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TECHNICAL PAPER

Indoor pollution and burning practices in wood stove management

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This study evaluates effects of good burning practice and correct installation and management of wood heaters on indoor air pollution in an Italian rural area. The same study attests the role of education in mitigating wood smoke pollution. In August 2007 and winters of 2007 and 2008, in a little mountain village of Liguria Apennines (Italy), indoor and outdoor benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations were measured in nine wood-heated houses. During the first sampling, several mistakes in heating plant installations and management were found in all houses. Indoor BTEX concentrations increased during use of wood burning. Low toluene/benzene ratios were in agreement with wood smoke as main indoor and outdoor pollution source. Other BTEX sources were identified as the indoor use of solvents and paints and incense burning. Results obtained during 2007 were presented and discussed with homeowners. Following this preventive intervention, in the second winter sampling all indoor BTEX concentrations decreased, in spite of the colder outdoor air temperatures. Information provided to families has induced the adoption of effective good practices in stoves and fire management. These results highlight the importance of education, supported by reliable data on air pollution, as an effective method to reduce wood smoke exposures.

Implications: Information about burning practices and correct installation and management of wood heaters, supported by reliable data on indoor and outdoor pollution, may help to identify and remove indoor pollution sources. This can be an effective strategy in mitigate wood smoke pollution.

Introduction

The burning of wood for domestic heating is a common practice in many developed countries, particularly those with cooler climates. Although wood heating is relatively inexpensive and reduces fossil fuel consumption, it can increase indoor and outdoor air pollution (Kaarakka et al., 1989; Gullet et al., 2003; Gustafson et al., 2007) by generating various air pollutants. Volatile aromatic hydrocarbons, such as benzene, toluene, ethylbenzene, and xylene isomers (BTEX), are present in wood smoke; benzene is the best-known compound due to its carcinogenic properties (International Agency for Research on Cancer [IARC], 2010). Wood smoke also contains other human carcinogens, such as benzo[*a*]pyrene, butadiene, and formaldehyde (Shauer et al., 2001; Hedberg et al., 2002; Wang et al., 2009), the toxic compound nitrogen dioxide (Levesque, 2001), and fine and ultrafine particles (Bäfver et al., 2011). The International Agency for Research on Cancer (IARC) classified indoor emissions from household combustion as likely to be carcinogenic in humans (IARC, 2010).

Several studies have shown high exposure to pollutants emitted by wood-fired boilers, mainly in rural areas, where the high availability of wood encourages its use (Gaeggeler et al., 2008; Galbally et al., 2009; Ward and Lange, 2010), whereas epidemiological and controlled-exposure studies have highlighted associations between wood smoke exposure and adverse human health effects in the respiratory system (Naeher et al., 2007; Po et al., 2011; Ghio et al., 2012) and in the cardiovascular system (McGowan et al., 2002; Rappold et al., 2011, Unosson et al., 2013).

Given the environmental and health problems, some developed countries have introduced wood smoke reduction programs. In the United States, the U.S. Environmental Protection Agency (EPA) established a best burn practice guide containing the practical tips for building a fire, choosing the right wood in the right amount, and all of the steps for obtaining the best efficiency from a wood stove or fireplace (EPA, 2014). Moreover, it has encouraged the choice of EPA-certified appliances that improve safety and efficiency, producing almost no smoke, minimal ash, and require less firewood. In 2013, the EPA tightened the air pollution limits for the new wood heaters, proposing new smoke emission limits (EPA, 2013). Moreover, the EPA has requested that states and local communities implement the voluntary replacement of older heaters with new burning technologies. Education and outreach programs have also been included to ensure that households burn wood more efficiently and cleaner.

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A policy for sustainable domestic energy use has been supported in Australia to preserve air quality, and educational interventions have demonstrated their effectiveness in increasing awareness of the smoke problem and in promoting responsible wood burning practices (Hine et al., 2011).

The use of wood heating is increasingly common in northern European countries because wood is a renewable fuel resource. The European Environmental Agency (EEA) indicates wood combustion as an important local source of harmful pollutants (EEA, 2012); however, there are no such reports concerning wood fuel use for domestic heating.

To our knowledge, no study has investigated the role of proper installation and correct use of wood stoves, fireplaces, and wood-fired boilers in indoor and outdoor air quality in Italy.

Incorrect management of wood-fired stoves and boilers may be a widespread problem in Italian rural and mountain areas, where do-it-yourself methods, without appropriate technical knowledge, are common. This potentially dangerous situation is favored by Italian legislation: heaters generating less than 35 kW can be freely installed without particular rules and controls. Proper installation and good practices could play an important role in minimizing indoor exposure to wood smoke.

The aims of this pilot study were as follows: to verify whether the use of wood as a heating source in Italy significantly reduces indoor and outdoor air quality; to evaluate the frequency of bad practices in fire management in a rural area; and to evaluate whether proper and authoritative information can modify incorrect practices and improve indoor air quality.

Materials and Methods

Sampling area

The studied area was Villanoce Village, which has 126 residents and is located on a plateau 880 m above sea level within Aveto Regional Natural Park (Genoa, Italy). The Aveto Valley is rich in wood; forestry is an old local tradition, and the use of wood for domestic heating is therefore very common. Agriculture, handicrafts, and summer tourism (two hotel restaurants) are the main local industries. A low-traffic country road crosses the village.

Nine families, selected based on volunteer criteria, were involved in this pilot study after a public presentation about the project. The two conditions for their selection were the use of wood for domestic heating and the absence of smokers in the family members. Each family lived in a private house; eight houses were old buildings whose main external walls, which in several cases were shared with other independent houses, were made of local stones. All nine houses were located inside the village, which originated in the Middle Ages; in the municipal area of Rezzoaglio (44.5272°N, 9.3893°E), where Villanoce Village is located, approximately 70% of the houses were built before 1945.

Sampling and interview strategy

PerkinElmer (Perkin Elmer Italia S.p.A.) stainless steel sample tubes prepacked with Chromosorb 106 (60/80 mesh) were used for diffusive sampling. Sampler tubes were conditioned before their use, by heating at 250 °C for 30 min under a stream of ultra-high-purity helium gas at 100 mL/min, in a PerkinElmer Automated Thermal Desorption (ATD) 400 system. Before the sampling, a diffusion cap was placed over the inlet of each sampler to ensure the correct gas diffusion into the adsorbent.

Three samplings were performed during the following periods: from 23 to 30 August 2007; from 22 to 30 November 2007; and from 9 to 16 December 2008. Below, these three sampling periods will be referred to as August 2007, November 2007, and December 2008, respectively. Daily weather conditions during samplings were obtained from the regional meteorological station located near Giacopiane Lake, 6.6 km from Villanoce Village and 1020 m above sea level (Supplemental Table 1S).

Three contemporary air samples were collected from each house: two indoor samples and one outdoor sample. The indoor samples were obtained from the room with the main heating device (room 1, usually the dining room or kitchen) and in the bedroom (room 2). These samplers were preferentially located in the center of the room, fixed under the swing lamp. The outdoor sampler was hung very near each house, usually fixed to the first-floor balcony railing. Each outdoor sampler was protected from the rain by a weather shield.

In total, 10 duplicates and 8 field blanks were used for each round of sampling.

Before the first sampling (August 2007), an Aveto Park staff member interviewed members of each family. A questionnaire was used to record detailed information about the home characteristics, heating device type, heated surfaces, and thermal insulation used in each monitored house. The items regarding the average daily wood consumption, management of the heating systems, and the possible indoor problems (i.e., presence of wood smoke and mildew on the house walls) were completed after each sampling (Supplemental Tables 2S and 3S).

After the second sampling (November 2007), each family was again contacted by the Aveto Park staff member and by a researcher from the Environmental Chemistry Laboratory to discuss the BTEX concentrations found outside and inside their home. During this discussion, results were compared between homes to attempt to explain the different pollution levels; if necessary, possible remedies were suggested.

In December 2008, the third sampling campaign was conducted. The family coded no. 5 declined to participate in this monitoring session. Afterward, the families were once again contacted to provide them with all of the obtained results and to discuss the findings. During this last visit, information was collected on the behavioral and technical changes that each family had made since the evaluation of the results obtained during the first sampling.

BTEX analysis

The passive samplers were analyzed within 7 days after collection. Benzene, toluene, ethylbenzene, and *o-, p-*, and *m*-xylenes (BTEX), sampled for seven consecutive days, were desorbed using a PerkinElmer ATD 400 and analyzed using a Clarus 500 gas chromatograph with a flame ionization detector (PerkinElmer) and a PerkinElmer PE-5 capillary column

Table 1. Experimentally determined diffusive uptake rates for 7 days of sampling at a temperature of 298.16 K and a pressure of 1013 mbar

Pollutant	Uptake Rate (mL min^{-1})
Benzene	0.34
Toluene	0.44
Ethylbenzene	0.42
m/*p*-Xylene	0.46
o-Xylene	0.46

(30 m × 0.25 mm × 0.25 μm). Details on the analytical procedures were previously published (Pala et al., 2006).

The calibration curve was obtained by injecting each sampling tube with 1 μL of a standard solution containing a known amount (from 0.2 to 100 ng μL^{-1}) of pure BTEX (from 99.5% to 99.9%) dissolved in methanol (Toxic Organic Mix 1A; Supelco). The mass of analyte was determined from the gas chromatographic area and corrected by subtracting the average blank area according to the calibration curve. BTEX concentrations were calculated according to eq 1 and corrected for the average temperature and pressure for the sampling period.

$$C = \frac{M_S}{U \times t} \quad (1)$$

where
C = concentration of analyte in air (ng/m^3)
M_S = mass of analyte in a sample (ng)
U = diffusive uptake rate (mL/min)
T = exposure time (min)

The diffusive uptake rate, used in the present study and reported in Table 1, was experimentally determined after exposure of Chromosorb 106 sampling tubes in a test chamber with controlled atmosphere (data unpublished). R^2 of the calibration curve for BTEX standard concentrations ranged between 0.996 and 0.999.

Field blanks and triplicate samples were used to verify the sampling methodology. Field blanks were analyzed to determine the limit of detection (LOD) and to set the zero concentration for each analytical run. The LOD for each BTEX, calculated as the average value of the field blanks plus 3 times the standard deviation, was 0.1 $\mu g/m^3$. The precision levels for benzene, toluene, ethylbenzene, *m*- and *p*-xylenes, and *o*-xylene obtained from the triplicate samples were, respectively, 4.5%, 5.7%, 3.2%, 7.3%, and 5.5%.

Statistical analysis

For each pollutant, mean, standard deviation, and range were computed for each concentration, and these results were stratified by season and room. To normalize the measures of the pollutant concentrations, a logarithmic transformation was applied. The concentrations of pollutants for each combination of room and season were compared using the *t* test for paired data. To explore the data dispersion, boxplots by season and room were created for each pollutant.

To quantify the changes in the concentration of pollutants considering the joint effects of season and room, a general linear model (GLM) was fitted, using the concentration of each pollutant as the dependent variable. To consider the heterogeneity intrinsic to each house, random effects have been included in the model (Twisk, 2003). Parameters estimated from this model can be interpreted as the ratio between the average concentration of a level of the covariate, season or room, and the average concentration of its reference level; it is therefore possible to compute the percentage change using $\text{ratio}^{-1} \times 100$. Finally, to assess the change in the concentration of pollutants in relation to the difference between indoor and outdoor temperature, another random effect model has been fitted, with the mean of the concentrations in room 1 and room 2 in winters of 2007 and 2008 used as the dependent variable. SAS software (SAS Institute, Cary, NC, USA) was used for the analysis.

Results and Discussion

Information from the questionnaire

Information obtained through the questionnaires showed frequent inadequate attention to the proper management of heating systems (Supplemental Table 3S): seven houses (nos. 2, 3, 4, 5, 7, 8, and 9) lacked the outside air intake near the stove that guarantees more efficient burning; the chimney pots of seven houses (nos. 1, 2, 3, 5, 6, 7, and 8) were lower than their respective roof ridges, a condition that is unfavorable for proper smoke dispersion, particularly on windy days; one chimney (house no. 4), which was not regularly cleaned, caught fire some months before sampling due to the accumulation of tar and creosote, a symptom of incomplete combustion; families declared that during the November 2007 samplings, wood smoke was present in houses nos. 2 and 5; fumes and vapors produced during cooking were not properly dispersed outside houses nos. 2, 4, 5, and 7. Five houses (nos. 4, 5, 6, 8, and 9) had signs of humidity and mold on the inner walls and glass windows, revealing poor indoor ventilation.

Based on the analytical results and family interviews, important indoor BTEX sources other than wood smoke were found in some houses: the presence of paint and solvents (house no. 1), incineration of plastic and paper wastes in the stove (house no. 7), and frequent use of incense (house no. 9). Furthermore, as shown in Supplemental Table 3S, only two houses (nos. 1 and 5) had complete thermal insulation (external walls, roof, double-glazed windows), which is the main requirement for reducing fuel consumption and related pollution. One house (no. 7) had aluminum window frames, whereas all the other window frames and doorframes were made of wood, which results in low airtightness.

BTEX concentrations

Concentrations of each BTEX and the sum of all BTEX (ΣBTEX) are reported in the Supplemental Material (Supplemental Tables 4S, 5S, 6S).

Table 2. Descriptive statistics and univariate *t* tests for paired data

Sampling Location	Sampling Period	*N*	Benzene Mean (SD) Range *P* value*	Toluene Mean (SD) Range *P* value*	Ethylbenzene Mean (SD) Range *P* value*	Xylenes Mean (SD) Range *P* value*
Outdoor	August 2007	9	0.88 (0.35)	2.03 (0.98)	0.55 (0.34)	1.84 (0.89)
			0.47–1.58	0.61–3.78	0.05–1.08	0.61–3.60
			<0.001	<0.001	0.743	0.114
	November 2007	7	6.72 (3.36)	4.92 (2.45)	0.67 (0.49)	2.46 (1.52)
			3.93–13.90	2.17–9.41	0.05–1.31	0.80–4.56
			—	—	—	—
	December 2008	8	4.60 (1.47)	1.71 (0.41)	0.41 (0.33)	0.76 (0.70)
			2.46–7.18	1.25–2.60	0.10–0.95	0.20–2.40
			0.239	0.022	0.565	0.021
Room 1	August 2007	9	3.59 (3.29)	30.38 (41.77)	4.28 (5.60)	21.83 (27.31)
			1.35–11.45	4.19–130.53	0.05–17.36	4.32–86.70
			0.001	0.286	0.052	0.080
	November 2007	9	12.22 (4.34)	33.50 (18.38)	9.31 (5.88)	44.11 (36.95)
			5.38–18.20	9.74–64.00	2.41–22.19	11.79–131.03
			—	—	—	—
	December 2008	8	8.34 (2.07)	14.74 (11.98)	3.02 (2.45)	11.64 (10.65)
			5.40–11.90	4.65–39.60	0.90–8.00	2.35–34.25
			0.105	0.003	0.002	0.003
Room 2	August 2007	8	3.74 (3.57)	34.60 (46.52)	5.34 (5.79)	25.62 (30.61)
			1.04–11.58	4.04–131.38	0.38–16.94	2.18–87.20
			0.004	0.299	0.227	0.259
	November 2007	9	11.43 (5.02)	37.27 (21.39)	7.91 (7.08)	37.04 (43.09)
			5.35–21.46	11.57–67.09	1.69–24.89	9.92–148.37
			—	—	—	—
	December 2008	8	11.05 (6.60)	13.96 (10.40)	2.55 (1.11)	11.18 (7.06)
			6.36–26.79	4.20—33.95	1.15–4.25	2.80–20.60
			0.828	<0.001	0.002	0.004

Note: **P* value from the *t* test, using November 2007 as the reference.

Regarding the descriptive statistics (Table 2), the average concentration of every pollutant increased from August 2007 to November 2007 and generally decreased from November 2007 to December 2008, independent of room. For benzene, comparisons with November 2007 emphasize that in all rooms, the concentration of this pollutant was significantly lower in August 2007 but not in December 2008.

In the winter samplings, all indoor measurements exceeded the European limit (Directive 2008/50/EC) for ambient benzene (5.0 $\mu g/m^3$ as annual mean). Regarding toluene, there was a significant reduction inside the houses in December 2008. Ethylbenzene and xylenes showed a similar pattern, with a greater reduction in the concentration inside the houses.

Boxplots of the log-transformed pollutant concentrations (Figure 1) highlight the existence of some outliers, which have been carefully analyzed. In August 2007, when the fireplaces were not used, an unusually high benzene value was recorded (11.4 $\mu g/m^3$ in room 1 of house no. 4). Both benzene and xylenes exhibited outliers in November 2007 (13.9 $\mu g/m^3$ of benzene was measured outside house no. 9, and 148.4 $\mu g/m^3$ of xylenes was measured in room 2 of house no. 1). In December 2008, a high value was observed for benzene inside one of the houses (26.8 $\mu g/m^3$ in room 2 of house no. 7). Discussion of possible sources of BTEX outliers is provided in the next section.

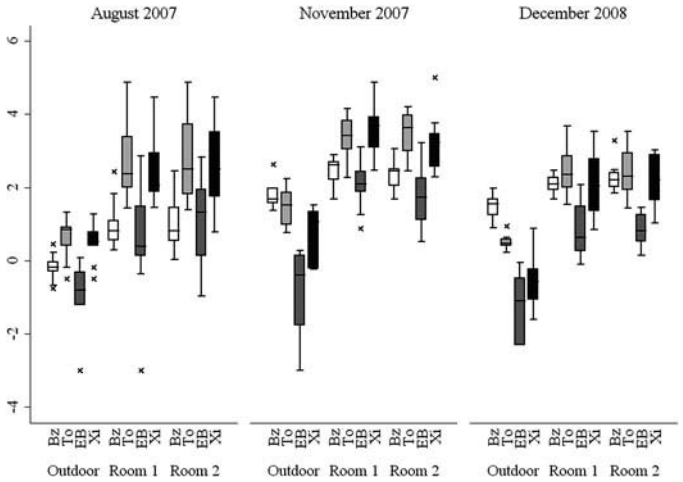

Figure 1. Boxplots of the log-transformed pollutant concentrations.

Table 3. Random-effect GLM: Ratio of the average concentration of an pollutant in each season and room with respect to the reference level (November 2007 or room 1)

Season/Room	Benzene β (95% CI) *P* value	Toluene β (95% CI) *P* value	Ethylbenzene β (95% CI) *P* value	Xylenes β (95% CI) *P* value
August 2007	0.21 (0.16–0.27) <0.001	0.49 (0.32–0.74) 0.001	0.47 (0.27–0.81) 0.007	0.55 (0.35–0.85) 0.008
December 2008	0.82 (0.64–1.06) 0.133	0.38 (0.25–0.59) <0.001	0.43 (0.25–0.75) 0.003	0.30 (0.19–0.47) <0.001
Outdoor	0.43 (0.33–0.55) <0.001	0.14 (0.09–0.21) <0.001	0.12 (0.07–0.21) <0.001	0.08 (0.05–0.13) <0.001
Room 2	1.03 (0.80–1.32) 0.842	1.03 (0.68–1.57) 0.873	1.08 (0.63–1.87) 0.780	0.96 (0.62–1.49) 0.853

A general linear model showing the joint effect of season and room is presented in Table 3.

For benzene, on average, the concentration in August 2007 was lower than that in November 2007 (−80%; $P < 0.001$); between November 2007 and December 2008, in contrast, there was no significant difference. The concentration of the pollutant did not differ between room 1 and room 2 but was different relative to outdoor measurements (−54%; $P < 0.001$). Toluene, ethylbenzene, and xylene concentrations showed similar patterns. November 2007 presented a significantly higher level of pollutants compared with the other two periods, with increases of 46–70%.

The concentration of all pollutants was lower outside the houses, with a reduction of approximately 85%, whereas there was no difference between rooms. This result is consistent with similar studies (Molnár et al., 2005) and confirms that the main BTEX sources originated indoors.

Removal of outliers from the statistical model did not substantially change the results.

Influential point analysis has revealed that for all pollutants, house no. 5 is very influential in the estimate of regression coefficients.

Finally, the temperature difference between indoors and outdoors during the winter seasons has shown a positive correlation with concentrations of pollutants (Table 4), with statistically significant increases from 15% to 23%, excluding benzene.

Table 4. Random-effect GLM: Variation in the concentration of an pollutant (β) due to an increase of 1 degree of temperature in the house, adjusting by season

Pollutant	β	95% CI	*P* value
Benzene	1.07	0.97–1.17	0.191
Toluene	1.21	1.06–1.38	0.006
Ethylbenzene	1.15	1.01–1.31	0.049
Xylenes	1.23	1.07–1.42	0.005

Main BTEX sources

The toluene/benzene ratio (TO/BZ) was calculated in an attempt to determine the sources of pollution (Table 5).

In both winter measurements, the toluene/benzene ratio in all outdoor samples was low, with mean values of 0.9 ± 0.4 in November 2007 and 0.4 ± 0.1 in December 2008. These ratios were consistent with the constant and extensive use of wood for heating and cooking, as demonstrated by several studies in which smoke produced by wood combustion was characterized by toluene/benzene ratios of 0.2–0.7 (Hedberg et al., 2002; Sallsten et al., 2006; Hellén et al., 2008).

In August 2007, the outdoor TO/BZ mean value of 2.5 ± 1.4 was significantly higher than the two winter ratios. This value was consistent with the ratios expected from traffic emissions (Schnitzhofer et al., 2008) at the mean air temperature registered during the August 2007 sampling (19.6 °C) due to the summer touristic presence.

In the winter samplings, several indoor measurements had TO/BZ ratios ≤2, consistent with wood combustion. The main exception was house no. 1 in November 2007. Information from the questionnaire identified the likely cause as the use of solvents and paints for home redecoration. This was confirmed by the very high ethylbenzene and xylene concentrations in the two rooms. In November 2007, relatively high indoor TO/BZ ratios were found in houses nos. 7, 8, and 9. In these cases, the possible BTEX sources other than wood fire might be plastic and paper waste incinerated in the stove (house no. 7), natural gas combustion and cooking emissions, as demonstrated by Kim (2011), due to inefficient kitchen exhaust fans (house no. 8), and incense burning (house no. 9).

Five families reported the evening use of wood stoves during August samplings due to a decrease in air temperature, and this most likely explained the high indoor BTEX concentrations found in houses no. 4 and 5 (Supplemental Table 4S). The high toluene/benzene ratios found in these two homes and in house no. 8 (Table 5) were tentatively explained by the storage and use

Table 5. Outdoor and indoor toluene/benzene (TO/BZ) ratios in wood-heated houses

	August 2007			November 2007			December 2008		
		Indoor TO/BZ			Indoor TO/BZ			Indoor TO/BZ	
House Code	Outdoor TO/BZ	Room 1	Room 2	Outdoor TO/BZ	Room 1	Room 2	Outdoor TO/BZ	Room 1	Room 2
1	1.1	5.3	7.7	0.7	10.1[b]	12.0[b]	0.6	5.3	4.5
2	5.0	3.2	2.5	1.5	2.3	2.1	0.3	1.0	1.0
3	3.1	4.6	8.2	0.9	1.5	6.9	0.6	1.8	2.1
4	1.2	11.4[a]	11.3[a]	0.4	1.3	1.5	0.3	0.5	0.4
5	3.8	9.9[a]	12.5[a]	0.7	1.1	1.3	na	na	na
6	2.1	2.2	2.6	0.6	1.6	1.7	0.3	1.3	1.1
7	3.6	6.2[a]	6.5[a]	1.7	3.5	4.1	0.3	0.6	0.4
8	1.2	16.4[a]	na	0.8	3.4	2.4	0.4	1.0	0.8
9	1.4	2.4[a]	4.3[a]	0.5	4.2	3.1	0.4	5.6	1.8
Mean	2.5	6.8	7.0	0.9	3.2	3.9	0.4	2.1	1.6
SD	1.4	4.8	3.7	0.4	2.8	3.5	0.1	2.1	1.3
Median	2.1	5.3	7.1	0.7	2.3	2.4	0.4	1.2	1.0

Notes: na = not available. [a]Declared use of wood stoves during sampling. [b]Declared use of solvents during sampling.

of newspapers, an important toluene source (Caselli et al., 2009), to set fire to the wood and by the low draft of cold flues, with the consequent presence of indoor smoke produced from newspaper combustion.

Finally, the results obtained in house no. 4 during the summer period, with the highest indoor BTEX concentrations, confirmed that the wood stoves were not properly operated. In August 2007, the cooking stove in the kitchen (room 1) was used to rapidly warm the house, whereas during the winter the wood-burning appliance was a boiler for central heating, placed on the ground floor in a dedicated room that was separate from the monitored rooms. With this model of wood boiler, only one daily wood charge is necessary, a characteristic that is very useful for reducing the possibility of indoor wood smoke emissions.

Differences between the two winter measurements

The actual wood consumption trends indicate that the colder outdoor air temperatures in December 2008 cannot explain the observed indoor pollution decreases compared with November 2007. In fact, during winter 2008, four families (nos. 4, 7, 8, 9) declared an increase in their wood consumption levels; in two cases (nos. 1 and 6), the consumption was the same, and two families (nos. 2 and 3) declared a decreased wood consumption (Supplemental Table 2S).

Most likely, there was an increased difference between the indoor and outdoor temperatures during the winter 2008 samplings, along with increased natural ventilation in the monitored houses, with higher exchanges between the more-polluted indoor air and the relatively clean outdoor air. The poor sealing of wooden window frames and doorframes in almost all of the monitored houses may have helped increase the room ventilation. The increased differences between the temperature of heater fumes and the outdoor air temperature may also have increased the flue draft, reducing indoor pollution.

Long periods of wind calms occurred in winter 2008 and may have favored draft and outdoor smoke dispersion from the chimneys that were too low, which is a very frequent installation error in the monitored houses and reduces fume draft due to air turbulence during windy periods.

It is very likely that in some houses, indoor air pollution also decreased because of technical improvements in the wood stove efficiency and because of behavioral changes by the dwellers before and during winter 2008. The main changes made in the houses were as follows: an air intake opening to the outside near the stove, an increase in chimney height, and the use of drier wood (house no. 7); an improvement in wood smoke diffusion by removing stovepipe bends (house no. 2); an increase in chimney height to better disperse wood smoke (house no. 1); installation of a new insulated chimney in place of the old one that caught fire (house no. 4); and a separation of the stove and kitchen pipes, which previously used the same chimney (house no. 8).

All participants reported increased attention during winter 2008, aimed at improving natural room ventilation, with windows that were kept open for at least half an hour in the morning, soon after first firing up the wood stoves. During this same period, in all homes, indoor wood smoke was not reported by

the owners and was not observed by our collaborators during their visits to the monitored houses.

Discussions and comments about the indoor air quality measured in each house also induced other changes that reduce indoor pollution: solvents and paints were no longer used in house no. 1, plastic and paper waste was no longer incinerated using the stove of house no. 7, and incense was no longer burned in house no. 9.

Conclusion

The study has confirmed that frequent errors in the self-installation of domestic wood heaters and their management may substantially contribute to indoor BTEX.

The main rules, as well as the errors that should be avoided, in wood-fired stove management are as follows: improve house thermal insulation to reduce wood consumption; install an outdoor air intake near each stove; create a separate chimney for each appliance; avoid the use of the stove as a waste incinerator; use only a small quantity of newspapers to start the fire; always keep the stove warm during use; avoid horizontal tracts and limit elbow turns in the chimney stacks; clean the chimney every year; and thoroughly ventilate the house soon after the fire is started.

The study indicates that air pollution monitoring with discussion of the results with heater users increases the residents' perception of the health risk and consequently their assimilation of information regarding good burning practices during wood heater management. Therefore, education, supported by reliable data on air pollution, can be an effective strategy for mitigating pollution from wood smoke. Further similar studies in rural areas where wood is used as a heating fuel are recommended to confirm these results and to support the decision to finance a public awareness campaign about correct wood fire management.

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Supplemental Material

Supplemental data for this article can be accessed on the publisher's website.

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