In-field charcoal stove emission factors and indoor air pollution in Nairobi, Kenya

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Introduction

- Kenya's household energy sources are like much of Sub-Saharan Africa and the rest of the developing world
  - Kerosene: 5.9 million homes
  - Charcoal: 2.8 million homes
  - Fuelwood: 4 million homes

  (HEDON 2008)

- Much potential to reduce greenhouse gas emissions and exposure to health damaging pollutants by promoting a switch to cleaner burning fuels and improved stoves

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Purpose

- Determine in-field emission factors for charcoal stoves (in realistic household settings)
  - CO_2, CH_4, total non-methane hydrocarbons (TNMHC), CO, PM, SO_2
  - Compare to IPCC default emission factors and other laboratory test data

- Simultaneously measure indoor air pollution levels (during charcoal stove use)
  - CO, $PM_{2.5}$, SO_2, HCHO (formaldehyde)
  - Compare to WHO and US EPA guidelines

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Methods: Overview & Design

- 4 households
  - 3 controlled cooking tests (ugali)
  - 1 typical evening meal
- New Jiko improved charcoal stove and charcoal given to each household
  - lit for at least 3 hours the day before testing to volatize any residual water and other volatile compounds in the stove

Methods: Emissions Sampling

- Emissions collected directly above stove using a 3-pronged aluminum sampling probe (Johnson et al., 2009)
- 3-sided aluminum curtain placed around the stove to minimize impacts from air currents
- Sample split into two lines:
  - 1 leading to an emission sample collection bag
  - 1 to a real-time CO-CO_2 monitor, followed by a SO_2 monitor
- A simultaneously collected sample was used to correct emissions for background concentrations in the kitchen
- Small aliquots of the emissions and kitchen background samples transferred to metal-coated multilayer Tedlar (MMT) bags
  - GC analysis of CO_2, CO, CH_4, and TNMHC (UC Irvine)
- Teflon filters inserted in-line to determine PM emissions

Methods: CO_2-equivalent Emissions

- $CO_2e = \sum GWP_i \times GHG_i$
  - GWPi is the 100 year global warming potential for each gas (relative to CO_2)
  - GHGi is the molar quantity of each greenhouse gas emitted
  - CO_2e(full): CO_2 (1), CH_4 (25), CO (1.9), TNMHC (4.1) (IPCC 1990; IPCC/Solomon 2007)
    - Black carbon analyses pending
  - CO_2e(Kyoto): CO_2 (1), CH_4 (25)

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Methods: Indoor Air Measurements

- Simultaneous with emissions measures
- Instruments installed 1.0 meter (m) from the center of the stove and 1.5 m above the ground
- $PM_{2.5}$: Real-time (TSI DustTrak 8520) and pump and filter sampling
- Real-time SO_2: RKI SC-01 (RKI Instruments, USA)
- Real-time CO: Draeger PAC III (Draeger, Germany).
- HCHO (formaldehyde): collected with Waters Sep Pak aldehyde cartridges (Waters Corp., USA); analyzed by HPLC by Berkeley Analytical Associates (Berkeley, CA, USA)
- Statistical analyses performed on SAS version 9.1 using general linear models (Proc GLM) with repeated measures, when appropriate, to account for repeated tests within the same households

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Results: Emissions (1)

	unit	CCT	Meal	IPCC
N	---	12	4	XXXX
NCE	%	81.2 ± 2.9	75.6 ± 3.4	XXXX
CO_2	g/kg	2543 ± 113	2394 ± 103	XXXX
CO	g/kg	273.2 ± 54.5	350.5 ± 68.5	XXXX
CH_4	g/kg	14.3 ± 5.6	15.0 ± 3.8	XXXX
TNMHC	g/kg	29.9 ± 13.6	53.4 ± 10.2	XXXX
PM	g/kg	14.07 ± 5.31	15.89 ± 7.69	XXXX
SO_2	g/kg	0.06 ± 0.04	0.05 ± 0.05	XXXX

NCE=nominal combustion efficiency

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Results: Emissions (2)
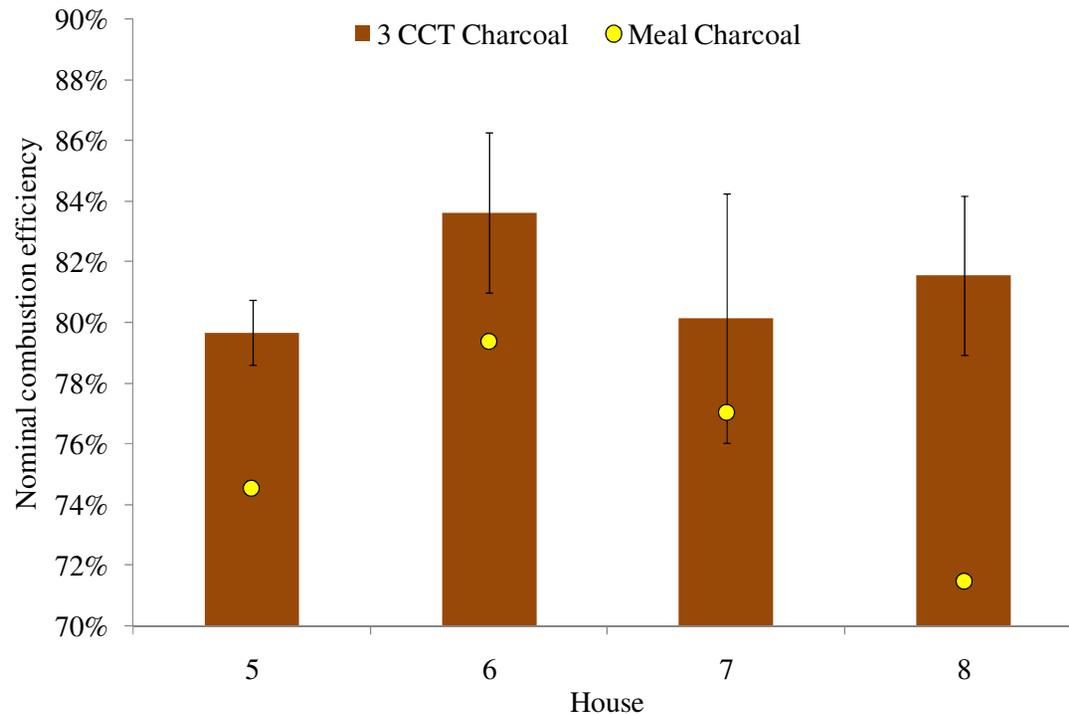
Comparison	N	NCE (p value)	PM (p value)	SO$_2$ (p value)
CCT vs. Meal	8	**<u>0.035</u>**	0.606	0.884

• CCT and meal emissions compared using paired sample Student's t-tests of significance

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Results: CO$_2$e Emissions

- Assuming non-renewable harvesting of charcoal

Test	N	CO$_2$e (full) (kg/kg)	CO$_2$e (Kyoto) (kg/kg)	IPCC
CCT	12	4.78 ± 0.41	3.53 ± 0.36	XXXX
Meal	4	5.26 ± 0.36	3.43 ± 0.27	XXXX

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Results: Indoor Air Pollution

	unit	CCT	Meal	All Day	Guideline
N	---	12	4	4	-----
PM$_{2.5}$	ug/m3	385 ± 96	294 ± 271	156 ± 30	75[*] (24-hour, Interim Target 1)
SO$_2$	ppm	0.02 ± 0.05	0.02 ± 0.02	0.00 ± 0.00	0.19[*] (10-minute)
CO	ppm	85 ± 35	96 ± 25	36 ± 13	90[*] (15-minute)
HCHO	ug/m3	64 ± 20	NA	NA	130[**] (15-minute)

[*] WHO Guideline

[**] US NIOSH Guideline

Results: Comparison Between Emissions and Indoor Air Pollution

- ** chart to come: showing PM, SO2, and CO emissions vs. IAP **

Discussion

- In-field emission factors vs. IPCC default values…
- Indoor air concentrations vs. guidelines…
- CCT vs. typical meals…
- Emissions vs. IAP…