**The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized Controlled Trial**

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**List of Acronyms:**

C Celcius

CO Carbon Monoxide

CEGA Center for Evaluation of Global Action

IAP Indoor Air Pollution

NGO Non-Governmental Organization

RCT Randomized Controlled Trial

SHE Solar Household Energy Inc.

SUM Stove Usage Monitor

WHO World Health Organization

Abstract

*Background:* Inefficient cookstoves contribute to deforestation and global climate change, require substantial time collecting wood (usually of women and girls) or money for fuel, and lead to over 1.5 million deaths a year.

*Objectives:* We examined the effect of solar ovens on fuel use, time spent collecting wood, carbon monoxide exposure, and respiratory illness symptoms.

*Methods:* We ran a randomized controlled trial among women interested in purchasing a solar oven in rural Senegal. Households randomly allocated to the control group received their stoves 6 months after treatments.

*Results:* 80% of our respondents typically cook for more people than the capacity of the solar oven. Thus, even cooks using the solar oven continue using their traditional stove. In the sixth month of owning the stove, treatments used their solar oven 19% of days measured. Treatment households did not have statistically significantly lower fuel consumption, time spent collecting fuel, or time spent next to the cook fire. However, treatments cooking for 7-12 persons had 14% lower firewood consumption (P < .01). There is no evidence solar ovens reduced exposure to carbon monoxide or self-reported respiratory symptoms such as coughs and sore throats.

*Conclusions:* These solar ovens were not effective in reducing the problems associated with large extended families using wood to cook. This evaluation was a policy success because its results halted the proposed nationwide rollout of the solar oven. It also demonstrates how to run low-cost randomized field trials, the value of stove usage monitors to provide objective measures of usage of new stoves, and the importance of measurement of existing stoves, not just new stove.

# Introduction

Over 3 billion people burn wood and other biomass for cooking (Mehta *et al.* 2006; WHO 2007b). Emissions from burning biomass fuels cause approximately 1.6 million premature deaths every year (WHO 2007b). This is a result of indoor air pollution leading to pneumonia, bronchitis, lung cancer, chronic obstructive pulmonary disease, and a host of other ills (Clark *et al.* 2007; Smith-Silvertsen *et al*. 2004; Diaz *et al.* 2007).

The most convincing evidence to date linking emissions from cookstoves and poor health comes from the RESPIRE study in rural Guatemala. The RESPIRE study found that moving from a traditional smoky indoor cookstove to a large built-in stove with a chimney reduced both exposure to carbon monoxide and women’s self-reported health symptoms. Importantly, the improved stoves also reduced the incidence of childhood pneumonia (Smith-Silvertsen *et al* . 2004; Diaz *et al.* 2007). These results are consistent with the large literature linking improved cookstoves to reduced emissions in carefully controlled conditions (e.g., McCracken and Smith 1988, Ezzati and Kammen 2002, Ezzati, Saleh, and Kammen 2000, Ezzati, Mbinda, and Kammen 2000, Dasgupta *et al.* 2004a, Dasgupta *et al.* 2004b, Dherani *et al.* 2008, and Albalek *et al.* 2001).

Further, traditional stoves also have high costs of fuel. In rural Africa these costs are primarily the many hours a week women and youth spend gathering fuel each week (Blackden and Wodon 2006), time that may come at the expense of education (Bruce *et al.* 2006).

Inefficient cookstoves also contribute to deforestation (United Nations Convention to Combat Desertification 2010) that contributes to global climate change. By one estimate household energy use in Africa is on track to produce 6.7 billion tons of carbon by 2050 (Bailis *et al.* 2005).

Despite generations of efforts designing and disseminating improved biomass stoves, they have yet to reach most of the world’s poor (Household Energy Network 2008). Authors of the few existing rigorous evaluations of the impacts of improved stoves cite the wide agreement in the scientific community that additional rigorous evaluations are needed to accurately evaluate the impacts of improved stoves, particularly on health (Bruce *et al*. 2006; Smith *et al.* 2000; Duflo *et al.* 2008).

Rigorous evaluations are crucial to understand the key issues present in both the supply and demand side of the adoption of an improved stove and to help craft solutions. The business and policy response should be quite different if the main barrier is poor stove design versus credit constraints versus lack of consumer information.

The importance of clean cookstoves has gained significant attention in the field of public health and international development, culminating in establishment of the over $60 million public-private partnership of the Global Alliance for Clean Cookstoves in September 2010. The Alliances’ goal is for 100 million homes to adopt clean and efficient stoves and fuels by 2020. This paper contributes directly to realizing that goal through imparting key lessons on how to effectively measure the impacts of an improved stove on wood use, time spent collecting wood, and respiratory health and carbon monoxide.

The objectives of this RCT are to measure the effects of the introduction of a solar oven on health, fuel use and time spent collecting fuel, and actual stove usage. In particular, because the solar oven requires a significant shift in behavior associated with cooking on a traditional wood-burning stove, we are interested in measuring whether households solar ovens can achieve similar effects as those of chimney stoves documented in the RESPIRE study.

# Methods

The area we study in the Western Sahel semi-desert Thiès region of Senegal is subject to all of the ill-effects of traditional cookstoves listed above: many hours a week spent gathering fuel, high exposure to indoor air pollution, and poor health.[[1]](#footnote-1)

The area is rural and poor. The population is young, with 60% under age 25. Education levels are low: 48% of teens 13-18 and 94% of those over 50 report zero or missing education. Women in our sample have mean earnings of $1.86/day and their husbands give them another $3.28/day for household expenditures. Our respondents live in large, often polygamous, households, averaging 12 persons, or a per person expenditure of 43 cents per day.

At the baseline 88% of households burn wood, 50% use farm waste, 8% use animal dung, 21% use charcoal (mostly for tea), and 74% use gas (mostly to reheat meals and to cook breakfast). The household’s choice of stove depends on the meal, season, and size of household. The choice of the kitchen varies widely as respondents report cooking in a semi-enclosed kitchen (49%), an enclosed kitchen with no windows (21%); a kitchen with thatch roof but no walls (20%); or outdoors (10%).

With these facts in mind, the NGO Solar Household Energy, Inc. (SHE) approached the local NGO Tostan, active in community development in Senegal, about deploying SHE’s HotPot solar oven in Senegal.

The HotPot- a panel solar cooker- uses a reflector to direct sunlight to a 5-liter black enameled steel pot that is within a larger tempered glass bowl with a lid. Heating occurs both from sunlight striking the black pot and from the greenhouse effect within the larger glass bowl. Effective cooking requires that the user angle the reflector to the sun, shifting it ever hour or so. Under a tropical sun the HotPot can cook rice in under an hour, a chicken in about two hours, and beans in four hours. In 2007 SHE carried out a small pilot study in Méckhé, Senegal with 20 consumers. SHE staff reported all the women found the stove fit well with their needs.

Tostan selected 20 villages that cooked primarily with wood in the Thiès region in northern Senegal for this pilot. Tostan also selected villages that had at least five years experience with Tostan. SHE trained Tostan staff on using the solar ovens. SHE and Tostan then carried out trainings and marketing demonstrations on how to cook with the Hotpot from Jan-March 2008.

Due to shipping constraints of the HotPot from Mexico to Senegal only half the target population could receive the stoves at one time. Thus the phased intervention fit well with the program needs.

A total of 50 solar ovens was available for each of the 20 study villages. Within each village 25 households in each village were to be randomly selected to receive the solar oven at the time of the baseline survey (April 2008) and up to 25 to receive the oven when the second shipment arrived (October 2008). Most villages had fewer than 50 women enrolled at the time of the randomization, so we have fewer controls than treatments (a ratio of 1.4 treatments per every control).

Both the baseline and six month follow-up surveys covered demographics, fuel use, time collecting fuel, cooking practices- including those associated with the solar oven, self-reported respiratory symptoms for respondents and their children, and cooking-related symptoms for respondents.[[2]](#footnote-2) For a subset of participating households we also measured carbon monoxide exposure for women cooking the lunch meal. At those households we also collected information on the cooking structure, time spent cooking lunch, and types of fuel.

### Stove Utilization

Following Ruiz-Mercado *et al.* (2008), we used ibuttons as our stove usage monitors (SUMs). The ibutton is a computer micro-chip enclosed in a 16mm thick stainless steel case, which we installed on the lid of all solar ovens.[[3]](#footnote-3)

We programmed the SUMs to take temperature readings every 30 minutes. The SUMs data indicate clear spikes when the solar oven is used; we use a reading of 110°F (43°C) or more to indicate usage. In our field tests, unused solar ovens left outdoors did not reach this temperature. Results were not sensitive to the precise threshold (see web appendix 1).

We had SUMs in place during the first month of solar oven ownership (April through May 2008) and during the sixth month of stove ownership (October through November 2008).

We also asked self-reported usage rates on the 6 month follow-up survey. Finally, we observed solar oven usage during household visits for the follow-up survey for the subsample where we measured carbon monoxide exposure.

### Primary Impact Measures

Households reported the quantity, financial cost, and time cost gathering several fuels last week including: wood, charcoal, gas, animal dung, and farm waste. We also weighed the wood respondents designated they used to cook the lunch meal yesterday from a large pile. At the follow-up we weighed the wood respondents indicated they used for all three meals yesterday.

We measured exposure to carbon monoxide with Dräger Color Diffusion Tubes (“CO tubes”). The CO tubes measure the time-weighted average concentrations of carbon monoxide in parts per million per hour (ppm/hour). We multiplied the reading by a factor to adjust for local humidity levels and top-coded the 6 month CO data, bringing 5 of our 275 observations down to the 95th percentile (32.19 ppm/hour).

With the help of Tostan’s local village point person, we selected a subset of households randomly to receive the CO tube. However, enumerators were instructed to skip households who were cooking only with gas. Unfortunately, we did not retain the count of treatment and control women and compounds that were not given CO tubes because they cooked with gas.

To measure exposure to carbon monoxide while cooking lunch, enumerators attached the CO tube to each cook’s attire in the morning in each of our 20 villages (between 8:30-10:00am) and collected them about 5 hours later (2:00-3:30 p.m.) after lunch.

We asked women to self-report if in the last 7 days they had experienced any of the seven respiratory illness symptoms: fever; sore throat; runny or stuffy nose; cough; wheezing or trouble breathing; woke up with chest heaviness at night; and coughed up mucus. At each survey round we also asked them to report on 4 symptoms for each of their children: cough or difficulty breathing; cold and coughed up mucus; runny or stuffy nose; and wheezing. At the follow-up we also asked respondents to report all seven respiratory illness symptoms for their husbands. We also collected self-reported symptoms associated with traditional cookfires: eye discomfort, headache, irritated throat, and back pain during cooking (as in Diaz *et al.* 2007).

## Estimation

We analyze the impacts *Yvi1* for woman *i* in village *v* at the follow-up (time 1) using OLS regressions controlling for a vector of baseline characteristics (*Xvi0*) and a vector of village fixed effects *FEv*:

*Yvi1 = Σsj βs Tvsi sizevi1 + Σk γk Xvik0 + Σv δv FEv + εvi*

where *Tvsi* is a dummy equal to one for treatment homes of size category *s.*  Because it is plausible the solar ovens had larger effects for smaller households, we interact the treatment effect with three categories of household *sizeiv1*: 6 or fewer people, 7-12, and 13 or more.

The baseline household characteristics include the number of people women report cooking for and its square, wood use at lunch the day prior to the baseline, the amount of money spent weekly on wood, the amount of money spent weekly on gas, the amount of money spent weekly on charcoal, kilograms of rice, 3 indicators for women’s salary category, and 3 indicators for the category of the husband’s financial contribution to the household. Continuous measures were bottom- and top-coded to the 5th and 95th percentiles to reduce the influence of outliers. To maintain sample size, we include a dummy when observations on a control variable were missing, and impute that value at its mean.

It is possible the number of people a woman cooks for at the follow-up is affected by having a solar oven. Thus, we re-estimate equation 1, but instrument for the number of people a woman cooks for at the follow-up survey (and interactions with treatment) with the number she cooked for at baseline (and interactions with treatment). The first stage is very strong (see web appendix 2).

We also measured household membership converting children into adult equivalents (as in Atkinson *et al.* 1995). We then examine quartiles of adjusted household size and their interactions with treatment. We report these robustness checks only for wood usage, as they had no effect on other specifications.

### Pipeline analysis

At baseline we surveyed 838 of the envisioned 1000 households in the combined control plus treatment groups (Table 1).

Twelve treatment households (4%) returned their solar ovens and dropped out of the treatment group, typically due to a financial shock such as a health problem. Tostan redistributed these solar ovens to control homes leading to a small amount of leakage. Thirty-six control households (10%) dropped out of the program as well.

Contrary to the intended study design, 33% (260) of our participant households lived in a compound with one or more other study participant.[[4]](#footnote-4) We use this unintended overlap to test whether solar ovens are more effective in compounds with multiple solar ovens.

Of the 790 participants who made up our final sample, only 736 weighed wood at the baseline. At the follow-up 744 households took the survey, of which 677 also weighed wood. Of those missing wood weighing, 67% on the baseline survey and 64% on the follow-up are due to the household reports she cooks primarily with gas. The additional missing 18 households at baseline (24 at the six month follow-up) are due to data collection error.

We permitted other women (usually from the same compound) to complete the survey if the enrolled woman was not present. At the follow-up 48% of treatment and 45% of control households had a substitute respondent. This rate was high in part because treatment respondents, who had already received their solar oven, had little incentive to be present in the village to take the follow-up survey. Additionally, the fish smelting season increased absenteeism in the two sea-side villages.

### Randomization tests

We ran a probit equation with the baseline variables listed in Table 2 including education, income, household size, time spent gathering fuel, kilograms of wood used, self-reported health, and so forth. The results were reassuring in that they collectively did not statistically significantly predict treatment (see web appendix 3).

## Summary statistics

At baseline, households used an average of 6.8 kg. of wood to cook the lunch meal.

For controls the mean wood collection time per day for the household was high at baseline (2.3 hours) and more than doubled (to 5.2 hours) at the follow-up. In addition to performing about half the household’s wood collection, women report spending an average of 5 hours a day cooking, of which about 3 hours are next to the fire.

At baseline 77% of women reported sometimes or always having their children present when they cook and 31% reported sometimes having their children on their back when they cook.

The average CO exposure for control women is 6.50 PPM/hour at the follow-up.[[5]](#footnote-5) Multiplying this hourly rate times the 5 hours daily women report cooking implies exposure to approximately 32.5 ppm of CO daily. This is 130% of the recommended 25 ppm limit for an 8-hour exposure recommended by the World Health Organization (Penney 1998).

Consistent with high smoke exposure, control women at the six-month follow-up reported an average of 2.88 of the four symptoms associated with cooking: eye irritation, headache, throat irritation, and backache.

Control respondents at the follow-up report an average of 3.93 of the seven respiratory illness symptoms we asked about (cough, sore throat, fever, stuffy nose, trouble breathing, chest heaviness and/or coughed up mucus). In contrast, these women reported a third fewer symptoms for their husbands (2.20, which is statistically significant less than their wives, P < .01). It is plausible that exposure to the cookfire is responsible for much of the women’s higher average number of symptoms, although higher awareness of their own symptoms and exposure to children with many infections may also play a role. Averaging over all children under 5 in the household, control children had a mean of 2.51 of four respiratory symptoms at the baseline.

# Results

## **Solar Oven Usage**

In the sixth month of having the stove, SUMs measured use on 19% of days. The weather that month was sunny enough for the oven to be used almost every day in almost every village.

When we asked for complaints about the solar oven, by far the most frequent was that the size was too small (50% of responses).[[6]](#footnote-6) This complaint corresponds with the high number of people our sample cook for; as noted above, at baseline about 90% of respondents reported cooking for more than six people (the capacity of the solar oven).[[7]](#footnote-7)

At the follow-up survey only 7% of treatments used the solar oven to prepare part or all of the lunch meal yesterday. Respondents reported the most common meal they prepared with the solar oven was dinner (40%), a snack (28%), or separate meals for children or diabetics (13%). The dinner meal is usually smaller than lunch and often porridge, which is well suited to solar cooking. As it is a common practice to pre-cook and then reheat food at meal time, cooking dinner concurrently with lunch was consistent with familiar cooking methods.

Importantly, when we observed cooking during the CO survey, every cook who was using the solar oven also had an additional wood or charcoal fire lit.

The stove usage monitors are critical in measuring stove usage. Solar oven users at the six month follow-up report using their solar oven 38% of days, double the 19% rate recorded by SUMs. When we observed stove usage at the six month follow-up, for the 17 of the 20 villages where the weather was sunny, 61% of women were using their solar ovens– or more than 3 times the average usage rate on days they did not anticipate our visit.

## Wood Usage

Table 3 presents the core regression results on fuel usage. Across many specifications, the point estimates shows a small decline in wood usage only among medium-sized (7-12 people) treatment households.

In the first model we interact treatment with three household size categories. Treatment households of size 7-12 persons showed a statistically significant drop in daily wood use of 1.4 kilograms per day (about 14% of the mean). Households of 6 persons or less or 13 and more do not show any economically or statistically significant change in fuel use.

In column 2 we add baseline control variables such as wood usage and measures of income. The point estimates are almost identical as in column 1.

We instrument for the number of people women report cooking for at the follow-up with the number they report cooking for at baseline (and the various interactions with treatment status). Our results are consistent with the OLS results, including the reduced form (Table 3 column 3).

To check robustness we measured kilograms of wood used four ways: used all day yesterday, used all day yesterday per capita, used preparing yesterday’s lunch, and used for yesterday’s lunch per capita. We examined only compounds with more than one study participant per compound, looking for a treatment effect among compounds with 2 or more solar ovens. In all cases, results were similar to those in Table 3. When we recoded our sizes of households giving more weight to adults than to children results were similar, though now the wood savings are statistically significant only for the smallest terciles of households equivalent to 6 persons and less (see web appendix 4).

## Time spent collecting fuel and cooking

The regression results show a small point estimate drop for the treatment effect on the time spent collecting fuels only for households of size 6 persons or less but the coefficient is not statistically significant (Table 4, col. 2).

Treatment status also had no detectable effect on the time women spend next to the cook fire (Table 4, col. 1).

To check robustness, we reran the time spent collecting wood models separately on the women’s time and the time of others in her household. Results were unchanged. Finally, we run total household time collecting wood constrained by only those whose wood collected lasts less than 2 weeks and find that treatment interacted with households of size 13 persons or more has a coefficient of 207 minutes per week (>4 hours/week) P<.05.

## Carbon Monoxide Exposure

In the follow-up survey 166 treatment households and 109 control households received the CO tube. The mean for the control group is 6.50 while the treatment group is 8.09 ppm/hour. The unexpectedly *higher* CO exposure among treatments is marginally statistically significant at the 10% level.

The regression analysis shows that the marginally significant difference in means is largely due to small households (Table 4, col. 3). The coefficient on the interaction of treatment times the woman cooks for 6 persons or less is 6.5 CO PPM/hour, which is statistically significant at the 5% level. Our sample is small (only 20 treatments with CO tubes had household size 6 or under), but the result is not due to outliers; this group has substantially higher median CO readings than the other groups.

## Self-Reported Health

In the regression analysis (Table 4, col. 4-6), we analyze women’s reports of symptoms for themselves and their children with controls for village, baseline number cooked for, several other baseline characteristics, and the women’s reports of their husbands’ respiratory symptoms.

For the count of 4 symptoms associated with cooking (eye irritation, headache, sore eyes, and back ache, col. 4) and self-reported respiratory symptoms (cough, etc., col. 5) there is no statistically significant difference between the treatment and control group.

Finally, we repeat the regression predicting the women’s reports of under-five children’s respiratory symptoms (averaged within the household; col. 6). Children aged 5 and under in households with 13 or more people have 0.30 more symptoms (SE = .13, P < .01) if they are in a treatment household than if they are in a similarly large control household. We do not want to make too much of this result, as the 3 household size \* treatment indicators are jointly not significant (P < .19).

In robustness checks we controlled for whether the women enrolled in the program are part of a polygamous household, and a dummy variable for whether she is employed or not. We removed the endogenous cooking in an enclosed or semi-enclosed hut. We ran the entire set of regression specifications individually for each of the four symptoms associated with cooking and for each of the seven respiratory symptoms. Results were largely unchanged.

## Limitations

Our study has several limitations. There was non-random attrition of a few percent of the sample and non-random missing data for a large share. Our data collection was organized around the “household,” but in many compounds women rotate cooking duties across meals or days with their co-wives and other compound members. We placed the carbon monoxide tubes only on woman intending to light a fire that day, but did not retain the count of women who were cooking with gas. We rely on self-reported use of wood and time spent collecting wood, both of which have substantial recall error. Finally, the carbon monoxide tubes measured CO exposure during the middle of the day, when most cooks prepare lunch. Thus, we missed any reduction in evening smoke inhalation among women who used the solar oven to pre-cook dinner. Although each of these issues limits our confidence in the precise estimates, we do not believe they substantially affect the overall results.

# Discussion

## Caveats

Numerous issues arose in our data collection that caution against over-confidence in our precise results. Some issues are familiar to most randomized trials, while a few arose due to the complexities of fuel use, cooking, and eating in our study population.

* Randomization was supposed to be limited to one woman per compound. In fact, many compounds had more than one participant.
* There was non-random attrition of (fortunately only) a few percent of the sample.
* There was non-random missing data of a more significant share of the sample.
* Our data collection was organized around the “household,” but in many compounds women rotate cooking duties across meals or days with their co-wives and other compound members. In addition, children and adults often move in complex patterns, using different stoves within and across compounds.
* We placed the carbon monoxide tubes only on woman intending to light a fire that day, but did not retain the count of women who were not lighting a fire.
* The carbon monoxide tubes measured CO exposure during the middle of the day, when most cooks prepare lunch. Thus, we missed any reduction in evening smoke inhalation among women who used the solar oven to pre-cook dinner.

Each of these issues limits our confidence in the precise numbers we report. At the same time, we believe each issue has only a small effect, so the measured results are close to what occurred.

# Conclusions

Cooks and their accompanying children are exposed to dangerous levels of emissions- 130% of the daily recommended level of CO- roughly equivalent to 1.5 packs of cigarettes a week. Thus, it is not surprising that at the follow-up control women report an average of four of the 7 respiratory symptoms we asked about (fever; sore throat; runny or stuffy nose; cough; wheezing; woke up with chest heaviness; coughed up mucus)—almost twice the rate they report for their husbands.

Stove usage monitors measured solar oven usage on only 19% of days during the sixth month. Low usage is not surprising given nearly 80% of our households report cooking for more than six people. Because the solar ovens are usually too small, all women we observed using a solar oven also had a fire lit.

The SUMs proved critical in measuring objective stove usage. Solar oven users at the six month follow-up report using their solar oven 38%, about double the SUM-measured usage rate of 19%. When we observed stove usage at the six month follow-up, women used their stove more than 3 times the actual usage rate. Given the wide discrepancies between self reporting and observed actual usage, we see a clear role for SUM‘s in future studies.

On average there was no overall detectable decline in wood usage for treatment homes. At the same time, there was a small decline in wood usage for medium-sized (7-12 people) households in the treatment group, and a similar drop for adult age equivalent small size households equivalent to 6 adults or less. Consistent with low usage of the solar oven and continued usage of traditional stoves, there was no detectable effect of solar ovens on time spent collecting fuel or on time spent next to the cook fire. There is no evidence solar ovens reduce exposure to carbon monoxide or self-reported respiratory symptoms such as coughs and sore throats.

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| **Table 1: Sample Size and General Attendance on Survey Days** |
|   | Random- ized treat-ment | Random-ized control | Total intention to treat | Treatment with at least one other treatment in com-pound | Control with at least one other treatment in compound | Only one control in compound |
|
| Households Inscribed in the Program who took Baseline | 465 | 325 | 790 | 171 | 159 | 226 |
| Withdrew from study either at 1 month follow-up or 6 month follow-up | 12 | 36 | 48 | ... | ... | ... |
| Number Households who took Baseline including those who subsequently withdrew | 477 | 361 | 838 | 184 | 186 | 300 |
| Baseline survey | Original respondent | 430 | 303 | 733 | 158 | 148 | 208 |
| Original respondent absent, but another woman in compound responded for her | 35 | 22 | 57 | 11 | 11 | 18 |
| Total who completed survey | 465 | 325 | 790 | 171 | 159 | 226 |
| Absent at Baseline  | 23 | 36 | 59 | 13 | 27 | 74 |
| Baseline wood weighing | Yes, woman weighed wood | 421 | 275 | 696 | 170 | 149 | 208 |
| No, cook with gas | 19 | 17 | 36 | 1 | 3 | 12 |
| No, took survey but left before wood weighing | 25 | 33 | 58 | 0 | 7 | 6 |
| Follow-up survey | Original respondent | 230 | 165 | 395 | 69 | 54 | 122 |
| Original respondent absent but another woman in compound responded for her | 214 | 135 | 349 | 63 | 56 | 95 |
| Absent at follow-up | 21 | 25 | 46 | 39 | 49 | 9 |
| Total who Completed Survey | 444 | 300 | 744 | 132 | 110 | 217 |
| Follow-up wood weighing | Yes, woman weighed wood | 406 | 271 | 677 | 128 | 106 | 193 |
| No, cook with gas | 27 | 16 | 43 | 4 | 4 | 10 |
| No, took survey but left before weighing wood | 11 | 13 | 24 | 0 | 0 | 14 |
| CO Tubes | Sub-sample CO tube | 166 | 109 | 275 | 39 | 38 | 84 |



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| **Table 3: Regression: Follow-up Kg. of Wood used Yesterday** |
| Coefficient (standard error) | y= Kg. of wood used yesterday, and Model 3 is the reduced form |
|   | 1 | 2a | 3 |
| Cook for 6 persons or less \*Treatment indicator c | 0.31 (0.73) | 0.20 (0.72) | ... |
| Cook for 7-12 persons \*Treatment indicator c | -1.38 (0.48)\*\* | -1.43 (0.48)\*\* | ... |
| Cook for 13 persons or more \*Treatment Indicator c | 0.10 (0.56) | -0.09 (0.54) | ... |
| Cook for 6 persons or less c | ... | ... | ... |
| Cook for 7-12 persons c | 1.75 (0.66)\*\* | 1.75 (0.65)\*\* | ... |
| Cook for 13 persons or more c | 2.43 (0.71)\*\*\* | 2.12 (0.73)\*\* | ... |
| Village fixed effects b | Yes\*\*\* | Yes\*\*\* | Yes\*\*\* |
| Lunch kg. of wood used b | ... | 0.29 (0.09)\*\*\* | ... |
| Amount of money spent last week on gas b | ... | 0.01 (0.00)\*\* | ... |
| Cook for 6 persons or less \*Treatment indicator b | ... | ... | -2.65 (0.91)\*\* |
| Cook for 7-12 persons \*Treatment indicator b | ... | ... | -1.47 (0.55)\*\* |
| Cook for 13 persons or more \*Treatment Indicator b | ... | ... | 0.48 (0.47) |
| Cook for 7-12 persons b | ... | ... | 0.16 (0.64) |
| Cook for 13 persons or more b | ... | ... | 0.06 (0.61) |
| Constant | 12.12 (0.80)\*\*\* | 6.29 (1.34)\*\*\* | 13.91 (0.71)\*\*\* |
| R2 | 0.291 | 0.343 | 0.283 |
| Observations  | 659 | 659 | 677 |
| Notes: ~ p<.10, \* p<0.05, \*\* p<0.01, \*\*\* p<0.001; Dependent variables are compressed to the 5th and 95% percentiles and imputed when missing; Data is only for those who have completed the baseline survey.  |
| a Other control variables included in Model 2 but not statistically significant and thus not shown include Baseline number of people for who whom women prepared lunch, Baseline number of people for whom women prepared lunch centered and squared; Baseline amount of money spent last week on wood and charcoal; Baseline kg. of flour and rice consumed per capita per week; terciles of low, medium, and high salary for women and their husbands. |
| b This explanatory variable comes from the baseline survey |
| c This explanatory variable comes from the Six Month Follow-up |

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| **Table 4: Regression Results** Coefficient (standard error) |
|  | 1 | 2 | 3 | 4 | 5 |  6 |
|   | Min. /day by cookfire | Min. / week household gathers fuel 2,4 | Exposure to Carbon Monoxide (ppm/ hour) | Own symptoms associated with cooking (0-4) | Own respiratory symptoms (0-7) | Child respiratory symptoms (0-4)5 |
| Cook for 6 persons or less \*Treatment indicator b | 18.26(19.74) | -77.17 (84.64) | 6.53(2.64)\* | 0.25 (0.27) | 0.15(0.46) | -0.07  (0.16) |
| Cook for 7-12 persons \*Treatment indicator b | -16.15(13.51) | 39.98(57.93) | 0.33(1.78) | -0.17(0.18) | 0.11(0.32) | 0.07  (0.11) |
| Cook for 13 persons or more \*Treatment Indicator b | -0.21(15.48) | 80.85(66.38) | 0.19(2.16) | -0.09(0.21) | 0.23(0.36) | 0.26 (0.13)\* |
| Cook for 6 persons or less b | ... | ... | ... | ... | ... | ... |
| Cook for is 7-12 persons b | 18.73(21.97) | -1.70(93.97) | 0.95(2.89) | 0.24(0.30) | 0.33(0.51) | 0.02 (0.18) |
| Cook for 13 persons or more b | 15.81(35.81) | -40.57(153. 25) | 3.99(4.93) | 0.10(0.48) | -0.19(0.84) | -0.04 (0.29) |
| Village fixed effects a | Yes\*\*\* | Yes\*\* | Yes\* | Yes\*\*\* | Yes\*\*\* | Yes\*\*\* |
| Lunch kg. of wood used a | 0.42(2.45) | 21.03 (10.49)\* | 0.07(0.32) | -0.01(0.03) | 0.04(0.06) | 0.02 (0.01) |
| No. people woman reports cooking for a | 0.69(1.22) | -2.51(5.24) | -0.07(0.15) | 0.02(0.02) | 0.01(0.03) | 0.02 (0.02) |
| Enclosed or semi-enclosed cooking area (not wall-less roof or open air) 3,b | -3.54(10.65) | -66.24 (45.66) | -2.16(1.36) | 0.16(0.14) | -0.08(0.25) | -0.10 (0.09) |
| # of 7 Women Respiratory Symptoms a | ... | ... | 0.11(0.23) | 0.03(0.02) | -0.02(0.00) | -0.01 (0.01) |
| # of 4 Respiratory Symptoms by Average Child a | ... | ... | -1.08(0.70) | 0.04(0.07) | 0.21(0.12) | 0.07 (0.04) |
| Minutes per day next to cook fire in preparing 3 meals a | 0.02(0.04) | 0.00(0.16) | 0.01(0.00) | -0.01(0.00) | -0.01(0.00) | 0.00 (0.00) |
| Min/week entire household collects wood a | ... | -0.01(0.03) | ... | ... | ... | ... |
| # of Husband's Respiratory Symptoms b | ... | ... | ... | 0.06(0.02)\*\* | 0.27 (0.04)\*\*\* | 0.01 (0.01) |
| Constant | 188.83\*\*\* (40.66) | 184.85 (177.41) | 11.52(5.46)\* | 1.92(0.59)\*\* | 3.78 (1.01)\*\*\* | 0.42 (0.35) |
| R2 | 0.100 | 0.141 | 0.294  | 0.106 | 0.139 | 0.299 |
| Observations | 701  | 704 | 250 | 701 | 701 | 660 |
| 1 All Regression specifications contain additional control variables not shown in this table and include: Number of people women cook for at baseline centered and squared, Amount of money spent on Charcoal, Wood, and gas at baseline, dummy variables for women's and her husband's household income at baseline, and kilograms of both flour and rice consumed per week at baseline by household. |
| 2 Additional Control Variables are the same as in footnote 1 with the addition of Total time spent by all the household collecting fuel at the baseline. Further, the y variable represents only households who women and/or other households report positive time spent collecting fuel. |
| 3 This is from the CO survey  |
| 4 A separate regression analysis replacing total household time (minutes/day) spent collecting fuel with only Women's time spent collecting fuel, the results (apart from Village FE's) remain insignificant. And as time spent collecting wood has a high variance due to some of our population collecting wood in stock we top and bottom code the time spent collecting fuel on the sixth month survey and rerun our regressions, but again they remain insignificant.  |
| 5 Because surveyors did not have a list of women's children at the six month follow-up to prompt women to report for the entire household it is possible that women did not report symptoms of ARI for all children present in the household. Thus, to avoid bias, we averaged all symptoms of all children reported per household to generate an "Average Child per Household" of ARI symptoms for all children 5 and under. |
| a This explanatory variable comes from the baseline survey |
| b This explanatory variable comes from the Six Month Follow-up |  |   |  |

1. We document these claims and describe the datasets below. Data from the next two paragraphs are from the baseline survey except data on cooking structures which is from the subsample of our six-month follow-up where we measured carbon monoxide exposure. [↑](#footnote-ref-1)
2. We also fielded a one-month follow-up, but solar oven usage was so low that first month (9% on average) that we only look for effects using the 6-month follow-up. [↑](#footnote-ref-2)
3. The ibutton is sold by Maxim. We appreciate advice from the RESPIRE team on the ibutton SUMs. [↑](#footnote-ref-3)
4. 41% (236) of treatments had one or more treatment and/or controls living in the compound and 54% (176) of control households have one or more treatments and/or controls living in the compound. (see web appendix 5) [↑](#footnote-ref-4)
5. Measured CO exposure was higher at baseline, but we believe measurement problems biased up those results. [↑](#footnote-ref-5)
6. The other common complaints were that it cooked too slowly (35%) and was not durable (11%). [↑](#footnote-ref-6)
7. An additional barrier was that the solar oven required women simmer, not fry, rice for the most common lunch meal of *ceebu jën* (Beltramo and Levine 2010). [↑](#footnote-ref-7)