Impact of residential wood burning on indoor air quality

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SUMMARY
This study aims at characterizing indoor air quality in single family dwellings burning wood regularly, studying the air change rate during wood burning and analyzing impact on outdoor air. Field investigations were performed, in February and November 2007, in six occupied houses located in rural areas (two equipped with an opened fireplace, two with respectively an old closed fireplace and a recent one, and two with respectively an old woodstove and a recent one). Continuous measurements of air temperature, relative humidity, carbon monoxide, nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs) were performed in the room equipped with the wood burning appliance. Moreover in this room and in the main bedroom, PM_{10} and $PM_{2.5}$, PAHs (on PM_{10} fraction), volatile organic compounds (VOCs), aldehydes, ketones, and tracers of wood combustion such as levoglucosan and methoxyphenols on PM_{10} fraction, were also measured. Air exchange rates and building permeability were characterized through different means.

KEYWORDS
Wood burning, PAHs, Particulate Matter, VOCs

INTRODUCTION
Data on the impact of domestic wood burning appliances on air quality are rather poor. Use of such heating systems may increase as the use of renewable energy is encouraged. Besides, according to national inventories, wood burning represents a non-negligible source of organic pollutants in ambient air. Thus the project aims at characterizing indoor air quality (IAQ) in single family dwellings burning wood, studying the air change rate during wood burning and analyzing impact on outdoor air. Field investigations were performed, in February and November 2007, in six occupied houses located in rural areas. Only the results concerning IAQ are presented hereafter.

METHODS
Six occupied houses located in rural areas (60 to 80 km North from Paris) were instrumented. Two houses were equipped with an opened fireplace, two others with respectively an old closed fireplace and a recent one, and the two last ones with respectively an old woodstove and a recent one. In each home, the measurements were operated before (one day) and during wood burning (one day with nominal burning conditions and the following day with reduced ones). Standardized wood logs (identical humidity content in particular) were provided by the French National School of wood industries for all the six campaigns.

In two rooms (e.g. the living-room, where the appliance was located, and the main bedroom), PM_{10} and $PM_{2.5}$ were collected on quartz fiber filters for a differed gravimetric analysis. Levoglucosan and methoxyphenols were also sampled on quartz fiber filters in the PM_{10} fraction. Both particulate (quartz fiber filters) and gas (ORBOTM 43 tubes) phases of PAHs (18 congeners) were sampled using a modified ChemPass sampler (R&P) with a PM_{10} head. Canister and Sep-Pack cartridges were respectively used for VOCs and aldehyde/ketone sampling. The samplings were performed during 8 h in the middle of each room, at about 1.5 m from the floor.

Only in the living-room, continuous on-line measurements were performed for:

- NOx: chemiluminescent analyzer (Thermo Environment Instruments 42C);
- PAHs: photo-ionization analyzer (ECOCHEM PAS-2000);
- CO and O_2: multigas sensor (OLDHAM MX2100);
- temperature: PT100 probe.

In two of the six dwellings, air leakage of the building envelope was measured using blower door technique. Moreover the air renewal rate was measured using tracer gas technique by the decay method. In the four other dwellings magnitude of air exchange was assessed through visual inspection of the envelope components and through spot measurements of CO_2 or exhausted airflow rate in case of a mechanical ventilation.

RESULTS

Indoor concentrations measured in the living-room are presented in Table 1. Table 2 focuses on both PM_{10} and $PM_{2.5}$ indoor (living-room and bedroom) and outdoor concentrations.

Table 1. Concentrations in the living-room by appliance and by burning condition.

Appliance	Burning condition	NO_2 [(a)] ($\mu g.m^{-3}$)	PAHs [(a,b)] ($ng.m^{-3}$)	PM_{10} ($\mu g.m^{-3}$)	$PM_{2.5}$ ($\mu g.m^{-3}$)	Benzene ($\mu g.m^{-3}$)	Formaldehyde ($\mu g.m^{-3}$)
Old woodstove	Without	nd	nd	nd	nd	1.5	14.1
	Nominal	23.9	29.8	nd	nd	5.4	17.8
	Reduced	12.8	13.1	nd	nd	2.0	15.4
Recent woodstove	Without	17.0	7.8	34.2	1.1	0.5	18.6
	Nominal	37.1	50.2	nd	23.1	10.9	36.4
	Reduced	53.2	79.7	67.0	11.8	8.5	32.4
Open fireplace 1	Without	4.6	3.7	<LoQ	<LoQ	1.4	12.3
	Nominal	11.7	27.5	1.2	3.4	4.1	9.0
	Reduced	8.0	4.8	2.3	1.1	3.3	9.0
Open fireplace 2	Without	34.6	12.8	3.9	nd	2.1	6.0
	Nominal	nd	nd	nd	nd	nd	nd
	Reduced	34.6	28.8	38.5	29.9	1.5	5.9
Old closed fireplace	Without	0.8	nd	nd	nd	8.8	21.2
	Nominal	16.6	7.3	51.1	nd	6.4	24.2
	Reduced	60.2	25.9	36.4	nd	7.5	18.9
Recent closed fireplace	Without	122.6	6.1	23.0	nd	1.3	12.2
	Nominal	246.7	13.4	70.7	33.8	7.4	26.9
	Reduced	115.9	17.1	130.1	66.4	18.1	25.0

nd: not determined (sampling or analytical problem); LoQ: limit of quantification

"without" means that the appliance was not operating

(a): average of 8-hour on-line measurements; (b): PAHs measured with the photo-ionization analyzer

Table 2. PM indoor and outdoor concentrations by appliance and by burning condition.

Appliance	Burning condition	PM_{10} ($\mu g.m^{-3}$)			$PM_{2.5}$ ($\mu g.m^{-3}$)		
		Living-room	Bedroom	Outdoor	Living-room	Bedroom	Outdoor
Recent woodstove	Without	34.2	2.1	22.9	1.1	1.1	14.6
	Nominal	nd	95.8	23.3	23.1	35.8	10.6
	Reduced	67.0	65.5	23.3	11.8	14.4	14.8
Recent closed fireplace	Without	23.0	nd	18.7	nd	53.5	12.7
	Nominal	70.7	nd	16.7	33.8	nd	9.9
	Reduced	130.1	155.4	8.6	66.4	nd	5.5

nd: not determined (sampling or analytical problem)

Air exchange measurements (2 houses) or estimations (4 houses) show that there is no difference according to burning conditions. Air exchange rate varies from 0.5 to 2.5 h^{-1}.

DISCUSSION

The NO_2 concentrations are influenced by the wood burning. But they remain in the range of NO_2 concentrations that were measured in 62 Parisian dwellings in 2000 (Mosqueron et al. 2002).

PAHs concentrations (measured with the photo-ionization analyzer) are influenced by wood burning and can reach rather high values, up to 80 $ng.m^{-3}$, in comparison to other studies such as RIOPA one, *Relationships of Indoor, Outdoor, and Personal Air* (Turpin et al. 2007); there is no specific data for French indoor environments. PAH particulate and gaseous phase measurements show that naphthalene has a major contribution in the total sum of PAHs.

In some dwellings, $PM_{2.5}$ and PM_{10} concentrations are clearly impacted by wood burning. Whereas the indoor/outdoor ratio is below 1 when the appliance is off, it overrides 1 during wood burning, largely in some cases (see Table 2). During the French national "Housing campaign" (Kirchner et al. 2007), $PM_{2.5}$ and PM_{10} were measured in the living-room in the presence of occupants (from 5 pm to 8 am on weekdays and 24h/24 during the week-end). The indoor concentration geometric means were respectively 19.1 $\mu g.m^{-3}$ (95th percentile: 133 $\mu g.m^{-3}$) and 31.3 $\mu g\ m^{-3}$ (95th percentile: 183 $\mu g.m^{-3}$). $PM_{2.5}$ and PM_{10} concentrations measured here during wood burning are above the mean values in French dwellings (except for open fireplace 1), but they remain in the range of possible indoor concentrations.

The indoor benzene concentrations are clearly influenced by wood burning, except in the case of old closed fireplace (without explanation). The indoor geometric mean measured during the French "housing campaign" was 2.1 $\mu g.m^{-3}$ (95th percentile: 7.2 $\mu g.m^{-3}$) (Kirchner et al. 2007). Concentrations in the instrumented houses are in the same order of magnitude than this mean value, whereas they are in the range of the higher values as soon as the appliance is on.

Finally, formaldehyde indoor concentration is not influenced by wood burning, which has also been previously observed by Lévesque *et al.* (2001) and Gustafson *et al.* (2007).

No common influence can be drawn between nominal and reduced burning conditions. When available, concentrations in the bedroom (not presented here, except for particles in Table 2) were in the same order of magnitude as the concentrations in the living-room, showing influence of wood burning even in distant rooms. Finally due to the very low number of tested appliances (one or two in each category), it was decided not to provide any comparison between them.

CONCLUSION

This study is the first to investigate the potential impact of wood burning on IAQ in France. It is also the first one to measure PAHs and tracers of wood combustion such as levoglucosan and methoxyphenols indoors.

The magnitude of the impact on indoor air is various depending on the compounds that are considered; major influence is observed on benzene, particle, and PAH indoor levels, minor one for NO_2. Formaldehyde indoor concentrations appear as not being influenced by wood burning, which is coherent with the fact that this compound has major other emission sources in residential environment.

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