Supporting information

Fugitive emissions of CO and $PM_{2.5}$ from indoor biomass burning in chimney stoves based on a newly developed carbon-balance approach

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Table S1. Fugitive and stack emission factors (g/kg, dry basis) and fractions of fugitive emissions of CO and $PM_{2.5}$ for different biomass fuels burnt in traditional build-in brick stoves. Data shown are the sample size (N), means and standard deviations (M±STD), geometric means (GM) and median values (M) for emission factors, and means with standard deviations for fugitive fraction.

		Stack emission factors			**Fugitive emission factors**			**Fugitive fraction**	
	N	**M±STD**	**GM**	**M**	**M±STD**	**GM**	**M**	**M±STD**	**M**
Carbon monoxide (CO)									
Wood branch	4	81.9±91.8	49.2	49.8	14.3±9.9	11.4	13.1	21.6±17.1%	14.7%
Wood logs	3	60.7±41.5	51.8	48.7	7.67±3.43	7.17	6.90	14.6±9.0%	19.0%
Corn cob	3	63.8±44.9	52.1	58.2	5.95±6.79	3.47	3.23	10.9±9.2%	12.9%
Corn straw	4	156±40.9	152	153	19.5±23.0	11.9	9.98	10.7±10.6%	7.4%
Rape stalk	4	149±81.7	129	148	16.1±12.3	12.4	14.0	10.0±6.2%	8.9%
Bamboo	4	57.0±49.8	40.5	45.8	7.67±5.04	4.94	9.24	12.7±8.2%	11.5%
Average		***97.7±70.6***	***70.5***	***87.6***	***12.3±12.1***	***7.99***	***9.24***	***13.5±10.3%***	***11.5%***
Particulate matter ($PM_{2.5}$)									
Wood branch	4	2.72±1.91	2.24	2.31	1.55±1.21	1.21	1.24	36.7±15.0%	40.3%
Wood logs	3	3.31±0.24	3.31	3.44	1.54±0.64	1.44	1.71	31.0±9.9%	36.0%
Corn cob	3	3.11±0.71	3.05	3.48	0.458±0.24	0.40	0.59	12.1±4.0%	14.3%
Corn straw	4	3.09±1.37	2.90	2.57	1.41±1.27	1.00	1.06	28.0±13.4%	31.6%
Rape stalk	4	2.45±0.91	2.28	2.81	1.59±1.16	1.15	1.72	34.8±15.1%	35.7%
Bamboo	4	2.62±1.00	2.48	2.48	0.759±0.481	0.61	0.78	21.6±11.7%	20.4%
Average	4	***2.85±1.09***	***2.64***	***2.87***	***1.24±0.95***	***0.90***	***0.91***	***27.9±13.7%***	***27.1%***

Table S2. Total emission factors (EFs, g/kg, dry basis) of CO and $PM_{2.5}$ for the different biomass fuels burnt in traditional build-in brick stoves. Data shown are means and standard deviations (M±STD), and geometric means (GM) from two calculation methods- the new approach considering fugitive and stalk emission difference separately in this study (EF_1), and the traditional CMB method (EF_2). Relative differences (R) in the total emission factors between these two methods were also calculated and listed ($R=EF_1/EF_2$).

	EFs summarized from fugitive and stack emissions		**EFs from the CMB**		**Average R**
	M±STD	GM	M±STD	GM	
Carbon monoxide (CO)					
Wood branch	96.2±101	64.1	86.9±93	57.8	111%
Wood logs	68.4±39.7	60.8	68.4±31.1	64.2	96%
Corn cob	69.7±43.5	58.7	66.9±40.6	55.7	106%
Corn straw	175±44.8	171	167±53	161	106%
Rape stalk	165±87.7	144	151±80	131	110%
Bamboo	64.6±53.7	46.5	59.6±45.9	45.3	104%
Average	***110±76.8***	***82.1***	***103±71***	***78.0***	***106%***
Particulate matter ($PM_{2.5}$)					
Wood branch	4.27±2.94	3.61	3.78±3.87	2.63	143%
Wood logs	4.85±0.64	4.82	4.17±0.97	4.10	120%
Corn cob	3.57±0.94	3.48	3.44±1.32	3.26	108%
Corn straw	4.49±2.54	4.07	3.56±2.48	3.07	134%
Rape stalk	4.04±1.89	3.56	2.51±0.98	2.31	156%
Bamboo	3.38±1.16	3.19	3.17±2.06	2.78	120%
Average	***4.09±1.80***	***3.73***	***3.40±2.07***	***2.92***	***132%***

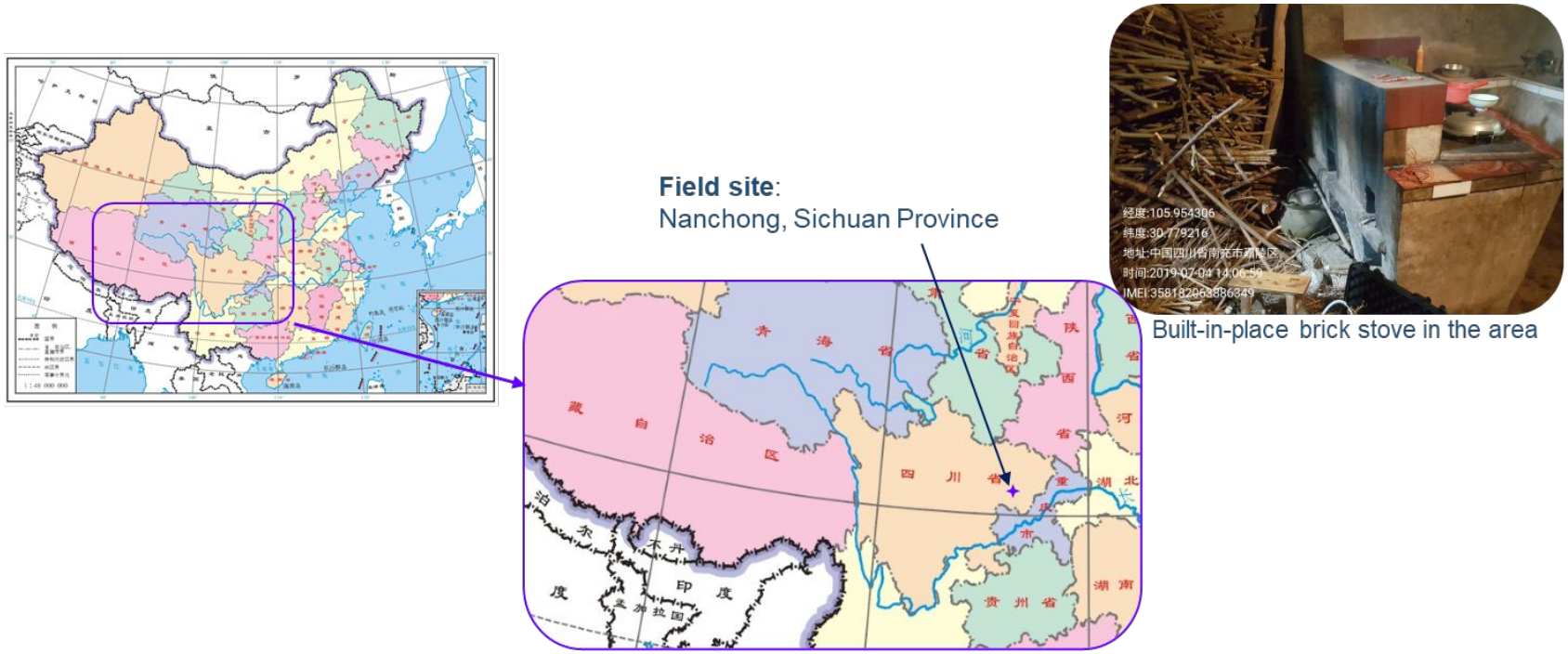

Figure S1. Sampling site and a picture of one typical built-in-place brick stove. The map is from Ministry of Natural Resources of the People's Republic of China (http://bzdt.ch.mnr.gov.cn). The picture was taken by the author Z. Luo.

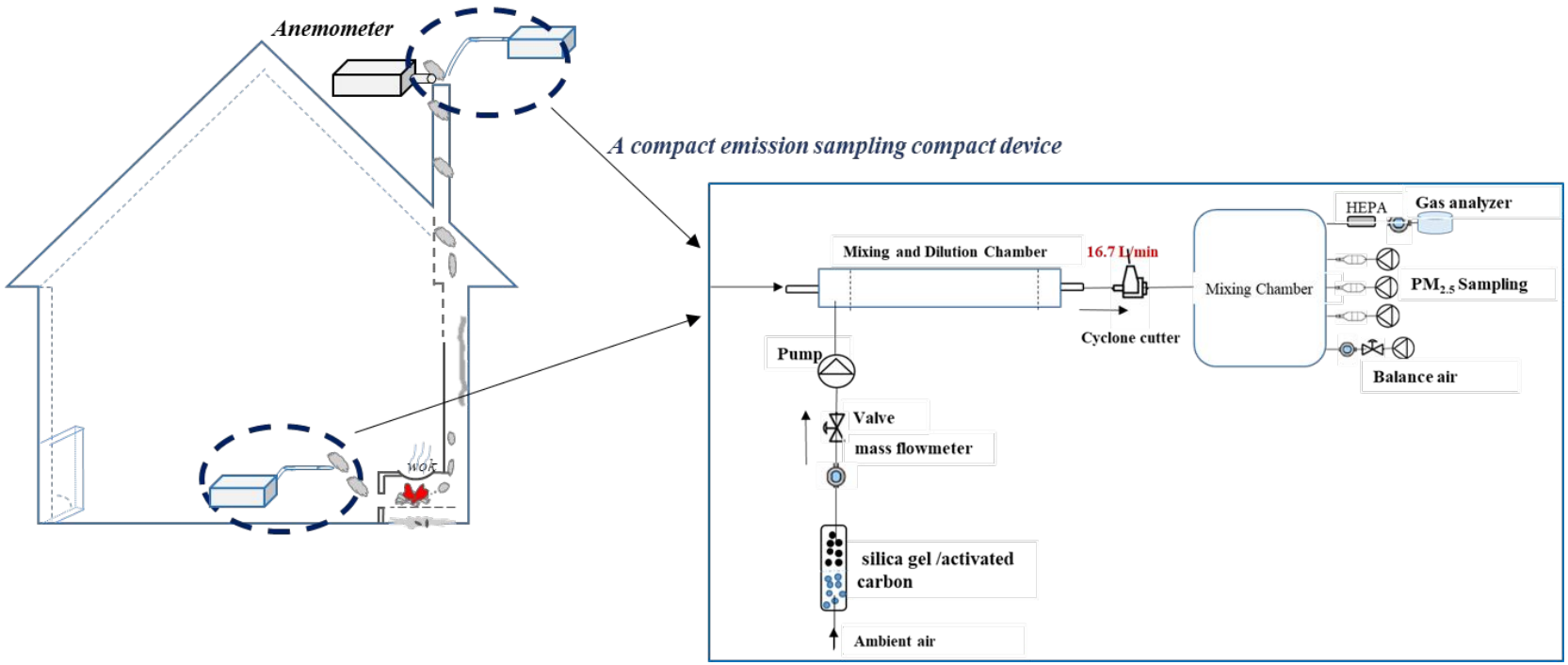

Figure S2. Layout of the compact emission measurement set. The emission sampling system is mainly composed of inlet, dilution chamber and sampling parts, with system power supplies. The diagram of the compact sampling system device is shown in Figure S1. A portion of emission smoke is drawn, diluted and mixed with filtered air, and then measured for gases and particle concentrations using online and/or offline instruments. A stainless-steel sample probe is used to sample emission exhaust. The sampled air enters the dilution chamber where it mixed with dry clean air filtered by active carbon and high efficiency particulate air (HEPA) filter. The dilution ratio could be adjusted by controlling the relatively gas flows of emission exhaust and filtered dry air. The diluted air then passes through a cyclone to collect $PM_{2.5}$ at a rate of 16.7 L/min, and enter to a small residence chamber with five outlet branches. Three parallel quartz fiber filters are used to collect $PM_{2.5}$ using active SKC pumps at about 3.0 L/min. The continuous gas monitor is used to measure real-time concentrations of gases including CO, CO_2, etc.,

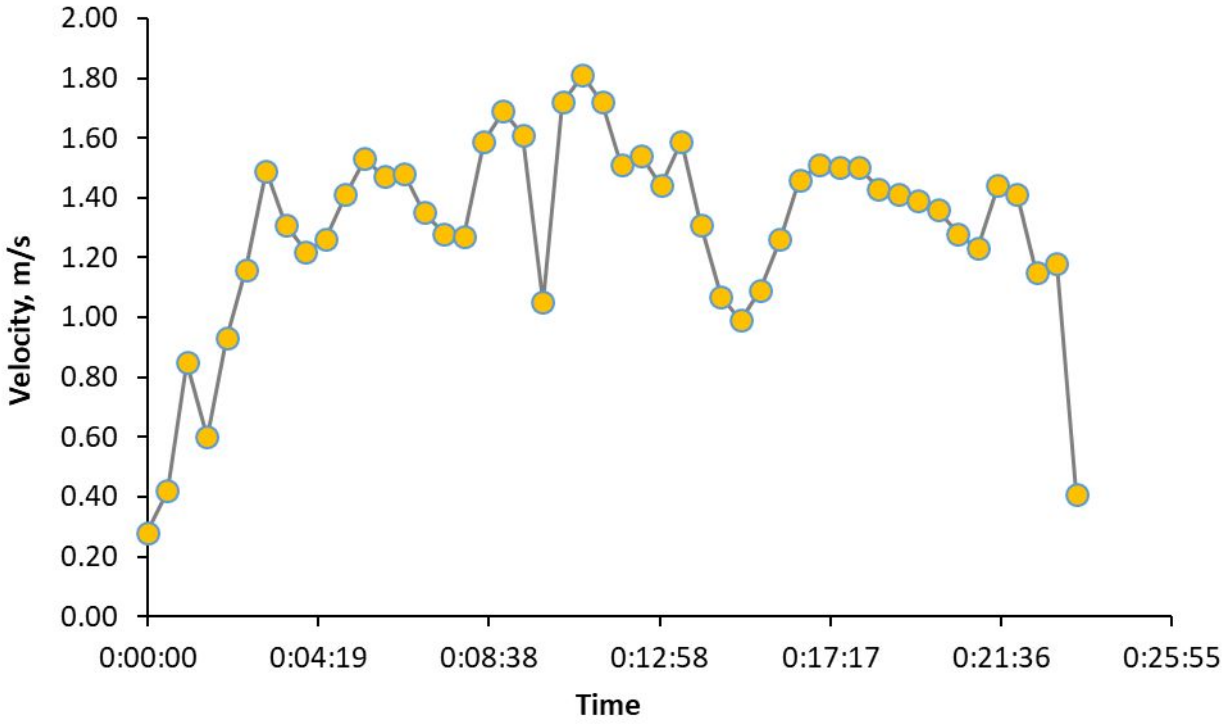

Figure S3. Real-time velocity of gas measured near the chimney outlet for one wood burning test.

Figure S4. Pictures of the field sampling of the chimney exhaust (left panel) and indoor fugitive emissions (right panel). Pictures were taken by the author (W. Du and G. Cai) and the use permission is obtained.

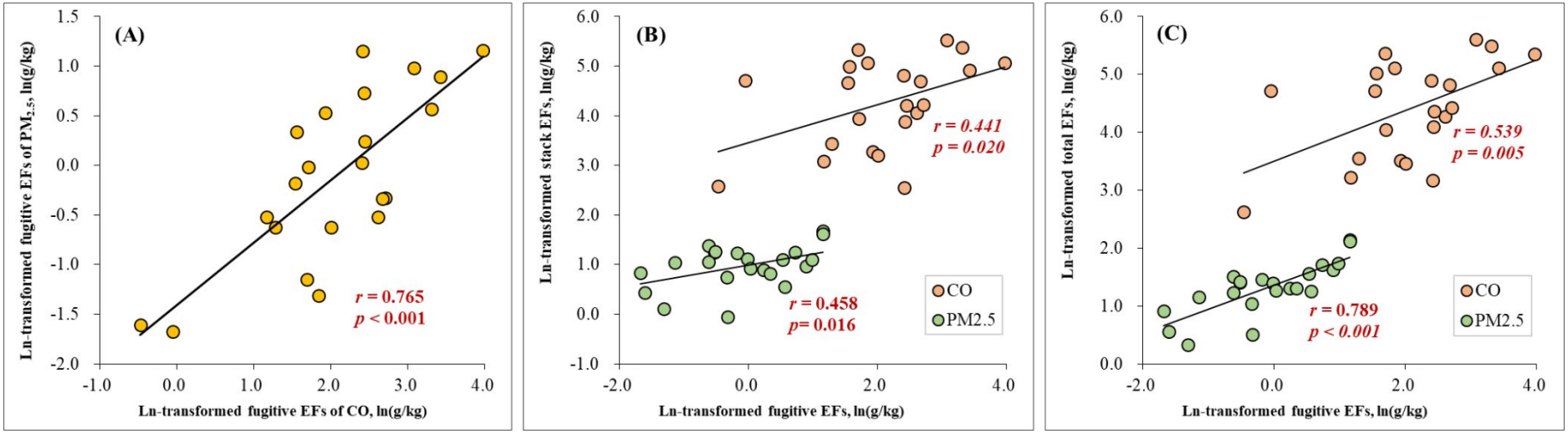

Figure S5. Correlation analysis for fugitive emissions between CO and $PM_{2.5}$ (A), and correlation between fugitive emissions and stack (B) and total emission factors (C).

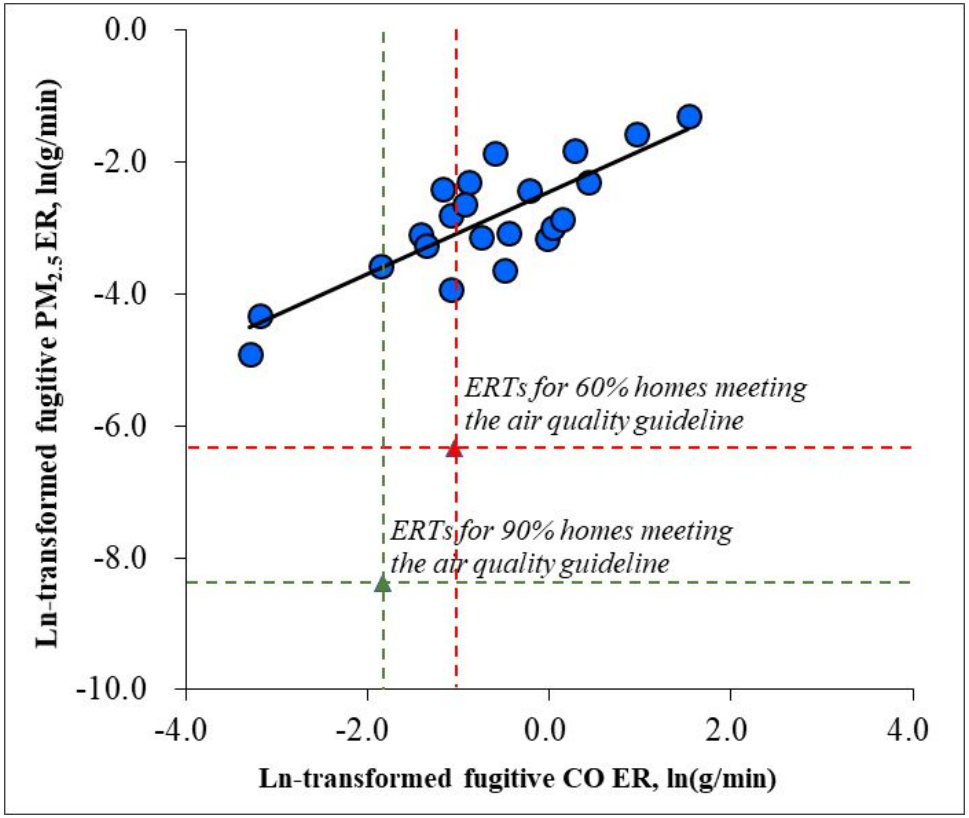

Figure S6. Fugitive emission rates of CO and $PM_{2.5}$ from the wood burning in brick stoves equipped with outdoor chimney in the present study. The results are compared to the emission rate targets (ERT), recommended in the WHO IAQ guideline-household fuel combustion, for 60% (red line) and 90% (green line) of homes meeting the air quality guidelines for $PM_{2.5}$ and CO.

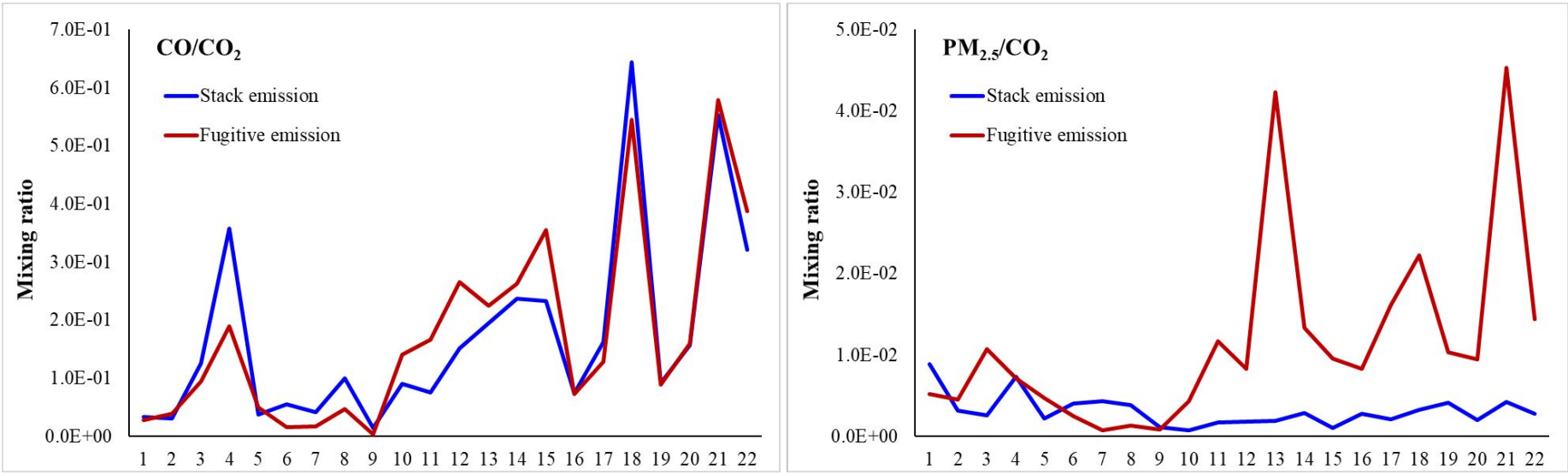

Figure S7. Mixing ratios of CO and $PM_{2.5}$ to CO_2 in the chimney stack and fugitive emissions from the twenty-two tests in the present field study on biomass burning in rural Sichuan.