# Monitoring and Evaluation of the Jiko Poa Cookstove in Kenya

**Berkeley Air Monitoring Group**

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# Executive Summary

The Jiko Poa is a locally manufactured rocket-type biomass cookstove being distributed in Kenya by the Paradigm Project[1]. The aim of this study was to provide a performance assessment for the Jiko Poa in Kenyan homes by analyzing its effects on household air pollution and fuel use, and by collecting qualitative and quantitative data on how the households valued and used it. The study employed a 'before after' design: initial baseline measurements and surveys were conducted in the homes, after which the Jiko Poa was introduced and a second round of measurements and surveys were carried out about two weeks later. The air pollution and fuel use indicators as well as qualitative metrics of usage and preferences were measured over the two 24-hour periods only. Quantitative measures of usage from temperature sensors were collected continuously over a longer time horizon for all the cooking devices in the home, starting after the introduction of the new stove and continuing in a subset of homes for 10 weeks.

Study components include:

- Temperature-based continuous stove use monitoring systems (SUMS) in 26 households;
- 24-hour measurements of fuel use and kitchen carbon monoxide (CO) and fine particulate ($PM_{2.5}$) concentrations in 50 households; and
- Qualitative survey of cooking habits and preferences in 50 households.

Study results revealed that all 50 households used wood as their primary fuel. Almost all households used a three-stone fire, but there were a few Jiko Kisasa and other idiosyncratic simple traditional stoves at baseline. A handful of homes had charcoal and/or LPG stoves available, but their use was reported to be minimal.

According to the survey, the four most important features of a good stove were that it used little fuel, cooked quickly, produced less smoke, and looked modern. These were the main reasons that households decided to purchase the Jiko Poa. Other important qualities were durability, portability, that the food tasted good, and that the kitchen and pots were cleaner. Nearly all participants felt that the Jiko Poa had all or most of the characteristics they valued.

[1] The Paradigm Project (http://www.theparadigmproject.org/home) is a social enterprise working to create sustainable social, economic, and environmental value within developing world communities. They plan to distribute 5 million stoves worldwide by 2020.

The survey results showed that cooks responded favorably to the Jiko Poa and reported using it for almost all of their cooking during the second 24-hour monitoring period. The stove-use sensors (SUMS), which track stove temperatures in order to create an objective record of the time the stove was lit, supported the reported data, showing that the Jiko Poa was used almost exclusively in this first 24 hour period.

During the first five weeks following the Jiko Poa's introduction, however, usage gradually decreased each week from an average of 1.3 uses per day during the first week to 0.4 uses per day during the fifth week. During the same time, traditional stove use also decreased from 1.6 to 1.0 uses per day. Overall wood stove usage dropped over time as the rainy season advanced, but no SUMS data was successfully collected on charcoal or LPG stoves, so it is not clear how much cooking was shifted to these devices. For weeks six through ten after the Jiko Poa introduction, the SUMS successfully captured data on 14 households, which showed continued modest but stable usage of the Jiko Poa.

The Jiko Poa usage results reflect the known limitations of the rocket stove technology; the primary reasons given for reduced use of the stove were that the cooks could not leave it unattended for slow cooking items such as githeri (a mix of beans and corn) or that they were not available to give the frequent attention the stove requires. Furthermore the seasonal variation in the availability of wood fuel during the rainy season may have had an impact. Nonetheless the fact that families were still using the Jiko Poa regularly for some cooking tasks 10 weeks after introduction underscores its value to biomass-dependent households.

The study also demonstrated the Jiko Poa's clear superiority in fuel efficiency and in the impact on household air quality over the traditional stove.

- Average wood use during the 24-hour monitoring period decreased significantly by 51% from 10.0 ± 1.5 kg/day before introduction of the Jiko Poa to 4.9 ± 0.9 kg/day after its introduction. Use of charcoal (the only other noticeable secondary fuel) remained low and constant on the two days of monitoring at about 0.1 kg/day.

- In comparing the before and after monitoring periods, we saw a 51% decrease in average 24-hour $PM_{2.5}$ concentrations (2537 ± 667 to 1250 ± 318 $\mu g/m^3$) and a 37% reduction in CO concentrations (38 ± 6 to 24 ± 5 ppm). Both reductions were statistically significant ($p=0.000$).Even after these reductions, however, pollution levels were 36 times the least stringent level that the World Health Organization (WHO) considers acceptable (Interim Target 1) for fine particulate matter and 2 to 5 times higher than the average recommended concentration guidelines for CO.

- Measured ambient (or background) $PM_{2.5}$ concentrations measured ranged from 3 to 92 $\mu g/m^3$ with a mean concentration of 22 $\mu g/m^3$ and median of 8 $\mu g/m^3$.

While the indoor air pollution reductions documented in this study are substantial and robust and comparable to those seen in similar studies in Sub-Saharan African, they must be taken in context in order to inform on potential health benefits. Both the baseline and after concentration levels indicate that the study kitchens were very unhealthy human environments. Despite the consistent performance of the intervention stoves, pollution levels were 36 times the least stringent level that the WHO considers acceptable for particulates and two to five times higher than the average recommended concentration limits for CO. Future research should focus on assessing how much time various household members spend in these smoky environments in order to better assess health impacts.

Finally the survey also sought to characterize the cooks' perceived benefits from adopting the Jiko Poa. Of the 92% of households reporting time savings and 80% of households reporting monetary savings from reduced fuel purchases, most invested that time or money into their homes and farms. The reported time saved was most often spent working on the farm, tending animals, or doing other household chores. Average monetary savings were $2.59 per week and generally used to purchase food, other household necessities, school supplies, or pay school fees. Those households with businesses outside of the home reported devoting the extra time and money to the business.

# 1 Introduction

## 1.1 Study Background and Objectives

Under Strategic Objective 4, the WASHplus project has the mandate to direct USAID resources towards testing new and innovative approaches and tools for implementation of high-impact indoor air quality interventions. As a result, Berkeley Air Monitoring Group was funded under this directive to work with WASHplus lead FHI360 and core partner Winrock International to leverage and extend an existing stove field testing program in Kenya to include a promising locally manufactured advanced biomass stove that would not otherwise have been evaluated. The results are expected to assist the USAID mission in Kenya and its implementation partners as they work to scale-up improved biomass stoves and to inform the sector more broadly on the field performance of rocket biomass stoves in Africa.

The aim of this study was to provide an assessment of the household air pollution, fuel use, behavior change, and socioeconomic impacts resulting from introduction of the Jiko Poa, a locally produced rocket-type biomass stove, in Kenyan households. The stove is currently being distributed by a social enterprise, the Paradigm Project[1], through direct sales and partnerships with NGOs. This study sought to measure impacts of the stove in households that were representative of typical direct purchasers of the stove (not those receiving the stove from NGOs). In order to achieve this, households in wood-using villages that were interested in purchasing the stove but had not yet received it were identified through a local dealer and were offered a discount in return for allowing monitoring to take place in their homes. A ‘before after’ study design was used where baseline measurements were made before introduction of the Jiko Poa. Then, households received the new stove and a second round of measurements was completed about two weeks later, once cooks had adjusted to using the new stove.

## 1.2 Study Location and Timing

The study took place in villages near the towns of Nyahururu and Embu in the Central Province of Kenya (Figure 1). Nyahururu households were located at an altitude of 2600 to 2800 m where weather was cool enough to require space heating. Embu households were at an altitude of 1200 to 1300 m where temperatures were warmer.

Fieldwork took place from mid-October through mid-November 2011. This was during the shorter of two Kenyan rainy seasons, which runs from mid-October through November. The data collection activities were scheduled to follow immediately after a similar study was done in the same region with the Envirofit G3300 rocket biomass stove.  This timing allowed Berkeley Air to reduce study costs by sharing training and instrumentation across both projects.

**Figure 1: Map of study location**

## 1.3 Traditional and Intervention Stoves

A three-stone fire was the most common stove used at baseline. Stones were either set in a triangle (Figure 2a) or arranged with the three stones forming a U-shape. Several homes had a Jiko Kisasa (also known as the Maendaleo) (Figure 2b). A few had other types of wood-burning stoves (Figures 2c-e), and charcoal stoves were also present in some homes. While 10 of the households owned an LPG stove, few used it on a regular basis. When LPG was used, it was generally only for making tea, heating water, or reheating food.

The intervention stove was the Jiko Poa, a locally made rocket stove (Figure 2f). The rocket stove, developed in the 1980s, is a stove with an L-shaped chamber where sticks are fed into the horizontal opening and the pot is placed on top of the vertical opening. This design is meant to improve combustion and heat transfer by insulating the chamber around the fire, generating a good draft to the fire, and lifting the sticks off of the ground (Bryden et. al. 2005).

**Figure 2: Stove photos: (a) three-stone fire, (b) Jiko Kisasa, (c-e) other baseline stoves, and (f) Jiko Poa.**


# 2 Methods

## 2.1 Study Design

This study was designed as a semi-controlled household experiment to monitor the household air pollution, fuel use, and socioeconomic effects of the Jiko Poa wood cookstove in Kenyan households.

The evaluation was planned to test the impact of the stoves in typical households under normal conditions and usage patterns. Sampling took place only on days when cooking was expected to be typical of an average day, to ensure that measurements would be comparable. During the after measurements, cooks were asked to use the improved stove at least some of the time, though they were allowed to use other stoves for some tasks if that was what they normally did. These somewhat controlled conditions allowed the study to test the performance of the stoves under realistic conditions.

The study was conducted according to a ‘before after’ study design. First, baseline measurements were made in each home. Then, study households received stoves in retail packaging and were shown how to use the stove properly. An attempt was made to mimic the typical purchase experience as closely as possible, although the intervention stoves were delivered to the homes by the study team because it was not feasible to have the commercial distributer visit the village each day. The households were then given about two weeks to adjust to using the new stove before the survey team returned to collect the after measurements. No control group was necessary since this was a short-term assessment.

24-hour measurements of fuel use and kitchen carbon monoxide (CO) and fine particulate ($PM_{2.5}$) concentrations were taken in 50 households. A socioeconomic survey was conducted in all households at the end of the monitoring period. This covered time and monetary savings associated with the Jiko Poa as well as user impressions of the intervention stove. Demographic information was collected for all households as was information on all meals cooked, other sources of indoor air pollution during the monitoring period, cooking habits, and seasonal variation.

Temperature-logging sensors were installed on all stoves in a subset of homes to track stove usage and adoption over a longer time period (10 weeks). The extent to which the introduced stove is used over the longer term will determine the extent to which indoor air pollution and fuel measurements made under somewhat controlled conditions can be applied to uncontrolled conditions.

## 2.2 Household Selection

Study participants were recruited with the assistance of a local dealer selling stoves for the Paradigm Project. The dealer had previously identified groups of women interested in purchasing the stove. Households were then offered a discounted price in return for participation in the study ($10 compared with $15 suggested retail price). All group members who met the study criteria -- that they had an indoor wood stove and used it for most cooking activities -- were invited to participate. Additional eligible households not on the original list were recruited until the target number of 25 households in each village was reached.

## 2.3 Stove Use and Adoption

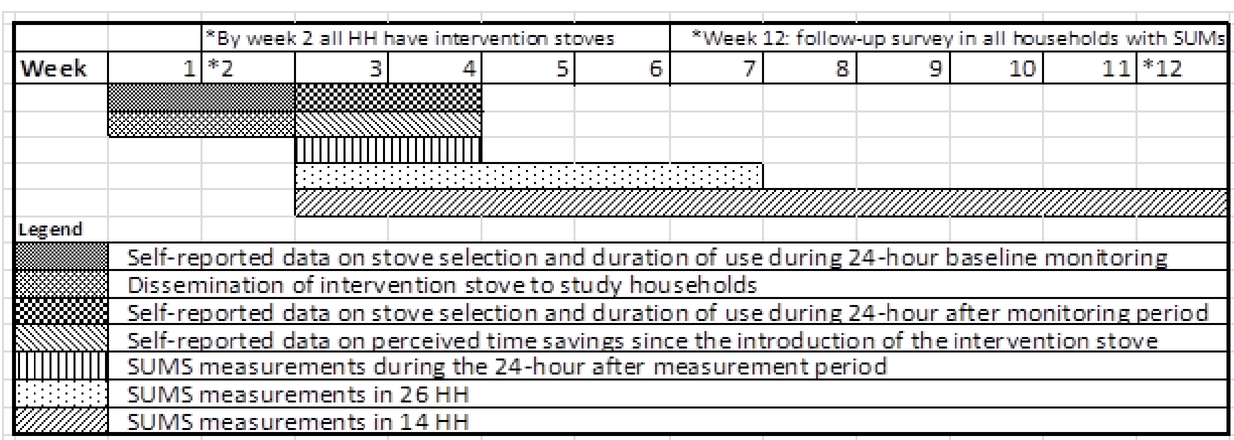
Table 1 below details stove use and adoption assessment methods used in this study, including surveys and temperature-logging sensors. The Stove Use Monitoring System (SUMS) (Figure 3) uses temperature-logging sensors affixed to the stove to collect data on frequency and duration of stove use. The sensors (iButton model DS1922T) were affixed to the back of each of the stoves (traditional wood, intervention, and any other stove present) and onto the kitchen wall in 26 homes. The SUMS recorded the stove temperature every seven minutes for five weeks in 26 households and for ten weeks in 14 households.

**Figure 3: Stove Use Monitoring System (SUMS)**

**Table 1: Stove use and adoption assessment methods**

| Method of Data Collection | Method Details | Resulting Usage Information |
|---|---|---|
| Stove use survey administered at the end of each 24-hour monitoring period (before and after Jiko Poa introduction) | Cooks were asked which stoves they used and for how long. In the after survey, they were also asked to estimate their cooking time savings in general, if any. | Reported number of stove uses and cooking time by stove type during the two 24-hour monitoring periods (before and after).<br><br>Reported general estimate of cooking time savings. |
| Stove use monitoring sensors (SUMS) | SUMS placed on all stoves in households during the after monitoring, and stove temperatures recorded for five weeks in 26 households and ten weeks in 14 households. | Measured number of uses during the 24-hour after monitoring.<br><br>Measured number of daily and weekly stove uses for an additional 5-10 weeks. |
| Follow-up survey | After 10 weeks, households were asked if they were still using the Jiko Poa and, if not, why. | Estimated stove adoption and reason for adoption patterns. |
| Stove use survey and SUMS comparison | Integrate survey results with SUMS data during the after monitoring period by comparing reported cooking activities to SUMS data. | Estimated discrepancy between cooks' reported stove use and measured stove use during the two 24-hour monitoring periods. |

**Figure 4: Timeline of Usage and Adoption Assessments**



## 2.4 Fuel Efficiency Assessment

Fuel efficiency was measured using a one day version of the Kitchen Performance Test Version 3.0 (Bailis, Smith, and Edwards 2007). All fuels to be used were weighed at the beginning and end of the 24-hour monitoring period. Fuels were weighed with Salter Brecknell ElectroSamson digital scales (Figure 5). Scales with 40 kg maximum capacity and 0.05 kg accuracy were used in most cases. All scales were calibrated before and throughout the study to ensure accurate readings.

Moisture readings were taken at the beginning of each monitoring period with a Delmhorst BD-2100 moisture meter so that fuel weights could be corrected to account for wood moisture (Figure 5).

**Figure 5: Fuel weighing and moisture readings**

## 2.5 Household Air Pollution Monitoring Methods

The air samplers and real-time monitors were placed in the kitchen. All equipment was collocated one meter from the stove and 1.5 meters above the floor (Figure 6). Equipment was placed in secure bags to reduce noise and to avoid disturbance to the monitors.

**Figure 6: Collocated monitors in a home**

During sampling, minute-by-minute kitchen concentrations were recorded using real time data-logging monitors for $PM_{2.5}$ (UCB-PATS, Berkeley Air Monitoring Group, Berkeley, CA USA) and CO (Pac 7000, Dräger, Lübeck, Germany) in all households.

Gravimetric $PM_{2.5}$ samples were also collected in half of the households using BGI Triplex cyclones (BGI Inc., Waltham, MA, USA) equipped with 37 mm diameter Teflon filters at a flow rate of 1.5 liters/minute using constant flow pumps (Casella Apex Pro, Casella CEL Inc., Buffalo, NY, USA). This achieved a median cut point of 2.5 μm.

During the first monitoring visit, kitchen, window, and door dimensions were measured, and the location of the monitoring equipment was recorded in order to ensure consistency in subsequent monitoring rounds.

Ventilation rates in all homes were estimated by calculating the rates that the kitchen CO concentrations decreased at the end of the cooking events according to the method described by McCracken and Smith (McCracken and Smith 1998). The ventilation rates are expressed in air exchanges per hour, the number of times per hour that the air in the room is completely replaced.

## 2.6 Ambient Air Quality

In order to assess background pollution levels, 24-hour gravimetric $PM_{2.5}$ samples were collected from ambient air in the vicinity of participating households using an AirMetrics MiniVol $PM_{2.5}$, $PM_{10}$ Sampler (Eugene, OR USA). 47 mm 2-micron Teflon filters with built-in support rings were used for sampling with a flow rate of 5 L/min. The MiniVol was placed in a location where it would not be disturbed, such as on the roof of a home or latrine (Figure **7**). The MiniVol's location varied to cover several locations within each village in order to get a representative sample of ambient particulate levels in the two villages.

**Figure 7: MiniVol placement**

## 2.7 User Perspectives and Assessment of Perceived Savings and Other Benefits

A questionnaire was administered to the main cook in the home after each 24-hour monitoring period (Figure 8). The questionnaires were written and answers recorded in English though the survey was administered in a local language (Swahili or Kikuyu). All members of the field team were fluent in English and Swahili, while two also spoke Kikuyu. Questions were pretested during the initial fieldwork that was expanded to include the Jiko Poa. Responses were recorded electronically via an Android phone (Samsung Galaxy Fit) or tablet computer (Viewsonic Viewpad 7). Household members were asked about their cooking activities during the sampling period, including time spent cooking, foods cooked, fuel type used, number of people cooked for, household demographics, and other sources of indoor air pollution, such as lamps, cigarettes, and incense. Perceptions of time and monetary savings, as well as frequency of stove use and impressions of the improved stoves were also collected.

**Figure 8: Surveyor administering questionnaire**

# 3 Results

## 3.1 Household Demographic Characteristics

Table 2 describes the demographic characteristics of study households. Households tended to be quite poor with nearly half reporting income of less than one dollar per day, and only 36% of households having electricity. Few participants had education beyond secondary school, and many had only a primary school education.

**Table 2: Household demographic characteristics**

| | | | | | |
|---|---|---|---|---|---|
| Mean Household Size | 4.1 ± 2.7 (range of 1-9) | | | | |
| Monthly Income (USD) | 0-30<br>48% | 30-60<br>8% | 60-90<br>0% | >90<br>2% | Did Not Respond<br>42% |
| Female Head of Household Education | None<br>14% | Primary School<br>44% | Secondary School<br>40% | Technical College<br>2% | |
| Male Head of Household Education | None<br>5% | Primary School<br>45% | Secondary School<br>31% | Trade School<br>19% | |
| Household's Main Income Source | Farming<br>72% | Commerce<br>2% | Salaried Position<br>16% | Temp. Employment<br>6% | Assistance from Children<br>4% |
| Electricity | Yes<br>36% | No<br>64% | | | |

| | | |
|---|---|---|
| Cell Phone Ownership | Yes 94% | No 6% |
| TV Ownership | Yes 62% | No 38% |
| Radio Ownership | Yes 88% | No 12% |
| Bicycle Ownership | Yes 50% | No 50% |
| Motorcycle Ownership | Yes 10% | No 90% |
| Refrigerator Ownership | Yes 2% | No 98% |
| Toilet Type | Private 94% | Public 6% |

Nearly all households had kitchens that were separate structures from the main house or had a chimney in the main house. Kitchens tended to be made of wood and corrugated metal with soil floors. 90% of households had a three-stone fire as the traditional stove with the stones either arranged in an equilateral triangle or a U-shape. 43 of the 50 households also owned a charcoal stove, while 10 owned an LPG stove (Table 3).

**Table 3: Kitchen characteristics of participating households**

| | | | | | | |
|---|---|---|---|---|---|---|
| Kitchen Location | Separate Room in Main House 16% | Separate Structure 84% | | | | |
| Cooking Location | Always Indoor 84% | Mostly Indoor 14% | Equally Indoor/Outdoor 2% | | | |
| Kitchen Wall Material | Concrete 10% | Wood 66% | Corrugated Metal 6% | Brick 4% | Clay 2% | Soil 12% |
| Kitchen Roof Material | Wood 2% | Corrugated Metal 96% | Soil 2% | | | |
| Kitchen Floor Material | Concrete 12% | Clay 2% | Soil 84% | Dung and Ash 2% | | |
| Open Eaves | Yes 80% | No 20% | | | | |

| | |
|---|---|
| Mean Kitchen Volume | 17.8 ± 5.8 $m^3$ (range of 5.2 – 50.0) |
| Baseline Wood Stove | Open Fire \| Jiko Kisasa \| Other<br>90% 4% 6% |
| Chimney | Yes \| No<br>16% 84% |
| Charcoal Stove Ownership | Yes \| No<br>86% 14% |
| LPG Stove Ownership | Yes \| No<br>20% 80% |

## 3.2 Stove Use and Adoption

Stove use and adoption outcomes are presented here from three perspectives. Section 3.2.1 presents the results of survey questions related to stove usage that were asked of participants on the baseline and after monitoring days about their practices during the preceding 24 hours. The reliability of this data is examined in section 3.2.3, which compares the respondents' recollection of their cooking activities during the 24-hour monitoring period with measurements taken for the same time period with temperature loggers (SUMS). Finally, a longer-term assessment of the adoption process is provided in section 3.2.2, where the results of 5 and 10 weeks SUMS measurements are presented. Note that all of these results are qualitatively distinct from the time-related results of the behavioral survey (section 3.5.3.1), which asked residents to compare the relative amount of time they spent cooking meals before and after the acquisition of the Jiko Poa.

### 3.2.1 Reported During Day of Monitoring

At the end of each of the two 24-hour monitoring periods, cooks were asked to recount which stoves they had used, for how long, and for how many people the food had been prepared. This information was used to calculate average daily stove use and cooking time. The data in Table 4 (below) reveals that the study households generally cooked between five and seven times per day, while Table 5 shows that their stoves were lit for six to seven hours each day.

Cooks reported that the baseline stoves (three-stone fire, Jiko Kisasa, and other wood) were almost completely replaced by the Jiko Poa during the second round of monitoring (Table 4 &

Table 5). Although there was a significant increase in reported stove uses between the two monitoring periods (5.3 to 6.8 uses per day), average cooking time did not change significantly. It is unclear whether this indicates a change in the total amount of cooking or if instead there were simply more short uses of the Jiko Poa, since it cannot be left unattended for as long as a traditional stove. No household reported use of an LPG stove during the monitoring periods; therefore use of those stoves is not reported.

**Table 4: Reported average number of stove uses per day by stove type on the two days of monitoring**

| | N | Baseline | After | % Difference | t-test[2] |
|---|---|---|---|---|---|
| All Stoves | 50 | 5.3 ± 0.7 | 6.8 ± 0.7 | 28 | 0.00 |
| 3 Stone Fire | 50 | 4.1 ± 0.7 | 0.2 ± 0.2 | -95 | 0.00 |
| Jiko Kisasa | 50 | 0.66 ± 0.63 | 0.04 ± 0.09 | -91 | 0.05 |
| Other wood | 50 | 0.44 ± 0.49 | 0 | -100 | 0.08 |
| Charcoal | 50 | 0.12 ± 0.16 | 0.14 ± 0.17 | 17% | 0.85 |
| Jiko Poa | 50 | NA[a] | 6.4 ± 0.1 | NA[b] | NA |

[a] Not applicable, as the Jiko Poa was not introduced until the after phase.
[b] Not available, as there is no before measurement; nonetheless there was nearly complete adoption of the Jiko Poa on the day of monitoring.

**Table 5: Reported average cooking time per day (minutes) by stove type on the two days of monitoring**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| All Stoves | 50 | 403 ± 57 | 373 ± 58 | -7 | 0.38 |

[2] A t-test is used to determine whether two groups are statistically different from one another. When a t-test has a p value of less than 0.05, the difference is considered to be significant (we are 95% confident that the values are truly different).

| | | | | | |
|---|---|---|---|---|---|
| Traditional stoves | 50 | 133 ± 222 | 15 ± 54 | -118 | 0.00 |
| Charcoal | 50 | 4 ± 5 | 3 ± 4 | -38 | 0.64 |
| Jiko Poa | 50 | NA[a] | 340 ± 25 | NA[b] | NA |

[a] Not applicable, as the Jiko Poa was not introduced until the after phase.
[b] Not available, as there is no before measurement; nonetheless there was nearly complete adoption of the Jiko Poa on the day of monitoring.

### 3.2.2 Results from Temperature-Based Stove Use Monitoring (SUMS)

26 households had valid SUMS data for both the traditional stove and the Jiko Poa for the first five weeks after the introduction of the Jiko Poa. Over this time we see usage of the Jiko Poa generally decreased each week from an average of 1.3 uses per day during the first week to 0.4 uses per day during the fifth week (Figure 9).

**Figure 9: Average Jiko Poa uses per day for each of the first five weeks of adoption for 26 households. The dashed line indicates the average value for that week**

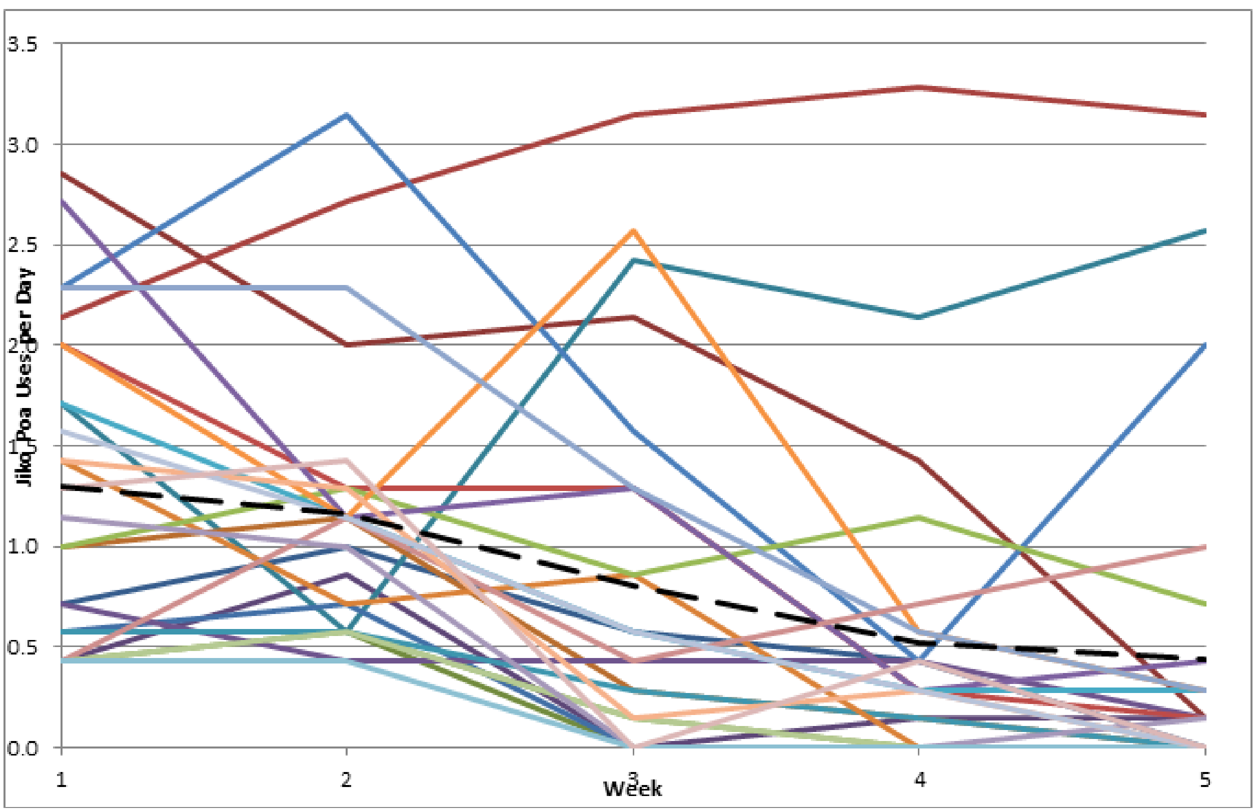


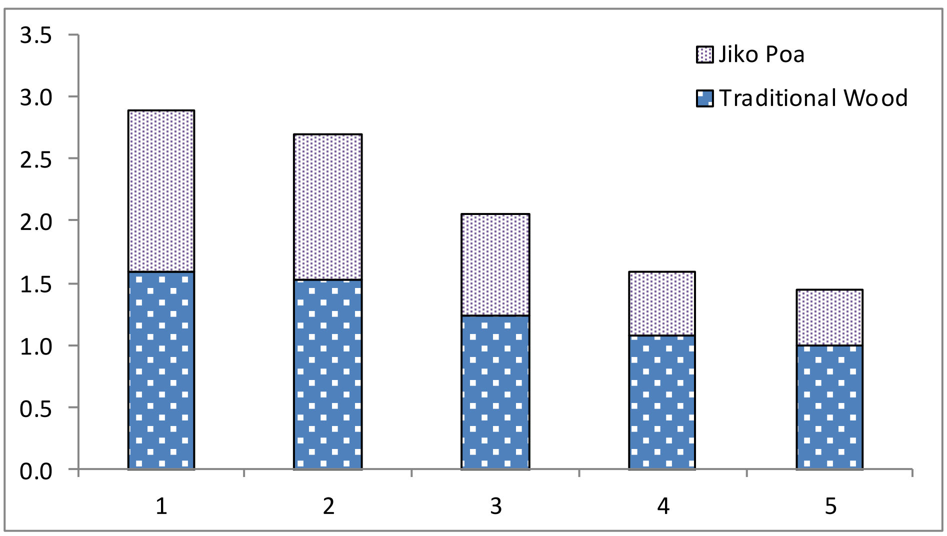

Table 6 and Figure 10 depict the average uses per day of both the Jiko Poa and traditional stove across all households (n=26) for the first five weeks after introduction of the Jiko Poa. In addition to the decline in Jiko Poa use as a fraction of the total wood stove usage per day (from about one half to one third), we also see that overall wood stove usage dropped over time, as the rainy season advanced. The reason for this decline in overall wood stove use is not clear. A few households also had a charcoal and/or LPG stove available, but those data are not included here because we were not able to get valid SUMS data for the charcoal stoves, and LPG use was a very small fraction of total stove use.

**Table 6: Average number of uses per day for the Jiko Poa and traditional wood stove by week**

| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 |
|---|---|---|---|---|---|
| Total | 2.9 ± 2.9 | 2.7 ± 2.4 | 2.0 ± 1.9 | 1.6 ± 1.5 | 1.4 ± 1.4 |
| Jiko Poa | 1.3 ± 1.7 | 1.2 ± 1.6 | 0.8 ± 1.9 | 0.5 ± 1.7 | 0.4 ± 1.8 |
| Traditional | 1.6 ± 2.2 | 1.5 ± 2.1 | 1.2 ± 2.2 | 1.1 ± 2.1 | 1.0 ± 2.1 |

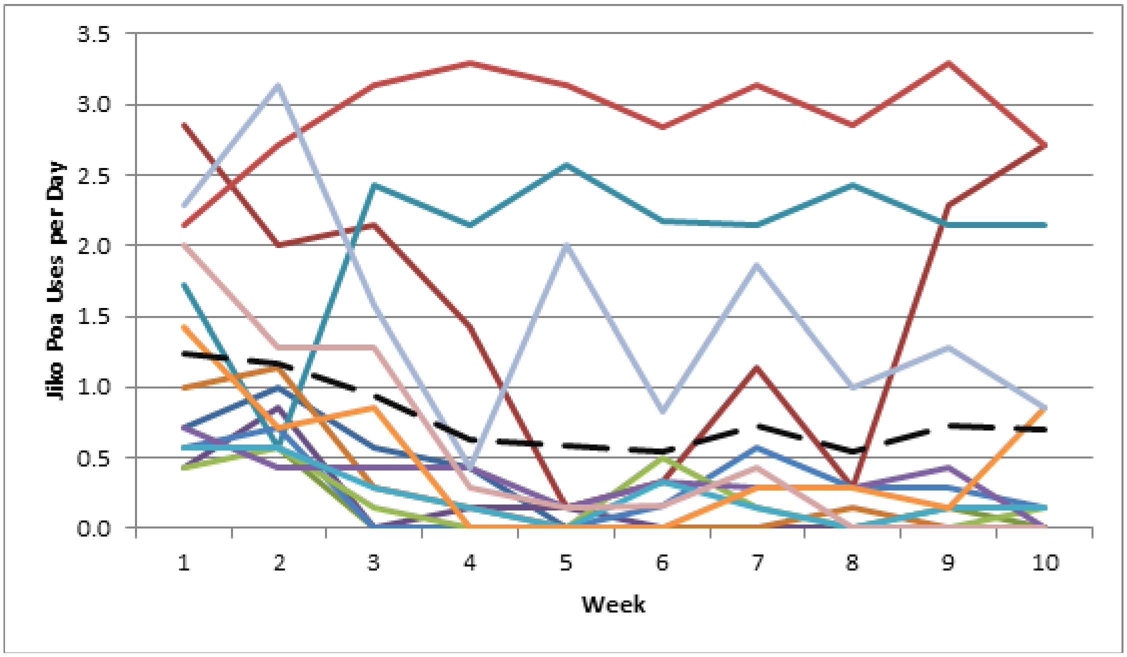
Table 6 depicts the average uses per day of both the Jiko Poa and traditional stove across all households (n=26) for the first five weeks. In addition to the decline in Jiko Poa use as a fraction of wood stove usage, we also see overall wood stove usage dropping over time, as the rainy season advances. The reason for this decline in overall wood stove use is not clear. A few households also had a charcoal and/or LPG stove available, but those data are not included here because the SUMS proved unreliable for charcoal stoves, and LPG use was a very small fraction of total stove use.

**Figure 10: Average uses per day of the Jiko Poa and traditional stove for all households over five weeks**




For the final five weeks of the study (weeks 5-10), the number of households with valid SUMS data drops to 14, and the data is only available for the Jiko Poa stove. This reduced data set is the result of challenges with the SUMS installation, including the placement of the sensors and the method for affixing them to the stove body, which resulted in some sensors overheating and some failing to record data successfully. Nonetheless, Figure 11 shows that Jiko Poa usage seems to have stabilized at an average of 0.5 to 0.7 uses per day for each of these weeks.

**Figure 11: Average Jiko Poa uses per day for each of the first ten weeks of adoption for 14 households. The dashed line indicates the average value for that week**




In response to the SUMS data, we asked the 25 households in Embu[3] whether they were still using the stoves 10 weeks after introduction and if not, why not. Of those households, 13 reported that they continued to use the stove every day, while five others said that they used the stove occasionally. Seven households had stopped using the stove completely. Of the cooks who had stopped using the stove or who only used it occasionally, the primary reasons given were that they could not leave it unattended for slow cooking items such as githeri or that they were not available to give the constant attention the stove requires. Some also did not use it because they found that it cooked slowly or because they had other fuels such as charcoal available.

### 3.2.3 Comparison of SUMS and Survey Data During Monitoring

One of the benefits of the SUMS is that it gives an unbiased account of how much a stove is used. SUMS can therefore be employed to examine the discrepancy between the amount that cooks report using their stoves and their actual stove use (in this case, during the 24-hour period when air pollution and fuel use measurements were also taken). In order to investigate the differences between survey responses and SUMS estimates, we compared the cooking activities reported during the after monitoring periods with the SUMS data from this same period.

[3] These 25 households were comprised of both those who were part of the SUMS subset and those who were not.

These data indicate that cooks in this study were very accurate in reporting their stove use during the 24-hour period when air pollution and fuel-use monitoring took place. The average discrepancy between reported stove use and SUMS estimates was within 10 minutes on average for total stove use as well as for use of the Jiko Poa and baseline wood stove (Table 7).

**Table 7: Average SUMS and reported cooking time (minutes) during the after monitoring period for all wood stoves, the Jiko Poa, and the baseline stove**

| | SUMS | Reported | Difference | t-test |
|---|---|---|---|---|
| All Stoves | 375±44 | 371±62 | 4 | 0.90 |
| Jiko Poa | 331±40 | 336±56 | -5 | 0.83 |
| Baseline | 29±28 | 21±30 | 8 | 0.50 |

These data indicate that cooks in these villages do not appear to have a strong bias in estimating their total amount of cooking or use of the Jiko Poa, with reported cooking times and SUMS estimates distributed fairly evenly around a one-to-one correlation (Figure 12). However, only two of 20 households with valid SUMS files reported using the traditional stove during the monitoring period, while five actually used it for some amount of time (Figure 13).

Note that these results relate only to the 24-hour "after" monitoring period, and do not conflict with the overall decline in Jiko Poa usage that was recorded using SUMS in the 10 weeks following its introduction (see 3.2.2 ). The overall decline in usage is discussed in Results section 4.

**Figure 12: Actual vs. reported cooking time during the 24-hour after monitoring period for each household.**

*N.B. The dashed line indicates a one-to-one correlation, and each dot denotes the comparison of the respondents reported usage time with what the SUMS recorded for the same period. Points* *on the line indicate exact agreement between the two metrics, while points above indicate that respondents underestimated their stove usage time, and points below show they overestimated it. As the points are fairly evenly scattered close to the* one-to-one *line, the data suggests that as a whole the group did not particularly over- or underestimate their usage time.*

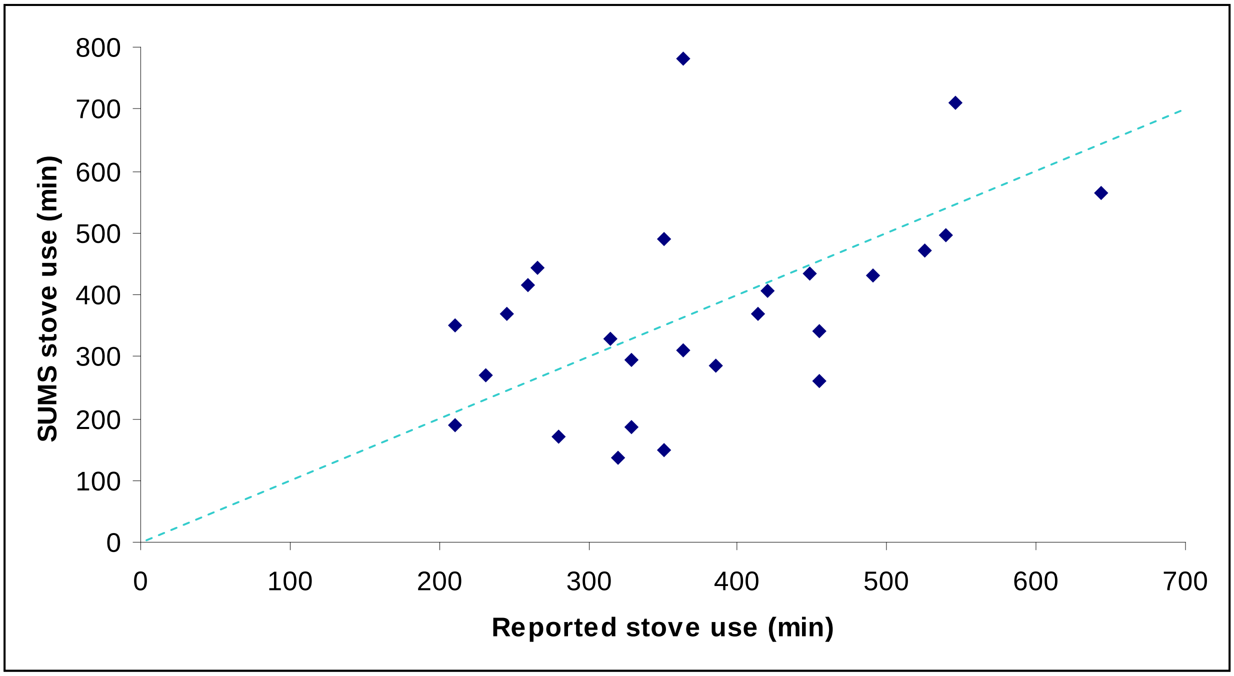
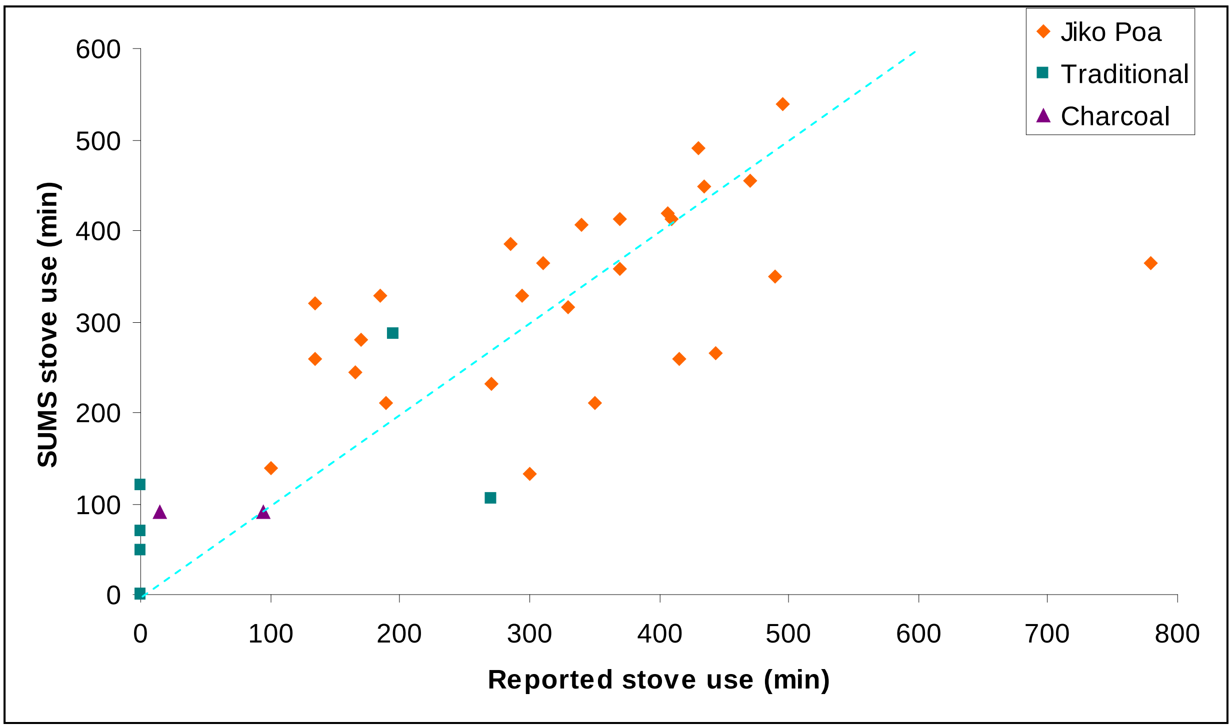


**Figure 13: Actual vs. reported cooking time for the Jiko Poa, traditional stove, and charcoal stove during the 24-hour after monitoring period for each household.**

*N.B. The dashed line indicates a one-to-one correlation, and each dot denotes the comparison of the respondents reported usage time with what the SUMS recorded for the same period. The different shaped points represent the different types of stoves. Points on the line indicate exact agreement between the two metrics, while points above indicate that respondents underestimated their stove usage time and points below show they overestimated it. As the points are fairly evenly scattered close to the* one-to-one *line, the data suggests that as a whole the group did not particularly over- or underestimate their usage time. However, note that square points on the y axis represent respondents who did not report any use of their traditional stove, while the SUMS data showed some usage.*




## 3.3 Fuel Consumption Measurements

Wood and charcoal were the only fuels used in the kitchens during the monitoring periods. The change in fuel use was calculated two ways – total wood used during the 24-hour monitoring period and wood used during the 24-hour period per standard person living in the household. The standard person concept accounts for differences in the amount eaten by men, women, and children. A male age 15 to 65 counts as one standard person, while women and men over 65 count as 0.8 standard person. Children under age 15 count as 0.5 standard person (FAO 1983). Wood savings calculations were similar under both calculation methods (48 to 51% for all households) and highly significant. Charcoal use was small and did not change significantly (Table 8 and Table 9). All wood weights are presented as dry weights, meaning that the weight of the water contained in the wood is not included. As with indoor air pollution measurements, wood use and percent reductions were higher in Nyahururu than in Embu.

**Table 8: Average daily fuel use per household for each fuel type by monitoring round and location.**

| Fuel Type | N | Baseline (kg) | After (kg) | % Change | t-test |
|---|---|---|---|---|---|
| All Wood | 49 | 10.0 ± 1.5 | 4.9 ± 0.9 | -51 | 0.000 |
| All Charcoal | 49 | 0.12 ± 0.12 | 0.05 ± 0.06 | -54 | 0.28 |
| Nyahururu Wood | 24 | 11.6 ± 2.6 | 5.5 ± 1.7 | -53 | 0.000 |
| Nyahururu Charcoal | 24 | 0.13 ± 0.16 | 0.06 ± 0.09 | -51 | 0.35 |
| Embu Wood | 25 | 8.4 ± 1.3 | 4.3 ± 0.8 | -49 | 0.000 |
| Embu Charcoal | 25 | 0.12 ± 0.18 | 0.05 ± 0.09 | -60 | 0.51 |

**Table 9: Average daily fuel use per standard person for each fuel type by monitoring round and location.**

| Fuel Type | N | Baseline (kg) | After (kg) | % Change | t-test |
|---|---|---|---|---|---|
| All Wood | 49 | 3.7 ± 0.6 | 1.9 ± 0.4 | -48 | 0.000 |
| All Charcoal | 49 | 0.05 ± 0.05 | 0.03 ± 0.03 | -43 | 0.37 |
| Nyahururu Wood | 24 | 4.0 ± 0.9 | 2.0 ± 0.6 | -50 | 0.000 |
| Nyahururu Charcoal | 24 | 0.05 ± 0.07 | 0.03 ± 0.05 | -42 | 0.32 |
| Embu Wood | 25 | 3.4 ± 0.9 | 1.9 ± 0.7 | -44 | 0.001 |
| Embu Charcoal | 25 | 0.04 ± 0.06 | 0.02 ± 0.04 | -48 | 0.65 |

### 3.3.1 Seasonal Fuel Consumption

This study took place during the short rainy season in Kenya (October to November). The longer rains fall from March through May.

In order to gain an understanding of the representativeness of fieldwork conducted during the wet season on cooking practices during the rest of the year, participants were asked a series of questions about seasonal differences in fuels used and how they are acquired.

During the dry season, all 50 households reported using wood as their primary fuel. 20 households reported charcoal as a secondary fuel and one used LPG, but only seven of these households reported using their secondary fuel more than one quarter of the time. 68% of households reported collecting all of their fuel during the dry season, while 26% bought all of their fuelwood, and 6% bought most of their fuelwood.

In the wet season, when dry fuelwood is less available, seven of the 50 households reported switching to charcoal as their primary fuel. Additionally, 26 other households continue to use wood as their primary fuel, but use charcoal as a secondary fuel during the wet season. Use of LPG also increases somewhat, with five households using it as a secondary fuel during the wet season. The proportion of households collecting their fuel remains similar during the wet season, with 61% reporting collecting all of their wood.

## 3.4 Household Air Pollution

### 3.4.1 Indoor Air Pollution Concentrations

Gravimetric measurements were used to adjust $PM_{2.5}$ concentrations measured with the UCB-PATS. The equation used for adjustment was calculated by running a regression of the gravimetric values on the UCB values for all households where both monitors were used. This resulted in the equation Grav = 1.087(UCB) + 0.106. The $R^2$ value for this regression was 0.85.

Table 10 and Figure 14 present the particulate matter results. Overall, there was a 51% reduction in $PM_{2.5}$ kitchen concentrations. This corresponded to a 53% reduction in Nyahururu and 48% reduction in Embu. However, in Nyahururu where altitude was higher and temperatures lower, absolute levels were greater, particularly during baseline measurements.

**Table 10: Average 24-hour $PM_{2.5}$ concentration by monitoring period for all households and by village ($\mu g/m^3$).**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| All | 50 | 2537 ± 667 | 1250 ± 318 | -51 | 0.000 |
| Nyahururu | 25 | 2946 ± 707 | 1395 ± 555 | -53 | 0.000 |
| Embu | 25 | 2129 ± 549 | 1105 ± 292 | -48 | 0.000 |

**Figure 14: Average 24-hour $PM_{2.5}$ concentration ($\mu g/m^3$) for each monitoring period by village.**

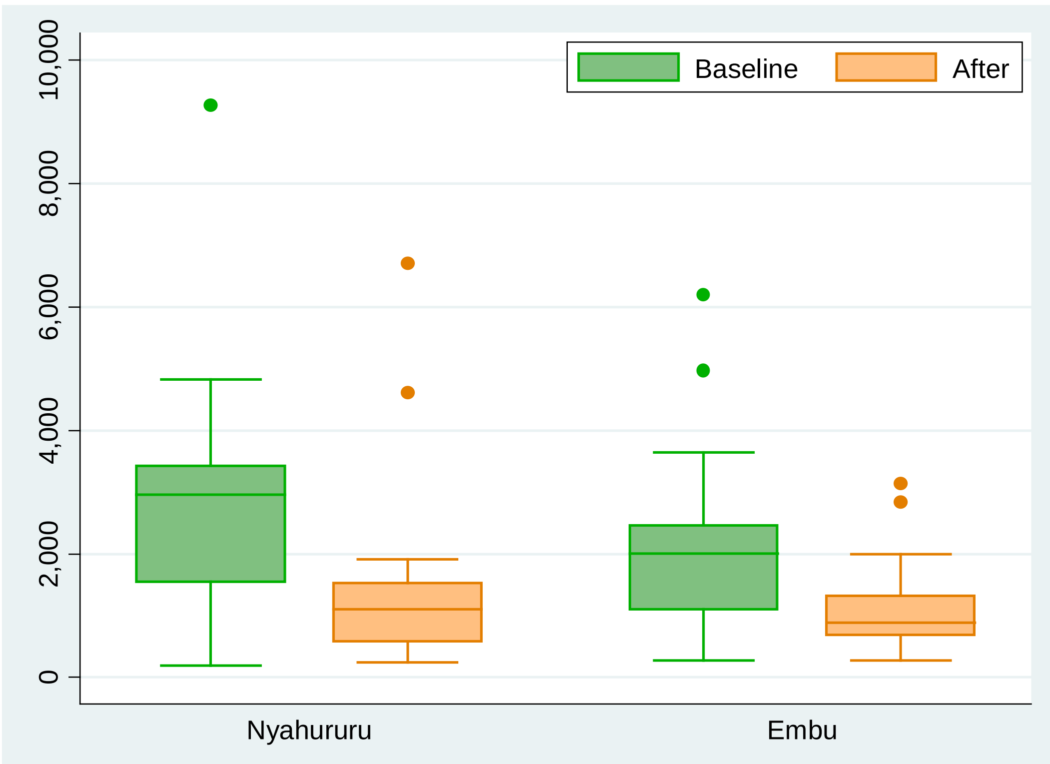
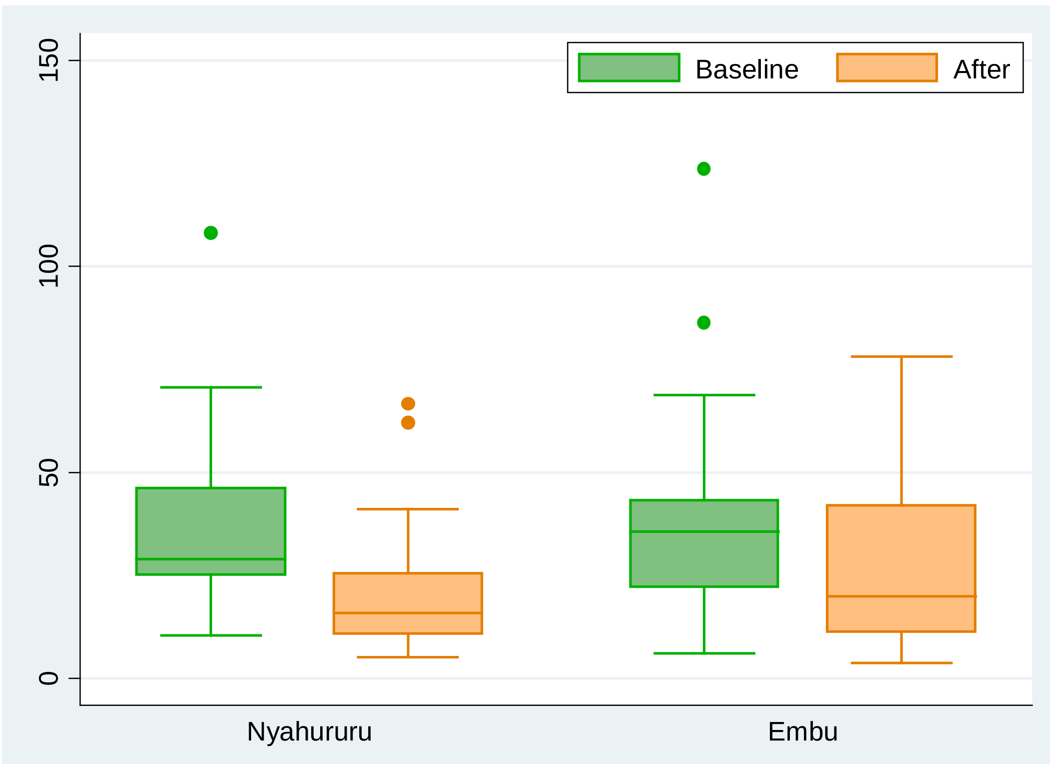



Table 11 and Figure 15 present the carbon monoxide (CO) results. Overall, there was a 37% reduction in CO kitchen concentrations. This corresponded to a 45% reduction in Nyahururu and 29% reduction in Embu. Unlike $PM_{2.5}$, CO baseline kitchen concentrations were similar in the two locations.

**Table 11: Average 24-hour CO concentration (ppm) by monitoring period for all households and by village.**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| All | 50 | 38 ± 6 | 24 ± 5 | -37 | 0.000 |
| Nyahururu | 25 | 38 ± 8 | 21 ± 6 | -45 | 0.000 |
| Embu | 25 | 37 ± 10 | 27 ± 8 | -29 | 0.007 |

**Figure 15: Average 24-hour CO concentration (ppm) for each monitoring period.**




For CO, average concentrations were calculated for the maximum 15-minute, one-hour, and eight-hour intervals during the 24-hour monitoring period, matching the time periods used by the World Health Organization (WHO) in its Air Quality Guidelines. Since CO values were similar across villages, interval values were not broken down by location. Significant reductions of 21%, 32%, and 43% were seen for the 15-minute, 1-hour, and 8-hour maximums, respectively (Table 12).

**Table 12: Maximum CO levels for 15-minute, 1-hour, and 8-hour intervals (ppm).**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| 15 minute | 50 | 243 ± 51 | 191 ± 34 | -21 | 0.046 |
| 1 hour | 50 | 175 ± 36 | 120 ± 22 | -32 | 0.002 |
| 8 hour | 50 | 72 ± 13 | 41 ± 8 | -43 | 0.000 |

### 3.4.2 Factors Affecting IAP

#### 3.4.2.1 Other IAP Sources

Aside from stove use, the important sources of air pollution in participating households were kerosene lamps and cigarettes. However, average use of both was low and did not change significantly between monitoring periods (Table 13).

**Table 13: Reported use of other sources of air pollution in the kitchen during the 24-hour monitoring periods.**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| Kerosene Lamp (minutes) | 50 | 89 ± 24 | 78 ± 22 | -12 | 0.54 |
| Cigarettes (number smoked) | 50 | 0.08 ± 0.07 | 0.10 ± 0.16 | 25 | 0.83 |

#### 3.4.2.2 Ventilation Rates

Ventilation rates in these homes are shown in Table 14 below. Overall, average air exchange rates decreased from 8.0 exchanges per hour in the baseline to 6.8 exchanges per hour during the after monitoring phase. Rates were somewhat higher in Embu than in Nyahururu where weather is cooler. The reduction in the average ventilation rate could be related to changes in weather and/or routine variation in kitchen ventilation practices such as opening doors and windows. It is also possible that people are less likely to open doors and windows when they are using the Jiko Poa than they would be when using a stove with higher emissions. While both average ventilation rates were relatively low, if the ventilation in the after period was as high as in the baseline period, the average indoor air pollution concentrations in the after period would have been somewhat lower and the percent reductions therefore somewhat greater.

**Table 14: Average air exchange rates (exchanges per hour).**

| | N | Baseline | After | % Difference | t-test |
|---|---|---|---|---|---|
| All | 50 | 8.0 ± 1.2 | 6.8 ± 0.8 | -16 | 0.04 |
| Nyahururu | 25 | 7.5 ± 1.3 | 6.4 ± 0.9 | -14 | 0.13 |
| Embu | 25 | 8.6 ± 2.1 | 7.1 ± 1.4 | -17 | 0.14 |

#### 3.4.2.3 Ambient Air Pollution

In total, six ambient $PM_{2.5}$ samples were obtained. Concentrations measured ranged from 3 to 92 $\mu g/m^3$ with a mean concentration of 22 $\mu g/m^3$ and median of 8 $\mu g/m^3$.

## 3.5 User Perspectives and Assessment of Perceived Saving and Other Benefits

### 3.5.1 User Perceptions of Stove Characteristics

According to the survey, the four most important features of a good stove were that it used little fuel, cooked quickly, produced less smoke, and looked modern. These were the main reasons that households decided to purchase the Jiko Poa (Table 15). Other important qualities were durability, portability, that the food tasted good, and that the kitchen and pots stayed cleaner. Nearly all participants felt that the Jiko Poa had all or most of the characteristics they valued. None of the participants listed as important a stove’s suitability to cooking githeri, a staple dish of corn kernels and beans that is cooked unattended at low heat for several hours. This omission is seemingly at odds with the women’s responses to another question about how well the Jiko Poa meets their range of cooking needs. In response to that question, the majority of cooks rejected the statement that it was at least as easy or easier to cook githeri on the Jiko Poa as on their traditional stove (see Table 18 below). At the conclusion of the 10-week study, the Jiko Poa’s unsuitability to cooking this dish was also cited as an important barrier to full adoption.

**Table 15: Main reasons households purchased the Jiko Poa.**

| | |
|---|---|
| Fuel Savings | 86% |
| Cooks Fast | 18% |
| Less Smoke | 16% |
| Modern | 8% |

In half of the households, the wife was the family member who made the decision to purchase the Jiko Poa. In most others it was the husband (20%) or husband and wife together (22%). Nearly all of the cooks reported that the Jiko Poa made them more modern (98%), more admired by their families (100%), and increased their standing in the community (96%). Most bought the stove because it promised fuel savings. Secondary reasons for purchase were reduced smoke and faster cooking. Cooks reported that the stove was well accepted by their families, with only five households reporting that a family member did not approve of their using the stove.

When asked to describe the type of person who would buy the Jiko Poa, the most common responses were someone modern and upwardly mobile. A Jiko Poa customer was also described as someone concerned about saving wood, either because they were an environmentalist or because they had a fuel shortage.

Cooks were also asked why their mother or a neighbor might or might not use the improved stove, in order to bring to light barriers to stove use that someone might not feel comfortable or appropriate to attribute to themselves. These reasons were in line with what attracted participants to the stove. The most common reasons given for why the others might use the stove were that it saves fuel, produces less smoke, and is portable. Reasons they might not adopt the stove were the need for constant tending, dry wood, and small pieces of wood (Table 16).

**Table 16: Reasons a mother or neighbor might or might not adopt the Jiko Poa (multiple answers were accepted).**

| Reasons might adopt | | | Reasons might not adopt | | |
|---|---|---|---|---|---|
| | Mother | Neighbor | | Mother | Neighbor |
| Saves Fuel | 86% | 96% | Requires Constant Tending | 66% | 64% |
| Less Smoke | 74% | 72% | Cannot Use Wet Wood | 48% | 54% |
| Portable | 70% | 70% | Need Small Wood Pieces | 46% | 50% |
| Cooks Fast | 56% | 62% | Cannot Use Big Pots | 44% | 46% |
| Looks Modern | 40% | 58% | Cost | 40% | 44% |

### 3.5.2 Jiko Poa Cooking Tasks

Households reported adopting the Jiko Poa for a variety of tasks (Table 17). In nearly all cases, the Jiko Poa was used for tasks for which the household's baseline wood stove, whether open fire, Jiko Kisasa, or another wood stove, had previously been used. Only one household reported replacing a task for which they had previously used LPG, and three replaced a charcoal stove for certain tasks.

Additionally, households generally found that the Jiko Poa was well suited to cooking their staple foods (Table 18). The one food that the majority of homes did not find to be at least as easy to cook on the Jiko Poa is githeri, a combination of corn kernels and beans that is cooked at low heat for several hours. The mixture is then fried, perhaps with other vegetables, before being eaten. While githeri is being cooked, it is often left unattended over burning embers or smoldering logs for an extended period of time. As the Jiko Poa is not well suited to being left unattended, many households continued to cook githeri on an open fire.

**Table 17: Tasks for which Jiko Poa is used.**

| Uses of the Jiko Poa | Percent of Households |
|---|---|
| General Cooking | 86 |
| Specific Foods | 12 |
| Heating Water | 64 |
| Tea | 58 |

**Table 18: Ease of cooking staple foods on the Jiko Poa compared to the traditional stove.**

| Food | Easier | Harder | Same | Not Sure |
|---|---|---|---|---|
| Ugali[4] | 60% | 24% | 6% | 10% |
| Githeri | 44% | 30% | 6% | 20% |
| Kienyenji[5] | 60% | 16% | 9% | 18% |
| Stew | 88% | 2% | 6% | 4% |
| Rice | 88% | 2% | 6% | 4% |
| Porridge | 72% | 6% | 4% | 18% |
| Water | 90% | 6% | 4% | 0% |

### 3.5.3 Perceived Savings and Other Benefits of Jiko Poa

#### 3.5.3.1 Time Savings

Socioeconomic benefits of improved stoves are primarily derived from time and fuel savings. Cooks were asked to give feedback on the overall impacts of the Jiko Poa. All cooks reported fuel savings, and most reported reductions in time spent procuring fuel and in cooking time, defined as the time the stove was lit (Table 19).

**Table 19: Reported changes in fuel use, cooking time, and time procuring fuel after purchase of the Jiko Poa.**

[4] Ugali is a dish made of maize meal cooked with water to a dough-like consistency. It is the most common staple starch in much of Eastern and Southern Africa.

[5] Kienyenji, also known as mukimo, is a Kenyan dish made of corn, beans, and/or greens mixed into mashed potato.

| | More | Less | Same | Not Sure |
|---|---|---|---|---|
| Fuel Use | 0% | 100% | 0% | 0% |
| Time Stove Lit | 26% | 68% | 4% | 2% |
| Time Procuring Fuel | 0% | 92% | 0% | 8% |

Of those who reported a reduction in cooking time, most savings were in the range of 30 minutes to several hours per day. Those who reported longer cooking time were fairly evenly spread from a few minutes to over two hours (Table 20). Using the midpoints of the time periods and three hours for those reported a change of greater than two hours results in an average 65 minute reduction in cooking time across all households.

**Table 20: Reported difference in cooking time per day.**

| | 0-15 minutes | 15-30 minutes | 30-60 minutes | 1-2 hours | >2 hours |
|---|---|---|---|---|---|
| If Longer | 23% | 23% | 23% | 23% | 8% |
| If Shorter | 3% | 9% | 15% | 35% | 38% |

The general impressions of household members on the effect of the Jiko Poa were compared to the actual reported cooking times during the two rounds of monitoring. While the amount of time the stove is used in any particular home varies greatly from day to day, it appears that on average the reported cooking time during monitoring (Table 5) was generally in line with overall impressions of faster cooking times (Table 20), with only a 35 minute difference between these values.

Of the 92% of households reporting time savings (Table 21), most spend their extra time doing farm work on tasks such as tending animals or crops or doing household chores. Some time was also spent resting and working outside the home.

**Table 21: Reported use of time saved.**

| | |
|---|---|
| Farming/tending animals/garden | 80% |
| Household chores | 39% |
| Rest | 11% |
| Working outside the home | 5% |

### 3.5.3.2 Monetary Savings

40 households reported that they were saving money due to fuel savings. The amount saved per week ranged from $0.50 to $10, with an average of $2.59 (Table 22).

**Table 22: Reported money saved from fuel savings per week.**

| N | Savings Range | Average Savings |
|---|---|---|
| 40 | $0.50 - $10 | $2.59 |

The 80% of households reporting monetary saving from reduced fuel purchases primarily invested their money in their homes. Monetary savings were generally used to purchase food or other household necessities or to buy school supplies or pay school fees. Those with businesses outside of the home reported devoting the extra time and money to the business. Many households devoted time and monetary savings to multiple activities (Table 21 and Table 23).

**Table 23: Reported use of money saved.**

| | |
|---|---|
| Buy food or other household necessities | 65% |
| Pay school fees/Buy school supplies | 23% |
| Hire farm laborers/house help | 15% |
| Invest in business | 5% |
| Savings | 5% |
| Buy farm inputs | 5% |

# 4 Discussion

## 4.1 Discussion of Qualitative and Usage Results

### 4.1.1 Study Limitations

Due to budget limitations, we were unable to fund a written translation of the survey into local language in advance of the fieldwork. Instead we relied on the enumerators to translate the questions verbally for each respondent. Although an effort was made to standardize key terminology during the field team training, we recognize that this approach provides less control than a written survey in the local language.

The SUMS dataset is more limited and less consistent than would have been desirable. Since SUMS were installed at the end of baseline monitoring, they provide insight on adoption of the Jiko Poa stove and its integration into the kitchen, but no information on baseline stove use. Challenges with the SUMS installation, including the placement of the sensors and the method for affixing them to the stove body, resulted in some sensors failing to record data successfully. As a result only half of the original subset of households where SUMS were installed provided 10-week data on stove usage, and for the final five weeks, the only valid data was for the intervention stove. Additionally, current SUMS data analysis methods are not fully automated, limiting the depth of the information on cooking activity that could be gleaned from the data.

### 4.1.2 Comparison of Reported and Measured Usage Results to Sector Norms

Despite its limitations, taken together, the reported and measured usage results are in line with several familiar conclusions. First, the transitions to cleaner and more efficient cookstoves (and to cleaner fuels) are not linear, and households often use multiple stoves and fuels in parallel to meet their domestic energy needs (Masera et al. 2000). For our study population, one of the barriers to full adoption was the preparation of githeri. Another may have been the seasonal impact of the rainy season on the fuelwood supply, although our results are not conclusive on this point. Further, it is widely acknowledged in the sector that while rocket stoves can provide measurable benefits to biomass-dependent households as seen here, in most cases, they are not energy game-changers. The level of modest but stable usage seen in this study is evidence of the value of the stove to households.

## 4.2 Discussion of Household Air Pollution Results

### 4.2.1 Study Limitations

Ventilation rates decreased by an average of 16% between monitoring periods. If this change was weather-related, as opposed to a behavioral change related to adoption of the Jiko Poa, then air pollution reductions related to the stove are likely somewhat underestimated.

Usage of both the traditional biomass stove and the Jiko Poa stove declined over the course of the 10-week adoption study. Due to budget constraints, no measurements of air pollution were made during this period. As a result, it is impossible to extrapolate the longer term impact of the Jiko Poa on air quality from this study.

### 4.2.2 Household Air Pollution Results Compared to Guidelines

Results of this study showed a 37% reduction in CO kitchen concentrations and a 51% reduction in $PM_{2.5}$ kitchen concentrations, with all reductions statistically significant at the 99% confidence level. While these reductions are substantial and robust, they must be taken in context in order to inform on potential health benefits. Both the baseline and “after” concentration levels indicate that the study kitchens are very unhealthy human environments. Despite the consistent performance of the intervention stoves, pollution levels were 36 times the least stringent level that the WHO considers acceptable (Interim Target 1) for particulates and two to five times higher than the average recommended exposure limits for CO (Table 24).

**Table 24: Comparison of after IAP levels with WHO guidelines.**

| | After Kitchen Concentration | WHO Guideline |
|---|---|---|
| $PM_{2.5}$ – annual (µg/m$^3$) | 1250 ± 318 | 35 (Interim Target 1) |
| CO – 24-hour (ppm) | 24 ± 5 | 6 |
| CO – 8-hour max (ppm) | 41 ± 8 | 10 |
| CO – 1-hour max (ppm) | 120 ± 22 | 25 |
| CO – 15-min max (ppm) | 191 ± 34 | 90 |

### 4.2.3 Household Air Pollution Results Compared with Ghana Gyapa Monitoring Results

The percent reductions in pollution levels observed in this study are similar to those from a study in Ghana of a similar rocket wood stove, the Gyapa. There, after introduction of the intervention stove, $PM_{2.5}$ concentrations decreased by 52% and CO concentrations decreased by 40% (Pennise et. al. 2009). However, the baseline kitchen concentrations measured in this Kenya study were three to four times the levels observed in Ghana (Table 25).

**Table 25: Comparison of average baseline IAP levels from this study and a similar study in Ghana.**

| | Kenya | Ghana |
|---|---|---|
| $PM_{2.5}$ (µg/m$^3$) | 2537 | 650 |
| CO (ppm) | 38 | 12 |

## 4.3 Fuel Use Results Compared with Previous Jiko Poa Fuel Measurements in Kenya

While this study carried out one-day fuel measurements, Berkeley Air had previously conducted three-day KPTs for the Paradigm Project in 2010 in three other Kenyan locations: Meru, Marsabit, and Nairobi. (NB: the 2010 study *only* measured fuel use, whereas the 2011 work reported here includes a broader set of indicators, including behavioral assessments and measures of indoor air pollution and stove adoption.) Current study values were converted to kg wood/person for comparison to the 2010 KPT figures. Observed wood use was two to three times higher at the Embu and Nyahururu sites, perhaps explaining the somewhat higher percentage fuel savings observed there (Table 26).

**Table 26: Comparison of wood use and percent savings from this study with 2010 results in Kenya (kg wood/person).**

| | N | Before | After | % Change |
|---|---|---|---|---|
| Current Study | 49 | 2.84 ± 1.82 | 1.48 ± 1.27 | -47 |
| 2010 KPT | 98 | 1.35 ± 1.16 | 0.83 ± 1.16 | -39 |

## 4.4 Further Research Needs

This study documented very high air pollution levels in Kenyan kitchens. At the same time, we observed that the stove was often left smoking when githeri was simmering or no cooking was taking place while nobody was in the kitchen. The next step to estimating health effects would be to measure personal exposure to PM and CO and document who spends time in the kitchen and when. An affordable personal PM monitor would greatly assist this effort.

Also of interest would be further investigation of barriers to stove adoption, such as the need for constant tending that makes preparing githeri more difficult on the Jiko Poa and challenges in having a constant supply of dry wood that is cut into thin pieces.

Currently, the benefits of SUMS are limited due to needs for sensors with increased memory and temperature thresholds and algorithms that allow for more accurate, faster processing of the temperature record.

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