Supplement of Atmos. Chem. Phys., 17, 13721–13729, 2017
https://doi.org/10.5194/acp-17-13721-2017-supplement

Atmospheric Chemistry and Physics
Open Access
EGU

Supplement of

Aerosol emissions factors from traditional biomass cookstoves in India: insights from field measurements

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Kitchen layout

The test kitchen was located on second floor of a house. It had one window located on the front wall, a U-shaped mud stove was fixed to this wall. The only door to the room was left fully open during all burns. All real-time instruments were placed in the back of the room, their inlets connected, via conductive tubing, to an eight-armed steel probe. Two Minivol samplers collected $PM_{2.5}$ samples on Teflon and quartz filters.

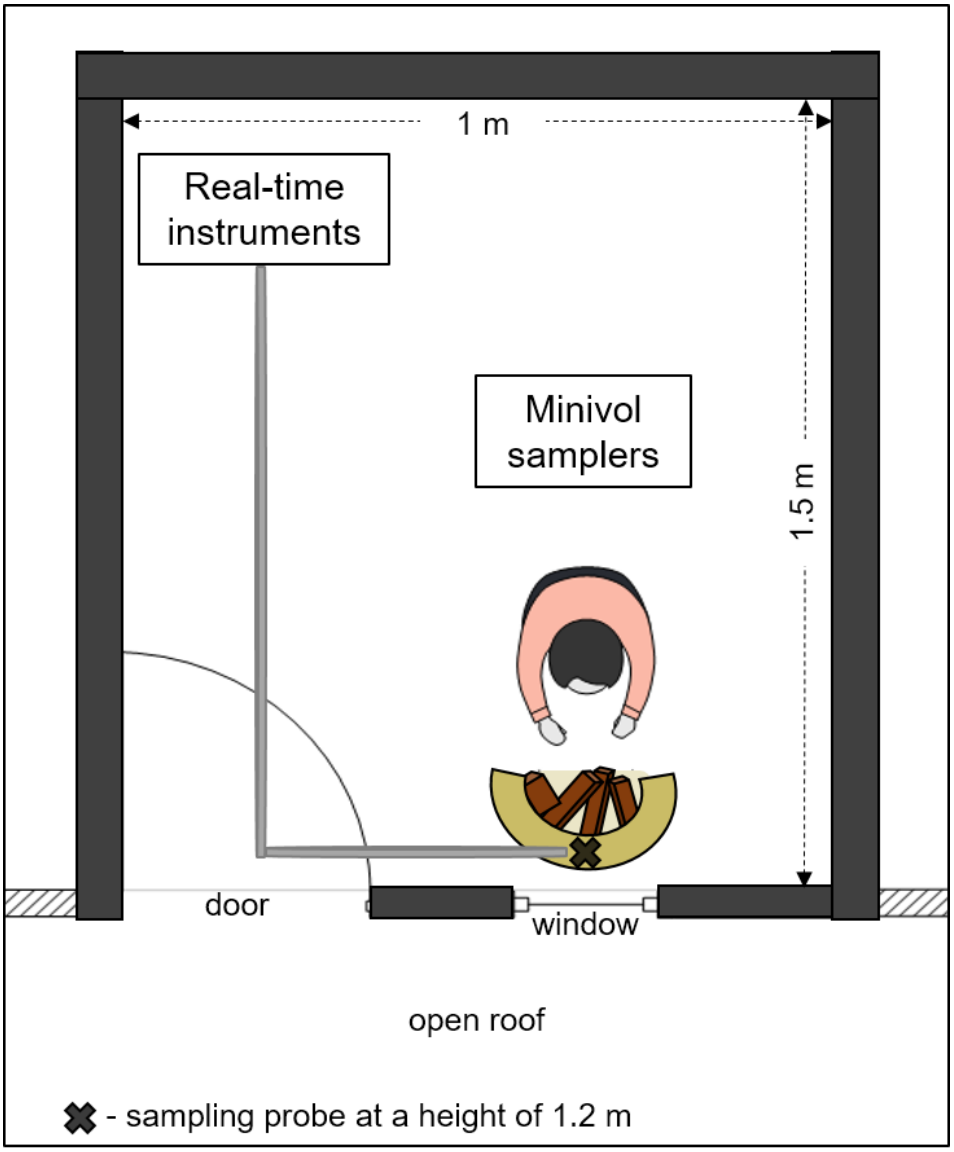

Figure S1: Schematic layout (top-view) of the kitchen

Wireless sensor data

Measurements from Sharp GP2Y sensors attached to the sampling probe (Sensor 1) and to the Minivol sampler (Sensor 2), from day 9 of the study, are shown in Figure S1. These sensors include an infrared emitting diode, the emission from which is scattered by the particles, and a phototransistor converts the scattered light to a voltage output proportional to the PM concentration.

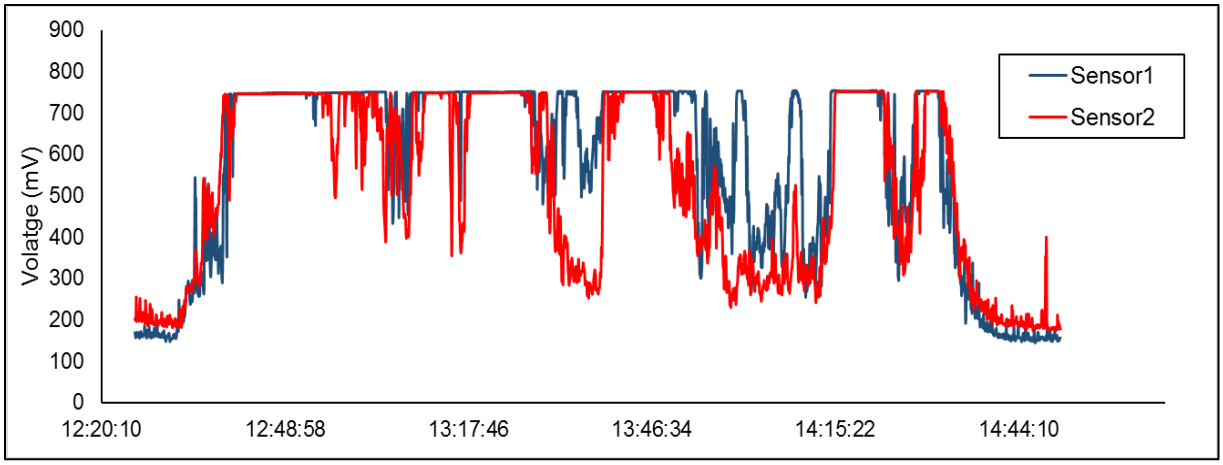

Figure S2: Raw signals from the PM sensors located at the sampling probe (Sensor1) and the Minivol $PM_{2.5}$ sampler (Sensor2).

The saturation voltage for the sensors is close to 750 mV, discarding all values higher than 750 mV, regression analysis of the remaining points yields a slope of 0.96. However, if the saturation threshold was set at 745 mV, the slope changed to 0.89. This is probably because saturation behavior for these sensors is a soft-limit saturation, such that the input-response relationship becomes non-linear at some voltage lower than the final limiting value of 750 mV. If measurements from this non-linear region are included, the linear regression analysis would give erroneous results. Therefore, we systematically reduced the threshold values until we observed negligible change in the regression slope. Finally, we discarded the data points where either of the sensors had readings above the linearity threshold (720 mV). About 60% of all data points were used, and a slope of 0.63 (R^2=0.65) was obtained. Therefore, the concentration measured by the Minivol sampler was adjusted upwards by a factor of 1.6 (=1/0.63).

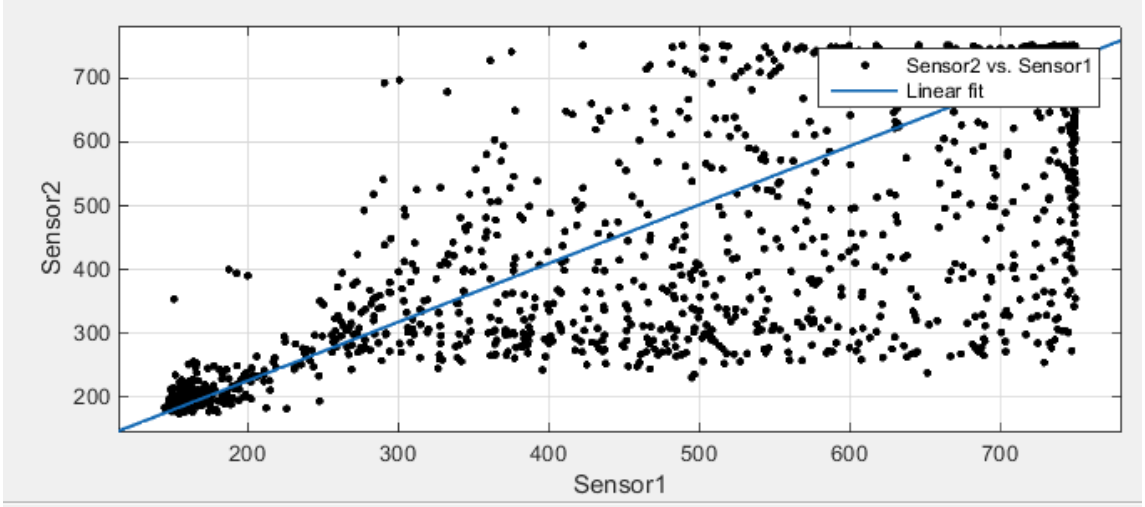

Figure S3: Scatter plot of measurements from Sensor1 and Sensor 2. Linear regression provided a slope of 0.63, with an R^2 of 0.65.

Real-time measurements

A sample plot of real-time particle and gas concentration profiles from day 9 of the study. Please note that the Sidepak instrument does not measure actual particle mass concentration, but instead measures light scattering at 670 nm wavelength and provides an equivalent concentration of Arizona Test Dust that would produce the same magnitude of light scattering.

Over a period of two hours, Sidepak PM measurements and CO concentration (solid in panel B) fluctauated every few minutes. Sidepak was saturated at an equivalent concentration of 20 µg/m3, giving the appearance of a steady state. Re-fueling typically caused a sudden change in particulate and CO emissions.

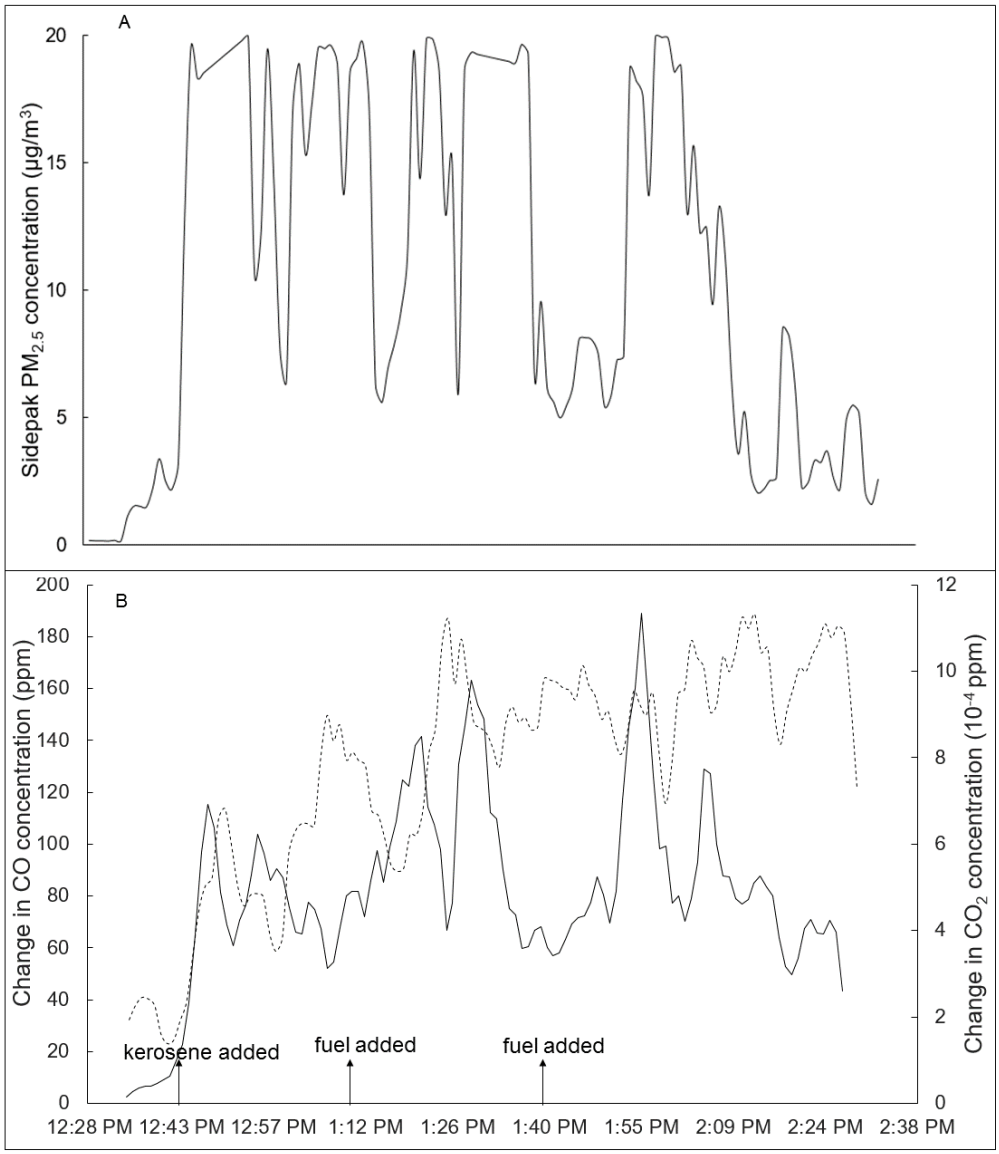

Figure S4: Real-time measurements of (A) Sidepak $PM_{2.5}$ mass concentrations in µg/m^3, and (B) CO concentrations (solid) in and CO_2 concentration (dashed), both in ppm.

Carbon Monoxide (CO) emission factors

Emission factors of CO were calculated using the equation below:

$$EF_{CO} = CMF_{fuel}\frac{C_{Co}}{\Delta C_{CO_2}\left(\frac{M_C}{M_{CO_2}}\right)+\Delta C_{CO}\left(\frac{M_C}{M_{CO}}\right)}$$

where EF_{CO} is the CO emission factor (g of CO released per kg of fuel burnt), CMF_{fuel} is the carbon mass fraction of the fuel, which ranged from 33% to 50% for the tested fuels. C_{CO} is the concentration of CO in g m^{-3}. ΔC_{CO2} and ΔC_{CO} are the concentrations above ambient levels of CO_2 and CO in g $m^{-3,}$ respectively. M_C, M_{CO2}, and M_{CO} are the atomic or molecular weights of C, CO_2, and CO in g $mole^{-1}$.

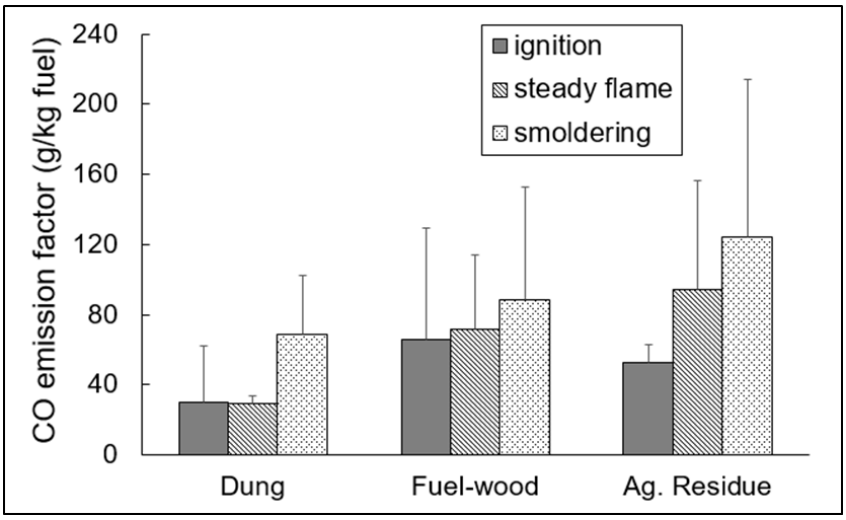

Figure S5: Fuel-wise average values of CO emission factors, categorized by observed combustion phases. One-sided error bars are shown to denote one standard deviation from the mean.

Both CO and $PM_{2.5}$ are products of incomplete combustion are their mass emission rates measured during lab cookstove tests are found to correlate (Roden et al., 2009). In this study, no correlation was observed between the estimated CO emission factors and corresponding $PM_{2.5}$ emission factors. Further, we plotted modified combustion efficiencies (MCE), calculated as the ratio of CO_2 concentration to $CO+CO_2$ concentration, against OC-to-EC ratios. MCE is typically treated as an identifier of combustion phase, with values greater than 0.9 associated with (Reid et al., 2005; Zhang et al., 2008). We found estimated MCE values above 0.9 for roughly 90% of all run time, even when no flaming phase was visibly observed. They showed no correlation with OC-to-EC ratios.

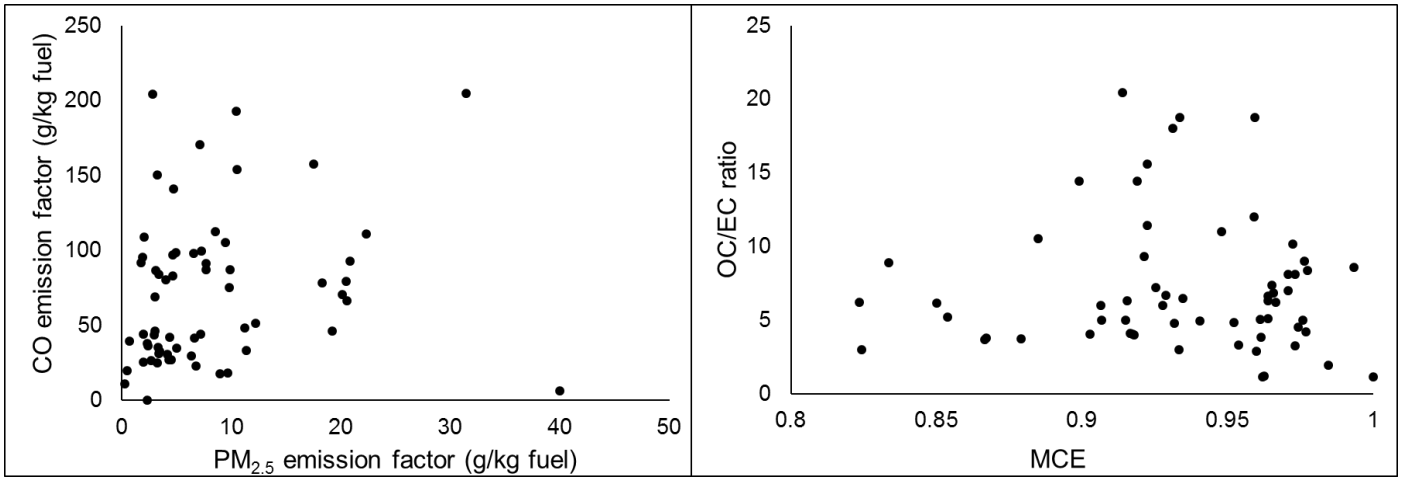

Figure S6: Comparisons of (a) CO vs $PM_{2.5}$, EFs and (b) OC/EC ratios vs modified combustion efficiency (MCE) values.

Individual emission factors

Particle ($PM_{2.5}$, EC and OC) emission factors calculated for each filter sample collected for different fuel types and burn phases, are tabulated below. Corresponding CO emission factors are also included. The particle emission factor data for each fuel type are represented as a box plot in Figure 2 of the manuscript.

Table S1: Emission factors of $PM_{2.5}$, CO, EC and OC for each all fuels in this study. All units are grams of pollutant per kilogram of fuel burned.

Fuel	Burn phase	Emission factor (g/kg fuel)			
		$PM_{2.5}$	CO	OC	EC
U.P. dung	Ignition	15	28	7.86	0.87
	Smoldering	28	121	20.40	1.41
	Smoldering	19	80	10.53	0.56
	Smoldering	8	54	5.62	0.05
	Ignition	11	35	0.38	0.00
	Steady flame	5	51	2.78	0.34
	Steady flame	5	39	2.81	0.73
Bihar dung	Ignition	62	10	7.92	0.92
	Steady flame	18	51	7.57	1.10
	Smoldering	35	172	25.23	2.39
	Ignition	32	103	20.55	1.17
	Smoldering	1	61	0.66	0.05
	Smoldering	4	41	1.97	0.19
Chh. rice straw	Ignition	31	110	10.44	0.01
	Smoldering	27	244	14.60	2.36
	Steady flame	17	75	12.12	3.64
	Steady flame	4	59	3.64	0.58
	Steady flame	4	57	3.45	0.47
	Steady flame	6	47	2.70	0.33
	Smoldering	5	55	2.60	0.42
Chh. t*ur* stalk	Ignition	7	129	0.80	0.00
	Steady flame	5	233	19.00	5.20
	Steady flame	15	163	2.96	0.59
	Ignition	32	144	16.37	4.02
	Steady flame	7	42	9.78	1.96
	Ignition	15	117	5.96	2.00
	Smoldering	12	142	3.74	0.26
	Ignition	4	0	4.43	3.88
	Steady flame	11	69	5.02	0.99
	Steady flame	30	72	12.82	0.68
	Ignition	3	68	0.80	0.68
	Steady flame	11	265	5.72	1.10
	Steady flame	3	142	0.69	0.07
	Steady flame	7	219	3.19	0.85

Raj. wood	Ignition	14	28	3.70	1.89
	Ignition	49	317	19.43	3.13
	Steady flame	16	239	9.53	2.53
	Steady flame	13	175	4.17	1.03
	Steady flame	8	153	3.05	0.61
	Smoldering	16	299	6.30	0.71
	Steady flame	32	123	12.56	2.61
	Steady flame	10	152	2.40	0.38
	Steady flame	0	117	0.00	0.00
	Ignition	7	150	5.04	1.23
	Smoldering	11	155	2.57	0.13
	Ignition	10	46	11.39	2.50
	Steady flame	7	65	3.30	0.50
	Steady flame	10	65	2.81	0.55
	Steady flame	5	48	3.86	1.19
	Steady flame	7	42	1.67	0.40
	Smoldering	0	17	0.09	0.01
U.P. wood	Steady flame	5	72	1.20	0.42
	Smoldering	3	148	3.02	0.67
	Smoldering	3	169	0.79	0.14
	Steady flame	4	317	3.90	1.29
	Steady flame	5	107	2.38	0.48
	Ignition	5	68	0.74	0.61
	Steady flame	5	135	1.86	0.26
	Smoldering	5	130	3.20	0.53
A.P. wood	Steady flame	3	39	1.47	0.18
	Ignition	15	136	9.42	0.82
	Steady flame	12	136	6.46	0.41
	Smoldering	6	124	2.70	0.41

References

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