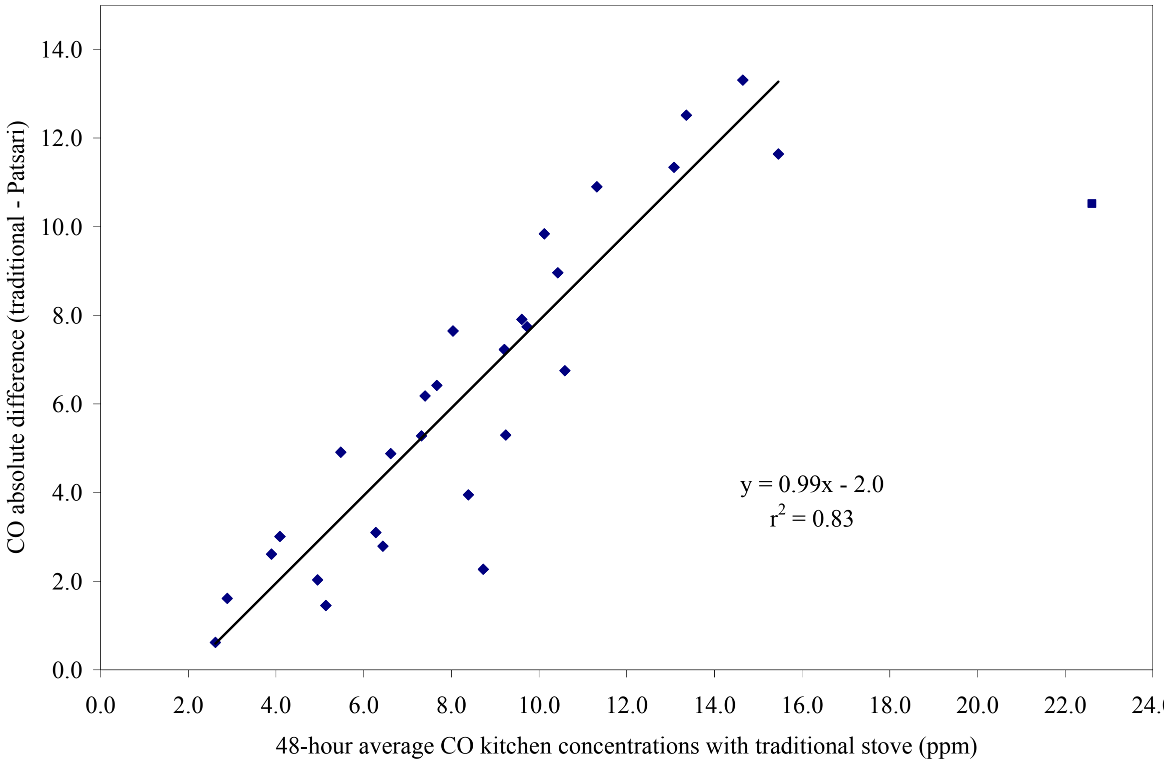


Figure 7. Absolute reduction from traditional to Patsari stoves in relation to initial concentrations: a) $PM_{2.5}$; b) CO, with data point at far right not included in regression line due to undue influence on the slope of the line.

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[1] health improvements, greenhouse gas emissions, and social and environmental impacts of the Patsari in the same area of Mexico will be reported elsewhere.

[2] For more technical details about the Patsari stove refer to *Masera et al 2005.*

[3] More information about GIRA can be found at: http://www.gira.org.mx

[4] http://www.ashdenawards.org/winners/gira

[5] A *comal* is a large metal or ceramic flat surface on which tortillas are cooked, which is sealed to avoid fugitive smoke emissions to the room.