REDUCING INDOOR AIR POLLUTION THROUGH PARTICIPATORY DEVELOPMENT IN RURAL KENYA

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ABSTRACT
Objective: To evaluate effectiveness of smoke reduction interventions in rural homes. **Methods:** 24-hour kitchen respirable particles ($kPM_{3.5}$), kitchen CO (kCO), and personal CO (pCO) for the cook were assessed before and after interventions in Kajiado (n=25) and West Kenya (n=25). Women participated in developing interventions, including improved stoves (12), enlarged windows (all) and eaves (27), and hoods (17). **Results:** Pollution/exposure levels were high: mean 24h $kPM_{3.5}$ 5,530 $\mu g/m^3$ (Kajiado), 1,710 $\mu g/m^3$ (West Kenya); 24h kCO 74.7 and 8.8 ppm respectively; 24h pCO 6.98 and 4.16 ppm respectively. Following interventions, there were marked reductions in all measures. For 15 homes receiving hoods, $kPM_{3.5}$ was reduced 75% (p=0.001), kCO by 77% (p=0.001) and pCO by 35% (p=0.011). Enlarged eaves and windows reduced $kPM_{3.5}$ by 62% (p=0.001) in West Kenya. Residents appreciated better lighting, ventilation and smoke reduction, although concerns about privacy required attention. **Conclusion:** This participatory approach achieved effective smoke reduction, and promoted interest in further development (155).

INDEX TERMS
Poor rural communities, Women and children, Indoor air pollution, Participatory technology development, Reduced exposure.

INTRODUCTION
At least 2 billion of the world's poorest people are still primarily dependent on biomass fuels (World Resources Institute 1998). The use of these fuels indoors on open fires and inefficient stoves with poor ventilation leads to high levels of smoke exposure and increases the risk of a range of important health problems, including pneumonia (Smith 2000) and chronic obstructive lung disease (Bruce 2000). Kenya remains one the poorer East African countries, with a large, poor rural population almost entirely dependent on biofuels. In such situations, there is limited opportunity for transition to cleaner fuels such as LPG, in part due to inadequate supply infrastructure and inability to pay for storage and appliances. The use of kerosene has also fallen in many rural areas due to price increases. In the absence of effective national policy on improving access by the rural poor to cleaner energy, biomass is likely to remain the most commonly used household fuel in rural areas for some time to come. The aim of this study was to initiate a process that could substantially reduce IAP, increase awareness and empower local people to continue making incremental steps towards a cleaner household environment and in time towards greater use of cleaner fuels. Specific objectives were to:

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- Carry out a baseline assessment of pollution and exposure, fuel use and house structure in typical rural homes.
- Identify participatory ways of alleviating indoor air pollution through the development and installation of interventions.
- Evaluate changes in pollution and exposure, and community views of the process used.
- Empower communities by making them aware of the risks associated with household smoke and enabling mechanisms for its alleviation

METHODS

The overall design was a 'before-and-after' comparison in two rural areas, (a) Kajiado south of Nairobi, and (b) two communities east and north of Kisumu near Kakamega and Kisii. Baseline monitoring was carried out over 1 year, followed by interventions over 6 months, then follow-up over the next year (total duration 2.5 years). This design was judged most appropriate given the participatory nature of the development work, which would have made use of control (non-intervention) areas very difficult to justify and maintain. A range of other factors that might influence pollution levels and exposure were assessed during the course of the study, so their potential effect could be assessed in the analysis. A total of 50 houses (25 per area) were studied: twice prior to the interventions, and twice after, each survey period being several months apart and timed to include one dry and one wet season. Selection criteria for homes were: the family was interested in the aims; the house structure should be typical; there was one or more children <5 years; the family was prepared to accept the questionnaires and pollution monitoring over the 2.5 years of the study; and they should be keen to implement changes to the homes in consultation with ITDG staff. This sampling was judged more likely to lead to success of the project than if a random sample was attempted. Information on the household, house (windows, doors, ventilation), stove type, fuels, and cooking (food types cooked, numbers cooked for) during the 24 hour periods of air sampling, was collected by interview using a questionnaire developed for the purpose.

24 hour particulate matter concentrations were measured using a Buck I.H. pump sampling at 2.2 litres/minute, a Higgins-Dewell type cyclone and 35mm glass-fibre filters. This produces a 50% particle cut-off at 3.5 µm. Pumps were calibrated using a Munro RM1069 rotometer prior to sampling each house. The cyclone was placed 1.2 metres (4 feet) above the kitchen floor, 1.2 metres horizontally from the hearth. Due to high levels of pollution, filter cassettes were changed after 12 hours. Carbon monoxide (CO) was measured in the kitchens using Gastech 1D (1000 ppm/hr) diffusion tubes co-located with the cyclone. The purpose of this was to measure CO as a health-damaging pollutant in its own right, as well as to use CO as a proxy for PM exposure for the women, based on the method described by Naeher et al (Naeher, 2000). Co-location of $PM_{3.5}$ and CO assessment in the kitchen allowed investigation of this association. 24 hour CO exposure for each woman (the cook) was measured at the same time as area sampling using a Gastech 1D tube placed in a holder on the left upper chest. The woman was asked to keep the tube/holder near her head when sleeping. The cook was asked to recall time spent in the kitchen during periods of cooking, for the same period as for air and personal sampling. Air sampling filters were prepared using standard procedures, in the Department of Analytical Chemistry, University of Nairobi. Regular checks were made on calibration of the balance, with repeat weighing and laboratory blank filters used for quality control. Each of the two field teams had a supervisor who was responsible for preparation of the questionnaires, CO tubes, filter cassettes and air sampling equipment (charging and calibration) for each house visit. The supervisor directly observed approximately 50% of household assessment (air sampling and questionnaires). Around 10% of questionnaires were repeated independently by the supervisor. On return from the field, the

supervisor re-checked and recorded the stored pump data (time elapsed, volume sampled, flow rate). Room and personal CO tubes were sealed at the end of the sampling period, and re-read blind by the supervisor (for analysis the mean of the field worker and supervisor readings was used). A proportion of filters prepared in the laboratory were used as blanks, and returned from the field unused to act as controls.

Options for interventions, which included improved stoves, enlarged and better positioned windows, enlarged eaves, and hoods with flues, were discussed with women both individually and in groups. Once a decision had been made by a woman on the intervention(s) she wished to try, these were developed and installed through partnership and discussion between the women, her husband, local artisans, and the technology Institute in Kajiado (for hood design and metal work). Exchange visits helped build confidence and encouraged women to try the interventions. Cost-sharing was sought from the outset, but this was very limited in Kajiado due to extreme poverty in the area, exacerbated by drought.

Data was entered in MS Access and all data-entry double-checked. Statistical analysis was carried out in SPSS. The distributions of all pollution/exposure measures were markedly positively skewed: for clarity of presentation however mean values are given, but non-parametric tests used for statistical comparison. Examination of the effect of interventions has been carried out in two ways. Before and after comparisons examine the means of changes in individual houses, for which paired tests were used (Wilcoxon). Independent sample tests (Mann-Whitney) were used for comparison of pre-intervention values in groups of homes subsequently receiving different interventions, and comparison of post-intervention values in groups of homes that have received the different interventions.

RESULTS

Table 1 shows the situation at baseline, with respect to key aspects of houses likely to affect smoke removal and dilution, together with the changes brought about by the project interventions.

Table 1. Summary of key house characteristics and changes introduced by the project

House feature	**Kajiado**		**West Kenya**	
	Pre-intervention	*Post-intervention*	*Pre-intervention*	*Post-intervention*
Type of stove	All open fire	All open fire	10 Upesi, rest open fire	All Upesi
Smoke extraction	None	12 received hoods with flue	None	5 received hoods with flue
Windows	Up to 4 or 5 small (< 15 cm)	All up to 4 windows, 50 cm	Variable number and size	All some increase in window area
Eaves spaces	None	2 had some eaves space introduced	All had some eaves spaces	All had eaves enlarged

The measure of personal exposure used in this study (24h mean CO) is not only of interest in its own right (as CO at high levels has an impact on health), but also as a proxy for PM. The overall (survey rounds pooled) Spearman correlation for kitchen $PM_{3.5}$ and CO was 0.95 ($p<0.0005$) for Kajiado and 0.85 ($p<0.0005$) for West Kenya. As expected, there was a weaker relationship between personal CO and kitchen CO, although the pooled Spearman correlation values of 0.71 ($p=0.001$) for Kajiado and 0.62 ($p=0.001$) for West Kenya clearly indicate that women living and working in more polluted kitchens receive higher average exposures.

Overall levels of kitchen air pollution were very high by international air quality and exposure standards: 24h average **kitchen $PM_{3.5}$** mean (±SD) for Kajiado was 5526.7 μg/m^3 (2561.9), for West Kenya 1713.6 μg/m^3 (1251.1). 24h average **kitchen CO** mean (±SD) for Kajiado was 74.7 ppm (28.25), for West Kenya 10.1 ppm (10.17). 24h average women's **personal CO** mean (±SD) for Kajiado was 7.0 ppm (3.60), for West Kenya 4.16 ppm (4.75). These pCO levels were 9.4% and 41% of the respective kitchen levels. The overall changes in pollution and exposure, taking all homes and both sites combined, showed significant reductions of 43% in $PM_{3.5}$ ($p<0.001$), 34% in kitchen CO ($p=0.004$), while the 16% reduction in personal CO was marginally significant ($p=0.06$).

Examination of sub-groups of houses allows some assessment of the effects of the various specific interventions, the most effective of which were the hoods/flues. ***Tables 2(a-c)*** show the impact of the hoods in the 15 homes (10 in Kajiado and 5 in West Kenya with complete pre- and post-intervention data). There were highly significant reductions kitchen $PM_{3.5}$ of 3308.6 μg/m^3 (95% CI: 1359.8-5257.4) and in kitchen CO of 37.1 ppm (95% CI: 18.17-56.03). The reduction in personal CO of 1.98 ppm (95% CI: 0.12-3.84) was also significant ($p=0.01$). For all three parameters, comparison of the two groups (those receiving hood vs. those not receiving) showed that the differences prior to the interventions were not significant, but that the post-intervention differences were significant.

Table 2(a). Change in 24 hour kitchen $PM_{3.5}$ (μg/m^3) in receiving hoods

Time	**Hoods (n=15)**		**No hood (n=31)**	
	mean	***(SE)***	***mean***	***(SE)***
Pre-intervention	4383.3*	962.8	3250.9*	385.6
Post intervention	1074.7**	253.5	2559.9**	457.8
Difference (pre/post)	3308.6	994.0	690.9	379.0
p-value:Wilcoxon	0.001		0.03	

* Difference (SE) in pre-intervention values = 836.6 (876.7): p=0.7 (Mann-Whitney)
** Difference (SE) in post-intervention values = 1516.3 (503.6): p=0.02 (Mann-Whitney)

Table 2(b). Change in 24 hour kitchen CO (ppm) in homes receiving hoods

Time	**Hoods (n=15)**		**No hood (n=31)**	
	Mean)	***(SE)***	***Mean***	***(SE)***
Pre-intervention	47.8	10.12	39.8	7.00
Post intervention	10.7	3.67	36.4	7.25
Difference (pre/post)	37.1	9.66	3.4	4.05
p-value:Wilcoxon	0.001		0.3	

* Difference (SE) in pre-intervention values = 6.1 (12.2) p=0.7 (Mann-Whitney)
** Difference (SE) in post-intervention values = 25.3 (7.9) p=0.007 (Mann-Whitney)

Table 2(c). Change in 24 hour personal CO for women in homes receiving hoods

Time	**Hoods (n=15)**		**No hood (n=31)**	
	mean	***(SE)***	***mean***	***(SE)***
Pre-intervention	5.71	0.72	5.52	0.92
Post intervention	3.73	1.22	5.07	0.80
Difference (pre/post)	1.98	0.95	0.45	1.02
p-value:Wilcoxon	0.01		0.9	

* Difference (SE) in pre-intervention values = 0.20 (1.32) p=0.3 (Mann-Whitney)
** Difference (SE) in post-intervention values = 1.44 (1.36) p=0.02 (Mann-Whitney)

All of the houses receiving hoods, also received some other interventions. The effect of these other interventions are discussed further below in analysis of the 31 homes across the two sites not receiving hoods.

Eaves: The effect of eaves enlargement could only be studied in West Kenya, as this intervention was generally unsuitable for the type of houses in Kajiado. Among the homes in West Kenya not receiving hoods, there were marked reductions of 62% in kitchen PM ($p=0.01$) and of 34% in kitchen CO ($p=0.09$) in 8 homes moving from small to large eaves. There were also reductions in personal CO, but these were not significant. Notable also was a marked reduction in the standard deviation of both kitchen pollution measures associated with eaves enlargement, indicating that the distribution had been narrowed and reduced.

Windows: The clearest information on the effect of windows comes from Kajiado, among the 12 houses not receiving hoods. The only intervention in these homes was the installation of up to 4 windows 50 cm across. There was almost no change in any of the three measures of pollution/exposure. The effects in West Kenya are harder to distinguish from the effect of enlarged eaves, although the eaves appeared to be the more important change.

Stoves: Kajiado provides no data on improved stoves as there was no locally available stove that the women felt was suitable. A comparison among the 18 homes in West Kenya not receiving hoods, showed that the changes in the 8 receiving improved (Upesi) stoves during the study were almost identical to those in the 10 homes that had the improved stoves from the start. As other changes (eaves, windows) were fairly well balanced across these two groups, this implies that the stoves did not bring about any marked reduction in pollution.

Other factors that may influence pollution and exposure levels

Time in kitchen: The amount of time women reported that they spent in the kitchen while cooking decreased in both areas following the interventions, from 2.5 to 1.5 hours ($p<0.001$) in Kajiado, and from 3.8 to 3.2 hours (NS) in West Kenya.

Numbers cooked for: The average number of servings (adjusted for the number of adults and children served) was remarkably constant in both areas across the period of the study.

Type of food cooked: since hard (e.g. maize) and soft (e.g. vegetables) foods require different cooking times, the balance between these types of food were assessed. The situation was complicated by drought, with food aid in the form of maize made available, particularly in Kajiado. The reported hard/soft food balance however, did not change significantly.

Type of fuel and adequacy of fuel supplies: all homes in both areas relied primarily on wood for cooking. Although there may have been changes in the type of wood used at various times, this information is not available. Wood was reported to be 'rather scarce' or 'very scarce' by 21% in Kajiado and 76% in West Kenya pre-intervention, and by 25% and 63% respectively post-intervention. There were no changes reported in fuel drying practices.

Rainfall: Average daily rainfall for the survey periods decreased in West Kenya from 5.82 mm pre-intervention to 3.96 mm post intervention. In Kajiado, there was an increase from 2.08 mm to 3.57 mm.

DISCUSSION

Inherent in this study was an element of conflict between robust scientific design of the evaluation and the needs of the development process. A randomised controlled intervention would have been unsuitable, and it was also felt that the use of a parallel control group in each area with no intervention over such a long period would have been counter-productive. A before and after design, with internal comparisons (e.g. houses receiving hoods vs. no hoods), was therefore used. The houses receiving any specific intervention(s) were inevitably self-selecting as the final decision about the type of intervention in each house was determined by the women, not the project team, but comparison of pre-intervention levels of pollution shows that the groups were fairly similar at least in that respect. Baseline levels of pollution were very high in comparison with international air quality standards (USEPA 1997), but similar (or higher in the case of Kajiado) to levels reported from other recent studies (Naeher 2000, Albalak 2001). The interventions were effective in reducing pollution levels, especially the hoods, although residual levels were still quite high. Enlargement of eaves also appeared useful, and reduced the number of homes with very high levels. Windows improved quality of life (bringing light into previously very dark homes), but were less effective at reducing pollution. Stoves had little impact on pollution in this small sample, although this type of stove can reduce emissions through improved combustion (Ezzati, 2000). Personal exposure was also reduced, particularly in houses receiving hoods. Although the apparent reduction in time spent in the kitchen (significant in Kajiado) could have contributed to this, the assessment method is not felt to have captured the time-activity patterns particularly well, particularly for Kajiado where fires are alight almost constantly (including all or part of the night). This aspect needs more thorough assessment in future studies. Women were generally very pleased with the interventions, and there has been considerable interest from husbands and neighbours. Work is continuing to promote wider awareness through video, exchanges and other means.

CONCLUSIONS AND IMPLICATIONS

It is the rural poor of developing countries who are most dependent on biomass fuels, who experience the greatest health impact from indoor air pollution, and are least able to move up the energy ladder. Working in partnership with local people, particularly women, local organisations and artisans, has led to the development and acceptance of interventions capable of substantially reducing pollution and exposure, and laid the basis for taking further incremental steps towards cleaner household energy options.

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