THE ROLE OF BIOETHANOL FLUELESS FIREPLACES ON INDOOR AIR QUALITY

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Abstract

This study concerns flueless fireplaces powered by liquid or gel bioethanol based fuels. These devices have a pleasant aesthetic design and they can be used in indoor environments; in particular, they do not need any connection to a stack to evacuate the flue gases.

This work evaluates the polluting impact of the mentioned fireplaces, with a special focus on their odour emissions, in order to assess the environmental impact of these items and to provide the European Commission the information to define the guidelines for a dedicated legislation. For these reasons, a series of experimental tests, structured with well-defined steps, alternating operation (combustion) and shutdown, was performed with several fireplaces.

The concentration trends of both the main combustion products and by-products and the odour were monitored; furthermore specific odour emission factors (OEFs) were calculated. The combustion pollutants were mainly released during the operation phase, while the most significant odour emissions occurred during shutdown. The average OEFs reached values between 40 and 110 during the shutdown, but they were below 10 [*100 ou_E kJ^{-1}] during the operation periods. The extent of odour emissions depends crucially on the burner design and geometry of each fireplace and the air-fuel contact surface is the most relevant parameter.

Moreover this study proved that the electronic nose can be a valid additional instrument in activities aimed at evaluating the indoor air quality, and considering its peculiarities, the idea of using it not only as an odour detector, but also as an integrated device in air ventilation systems for indoor environments, is interesting and achievable.

Keywords: electronic nose, odour, combustion, air quality, ethanol, flueless fireplaces

1. Introduction

Environmental pollution is an important field of research and recently a strong interest in indoor environments pollution has grown [1-2]. The reasons for this new focus concern the high amount of time spent by many people in indoor environments [3-5] and the high concentration levels of some pollutants that can be reached in such spaces. The outside air, which may already contain a significant level of pollution, gets in closed environments, where it can stay for a long time. During this period, the air enriches of pollutants coming from building or furnishing materials [6] rather than by the activities carried out in indoor environments, such as cooking, kerosene heating, wood burning, candles and incenses burning [7-11]. Problems like the building related illnesses (BRI) and the sick building syndrome (SBS) exist and they are linked with the bad quality of indoor air [12-14]. Furthermore, because of the growing interest about energy saving problems, the aeration standard is usually low and obviously it penalizes the air quality [15-16].

As well as the pollutants, odour is one of the main causes of bad indoor air quality [2-6]. Nowadays the public opinion pays a lot of attention to odour, in fact, often people associate it with the presence of possible health hazards [17]. In general, this relationship is not verified, due to the fact that for many chemical species the odour threshold concentration is lower than the corresponding threshold limit value (TLV) which could eventually have health effects.

This study concerns flueless fireplaces powered by liquid or gel bioethanol based fuels. These devices have a pleasant aesthetic design and they can be used in indoor environments; in particular, they do not need any connection to a stack to evacuate the flue gases. This is allowed because their manufacturers claim that these fireplaces are decorative items and therefore heating is not the primary objective. For marketing purposes, the producers focus on the biological origin of the fuels, relying on the fact that people commonly associate the use of “natural” products with zero emissions. However, it must be stressed that the prefix “bio” refers just to the ethanol production process, which is based on the fermentation of biomasses, but ethanol is not the only constituent of the fuel [18].

For the reasons set out above, these fireplaces were very successful and a great amount of them has been sold in Europe.

Flueless bioethanol fireplaces represent a source of indoor air pollution in those domestic or non-domestic places, where they are installed and used, due to the fact that combustion products are entirely released in the ambient where people live or spend a long time. As in these devices a combustion reaction happens, in order to ensure no health hazards, this kind of fireplaces should comply with specific regulations. Besides, as decorative devices, they are not subjected to those compulsory regulations and standards applicable to heating appliances [19]. Nevertheless, up to now, there is no dedicated legislation in Europe [20], but only a few national regulations exist; they indicate some building characteristics and describe the conditions to ensure safety and to conduct performance tests.

Only two studies were published about this topic: one in France [18] and the other in Germany [21]. They both revealed problems regarding safety as well as air quality; they highlight some problems concerning especially the release of CO, NOx and Volatile Organic Carbons (VOCs) into the indoor environment. Hence, the European Union decided to investigate whether it is worthwhile to create a specific legislation for fireplaces fueled with bioethanol [20], by activating also a study on alcohol-powered flueless fireplace combustion and its effects on indoor air quality [22].

The aim of this work is to evaluate the polluting impact of the mentioned fireplaces, with a special focus on their odour emissions. For this reason, the odor concentration trends were detected and the corresponding odour emission factors (OEFs) were calculated. Each OEF consists of the instantaneous odour production term within the balance imposed on the considered system, weighted with respect to the thermal power of the examined fireplace. In order to carry out these analyses, the use of the conventional analytical instrumentation was combined with an electronic nose monitoring.

An interesting feedback of this study is into evaluate the electronic nose performances within the indoors, in order to investigate the possibility of using it as an additional tool to improve the results of experimental activities aimed at evaluating the air quality. A further aspect is the evaluation of the opportunity to employ an electronic nose as an integrated device in air ventilation systems for indoor environments.

2. Materials and Methods

The experimental activity was carried out inside a ventilated test chamber (3.4 x 2.9 x 3 m^3), whose ventilation conditions were appropriately controlled. Five different fireplaces, three powered by liquid fuels and two by gel fuels, respectively, were tested. The main technical data of the investigated fireplaces are summarized in Table 1.

Fireplace	Fuel	Provenance	Fuel tank capacity [L]	Ignition	Nominal thermal power [kW]	Maximum autonomy [h]	Price range [€]
S1	Liquid	China	0.8	By hand	2	1.4	< 100
S2	Gel	Germany	1.5	By hand	4	2.3	≈ 150
S3	Liquid	England	5	Automatic	6.2	4.9	≈ 2500
S4	Gel	Portugual	2	By hand	2.7	7.2	800-1000
S5	Liquid	Italy	5	Automatic	4	7.7	1500-2000

Table 1: Main technical data of the investigated fireplaces

The study also involved the use of different bioethanol based fuels, three gel and three liquids (Table 2). They contain denatured bioethanol and other substances, such as perfumes and dyes [18], whose quality and quantity are often not specified (Table 3).

Bio-ethanol containing fuel	Type	Provenance	Boiling temperature [°C]	Autoignition temperature [°C]	Heating value [MJ/kg]
L1	Liquid	Germany	78	423	27.33
L2	Liquid	Slovenia	78	407	28.03
L3	Liquid	Europe	78.3	407	28.06
G1	Gel	Germany	78.5	439	24.72
G2	Gel	France	78.8	429	24.35
G3	Gel	Holland	79.6	431	19.6

Table 2: Main technical data of the tested fuels

Typical additives/constituents	
Liquid fuels	Gel fuels
Isopropyl alcohol Methyl-ethyl-ketone Denatonium benzoate Methyl-isopropyl-ketone Ethyl-sec-amyl-ketone Tert-butyl alcohol	Gum Xanthan 2-methyl-heptanone

Table 3: Typical additives and secondary constituents of the investigated fuels

During the experiments, all the parameters were monitored using a combined set of different experimental techniques, in particular macro species, such as CO_2, CO, NOx, were measured using continuous gas analysers (HORIBA PG-250, with NDIR and chemiluminescence detectors).

A specific sampling technique (with Tenax™ and Carbosorb™ sorbent cartridges) was also adopted to collect some micropollutants such as Volatile Organic Carbons (VOCs); then, their identification and quantification was done by means of proper GC-MS analysis. The hygrometer data-logger PCE HT 110 measured the temperature and the relative humidity inside the ventilated test chamber. This device allowed the continuous monitoring of these parameters by means of two specific detection channels.

An electronic nose, EOS 507 C [23] developed in collaboration with Sacmi (Imola, Italy), was employed in order to detect the odour trends. This device is shown in figure 1.

Figure 1: Electronic nose EOS 507 C

This electronic nose is equipped with six metal oxide semiconductor (MOS) sensors, different in type and exercise temperature (table 4), whose resistance values change as a function of the interacting compounds.

Sensor	Semiconductor	Support	Dopant additive	Exercise temperature [°C]
1	SnO_2	Al_2O_3	Mo	550
2	SnO_2	Al_2O_3	---	525
3	SnO_2	Al_2O_3	---	310
4	SnO_2 - MoO_3	Al_2O_3	---	320
5	SnO_2	Al_2O_3	---	813
6	SnO_2 -TiO_2 - Nb_2O_5	Al_2O_3	---	500

Table 4: Structure of EOS 507 C sensors

This electronic nose is therefore provided with an autonomous system for the reference standard daily preparation (n-butanol), continuous auto-calibration and it is also able to adjust the humidity of the reference air, depending on the sample humidity, in order to improve the measures reproducibility. In this way, the EOS 507 C automatically runs a calibration procedure every day and every time it is necessary. This means that when the electronic nose perceives a significant variation in terms of sample humidity, it stops operating and it defines a new humidity work value, depending on the humidity content measured, and re-calibrates according on such value.

The instantaneous output signal considered for each sensor (1) is expressed in Eos Units (EUs), using the following formula:

$$EU_i = a_i * \left(\frac{R_i}{R_{std,i}}\right)^{b_i} \qquad (1)$$

where R_i is the resistance value, $R_{std,i}$ is the standard resistance value, a_i and b_i are characteristic coefficients depending on the sensor type.

The Eos Units, so defined, can be correlated with odour concentration (in odour unit for cubic meters – ou_E/m^3).

The EOS 507 C has also to be able to recognize the different operation phases of the test cycle. For this purpose, a suitable instrument training is necessary. When the EOS 507 C works in training mode, it mixes a defined sample percentage with neutral air, then it dilutes this mixture with neutral air in several steps, in order to smell it at rising concentration levels, finally the EOS 507 C labels the sample. Each training sample is previously submitted at sensorial olfactometric analysis (EN 13725, 2003) [24], in order to determine its odour concentration (ou_E/m^3), which is an indispensable input data for the EOS 507 C training. As a matter of fact, the training procedure implies the attribution of the EU_i values to the dilution steps of the sample. The data relevant to the training operations constitute a reference library, which is used to perform the recognition.

During the experimental tests, both the HORIBA PG-250 gas analyzer and the electronic nose were interfaced with the ventilated chamber air, thanks to some sampling points, placed on the test chamber air outlet pipe; meanwhile the hygrometer data-logger PCE HT 110, placed in close proximity of the tested fireplace, monitored temperature and relative humidity (figure 2).

As regards the non-continuous samplings of volatile organic compounds by means of sorbent cartridges, they occurred thanks to another sampling point placed on the air outlet pipe of the ventilated chamber.

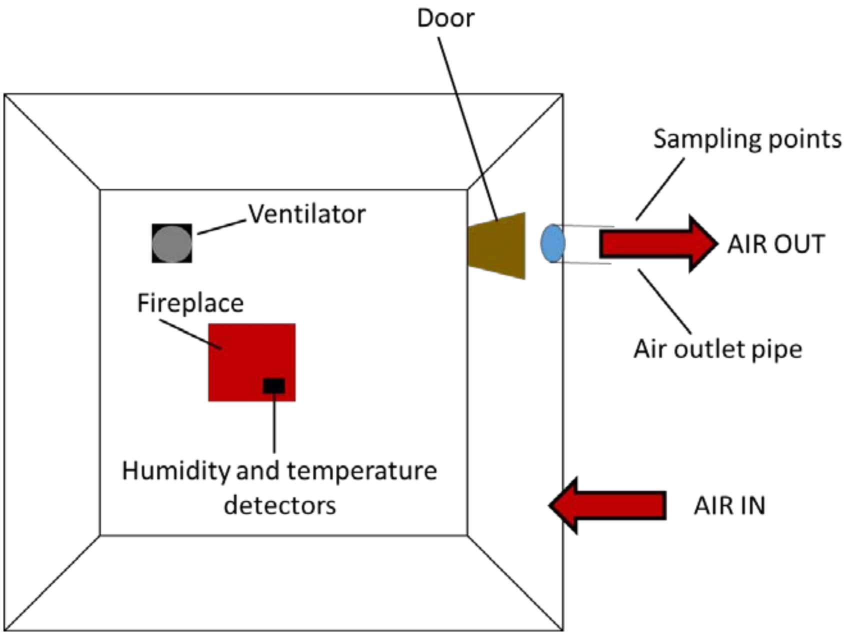

Figure 2: sketch of the ventilated chamber

Before starting the experimental activity, in order to verify the reliability of the EOS 507 C response, the performances of its sensors have been tested, with respect to a reference mixture of neutral air containing 54 ppm of n-butanol: this sample was analyzed by the electronic nose in ascending concentration levels. n-butanol is the reference substance, used to calibrate the sensors, so, facing them with such compound (mixed with neutral air), the responses of all the sensors are expected to be similar. In particular the responses in terms of EU_i should be linear and increasing with the sample concentration.

A series of fifteen experimental tests, each constituted by two test cycles, were performed within the ventilated test chamber. Each test was composed of a series of steps: blank (during which the test room was purged with pre-filtered air and the blank concentrations were recorded for 1 hour at least), operation 1 (combustion period), shutdown 1, operation 2 and shutdown 2: all the phases lasted one hour. Each experiment involved a specific fireplace powered by a well-defined fuel and an established number or air changes per hour ACH (0.2, 0.5, 0.8 or 1 h^{-1}) for the test chamber volume.

For each kind of fireplace, a training set consisting of three files (blank, operation and shutdown) was obtained. All the tests were monitored in terms of main combustion products, such as CO (ppm), CO_2 (vol%), NO_x (ppm), and odour (EU) emissions. A specific software, developed by Sacmi (Imola, Italy) for pattern classification (NPC-Nose Pattern Classifier), allowed to match each monitoring file with a training set. In this way, for each recorded measurement, the recognition of a certain working phase has been determined. Usually the results are influenced by the choice of the training sets and the reference sensors: these parameters can be selected by means of the NPC.

In every test cycle, the phases are unequivocally marked, because of the manual actions (turn on and shut down) of the operators, thus making possible to check for the correctness relevant to each recognition output. For each phase of every test cycle, the percentage of correct recognitions was then evaluated with respect to the total number of recognitions.

With the aim of assessing the characteristic odour impact of each fireplace, specific odour emission factors (OEFs) [ou_E kJ^{-1}] were then evaluated in term of odour emitted during the time related to the apparatus thermal power.

In order to determine the OEFs relevant to the different phases of each test cycle, an odour material balance on the ventilated test chamber was set, according to the following expression:

$$V * \frac{dEU_i}{dt} = Q * EU_{i,IN} - Q * EU_i + OEF_i * Pw \qquad (2)$$

where V [m^3] is the ventilated chamber volume (29.6 m^3), Q [m^3 min^{-1}] is the volumetric air flow rate (0.5 or 0.4 or 0.25 or 0.1 m^3/min) fed to the ventilated chamber, $EU_{i,IN}$ [ou_E m^{-3}] is the inlet air EU value registered by sensor (1) at time t=0, EU_i is the outlet air EU value relevant to sensor (1) at time t>0, OEF_i is the odour emission factor relevant to sensor (1) from t=0 to t >0 and Pw [kJ] is the nominal thermal power of the considered fireplace.

Solving the balance, the instantaneous emission factors [ou_E kJ^{-1}] were evaluated as follows:

$$OEF_{i,(t-t_0)} = \frac{Q}{Pw} * \frac{EU_{i,t} - EU_{i,0} * \exp\left[-\frac{Q}{V} * (t - t_0)\right]}{1 - \exp\left[-\frac{Q}{V} * (t - t_0)\right]} \qquad (3)$$

where $EU_{i,0}$ and t_0 are the starting EU and time values of the considered working phase (operation 1 or shutdown 1 or operation 2 or shutdown 2), respectively.

For each phase of every test cycle, a characteristic odour emission factor value was calculated as the mathematical average of all the instantaneous $OEF(t)_i$, then the statistical t-Student test allowed the comparison between analogous average odour emission factors.

To better understand the phenomena occurring in no flame condition, after the switch off of the fireplace, a separated series of laboratory tests concerning the detection of odour emission in vapor phase from liquid and gel fuels and the measurement of odour of the main combustion gases were carried out by means of the EOS 507 C. Species like CO and CO_2, pure ethanol and fuels vapors were analyzed in ascending concentration levels by EOS 507 C, with the aim to investigate the role of the individual species on the overall olfactory footprint. Each combustion product (i.e., CO or CO_2) was provided by a gas bottle containing the reference species diluted in a nitrogen atmosphere; then, these streams were diluted with neutral air by means of suitable flowmeters, in order to subject to the electronic nose mixtures characterized by compositions comparable to those recorded during the ventilation chamber tests. Pure ethanol and the bioethanol based fuels were individually put in Nalophan^{TM} bags with neutral air at 20°C; then, reached the vapor phase equilibrium, these mixtures were diluted to a well-defined quantity of ethanol (455 ppm).

3. Results and discussion

As shown in figure 3, the calibration of EOS 507 C with n-butanol highlighted that the responses of sensor 5 are not linear and that the outputs of sensor 2 are not comparable to those of the other sensors, whereby, being n-butanol the reference substance for sensors calibration, the responses of all sensors to this substance should be linear and similar. Only the responses of the sensors 1, 3, 4 and 6 were considered reliable.

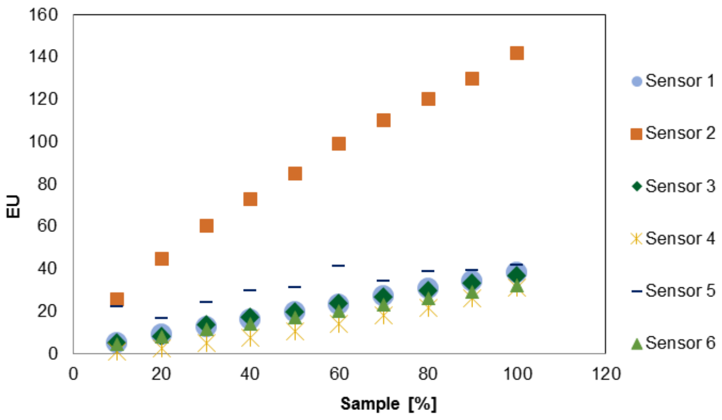

Figure 3: manual calibration with n-butanol results

Table 5 shows the training conditions implemented for each fireplace, in terms of fuel, air changes per hour (ACH), use of the ventilator, sampling phases and EOS 507 C training conditions. The sampling time from the beginning of the phases and the corresponding odour concentrations are listed. Concerning the EOS 507 C training mode, the percentage of the sample mixed with neutral air, the range of sample concentrations analyzed and the corresponding dilution step are reported.

Fireplace	Fuel	ACH [h^{-1}]	Ventilator	Sampling phases						EOS 507 C training mode		
				Blank		Operation		Shutdown				
				Time [min]	C_{od} [ou_E/m^3]	Time [min]	C_{od} [ou_E/m^3]	Time [min]	C_{od} [ou_E/m^3]	Sample [%]	Range [%]	Step [%]
S3	L1	0.5	ON	30	8	20	40	10	50	80	20-100	20
S1	L1	0.5	OFF	30	50	20	300	10	1000	50	70-100	10
S5	L3	0.2	ON	30	10	20	300	10	200	50	70-100	10
S4	G2	0.5	OFF	30	5	20	500	10	500	50	70-100	10
S2	G2	0.5	OFF	30	20	20	150	10	350	50	70-100	10

Table 5: training conditions of the EOS 507 C

For all the fireplaces considered, the EOS 507 C training results highlighted the instability of the responses given by sensor 1; its response did not change when increasing the sample concentration and the data related to the operation phase (combustion period) indicated this phase to be less odorous than the blank one, which is logically not acceptable. Therefore, the whole experimental activity exploited only the responses of sensors 3, 4 and 6. As an example, figure 4 shows the training data relevant to the S1 fireplace.

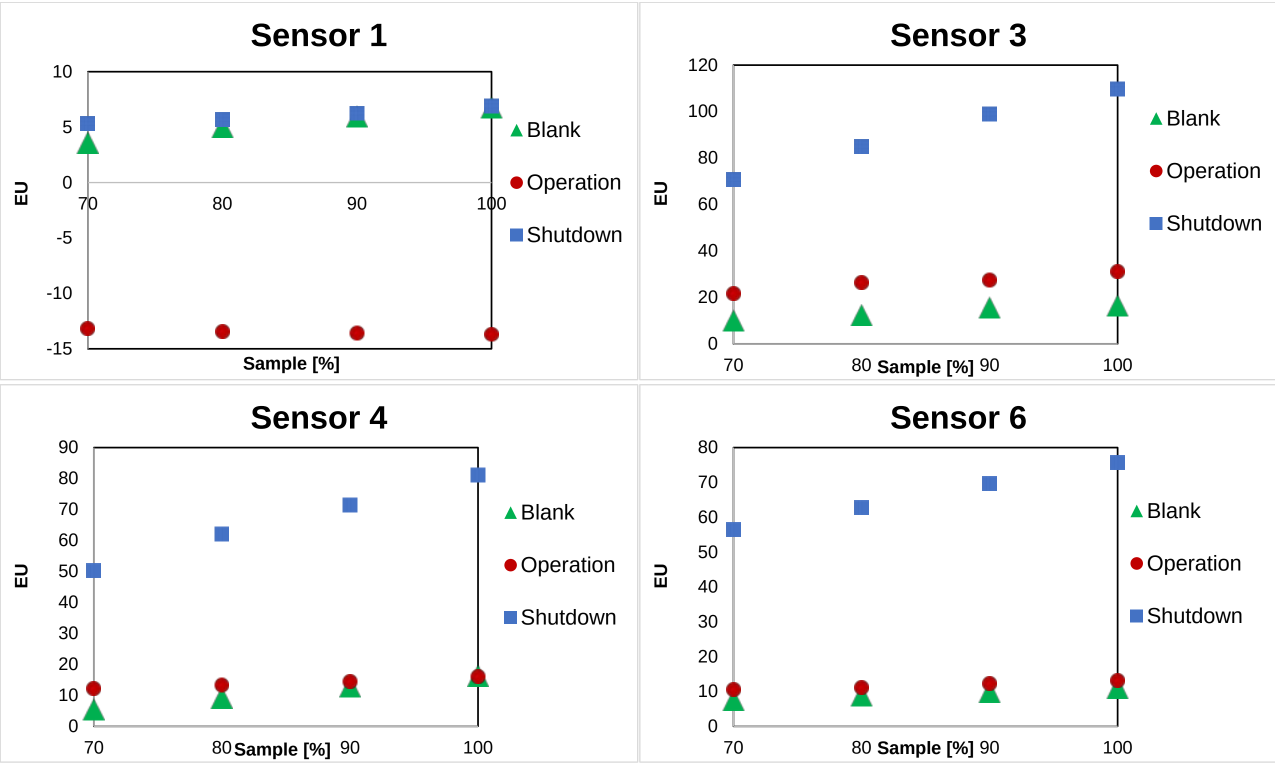

Figure 4: Example of EOS 507 C training results (fireplace S1)

The samples dilutions percentages were chosen privileging high concentration levels, in order to avoid background noise. The choice of the training phases was optimized, so that the electronic nose was able to distinguish among the different periods of operation (blank, operation and shutdown): this entailed to provide the EOS 507 C with a robust training dataset, in order to make it able to reach satisfying recognition levels.

For each test cycle humidity, temperature, CO_2, CO and NO_x concentrations increased during operation (combustion phase) and decreased during shutdown, phase in which the combustion reactions were stopped and polluted air was purged. The graphs presented in figure 5 are an example of the typical trends of temperature, absolute humidity, and pollutants concentrations (ppm_v or %vol) within the context of a test cycle (fireplace S1, fuel L2, and ACH = 0.5).

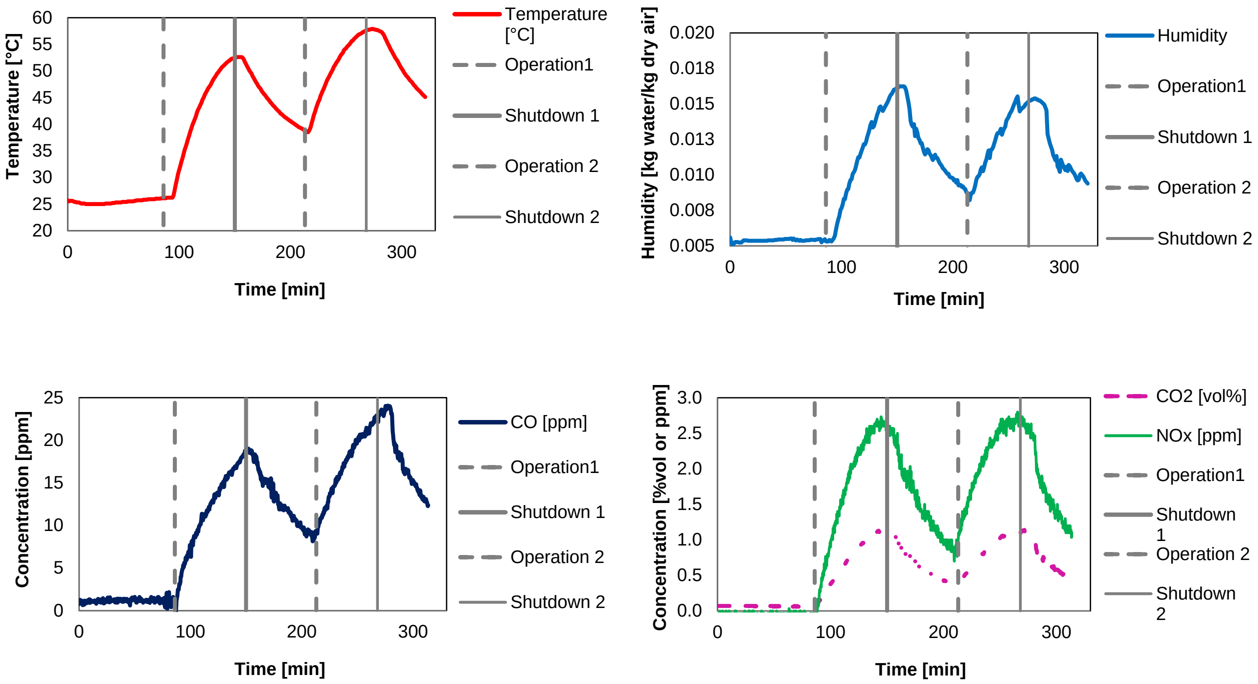

Figure 5: example of temperature, absolute humidity and main pollutants concentrations trends for a typical test performed with fireplace S1, fuel L2 and ACH = 0.5

The trends of volatile organic compounds differed from those of the main combustion products, in fact these emissions were low during the operation and increased as soon as the switching off happened. The following graph (figure 6) shows the results of the volatile organic compounds offline measurements during the first single whole phase for the fireplace S1. The gas sample related to the vanishing phase was collected as soon as the flame was turned off.

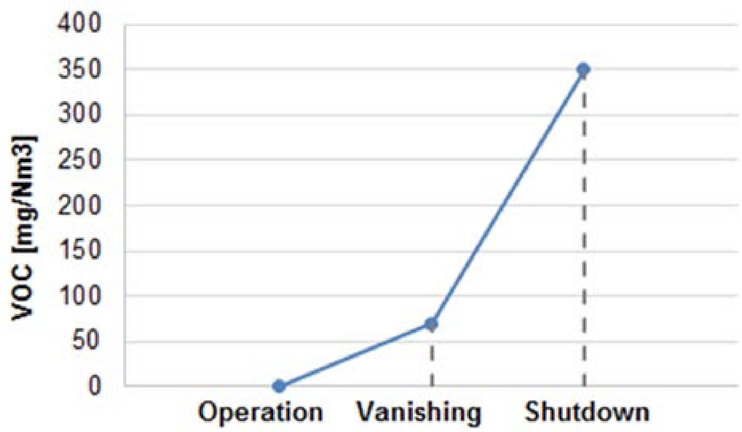

Figure 6: Example of Volatile Organic Compounds (VOC) results obtained in a cycle test performed with the fireplace S1

The main volatile chemical detected is ethanol; among the other species, observed in much lower concentrations, heavier alcohols, like 2-propanol, and some other oxygenated species, but also aliphatic hydrocarbons and some aromatics (toluene in particular) were found in several test cycles, thus confirming previous literature findings [18-21].

The key phenomenon is the fuel evaporation, which is influenced by the fireplace design. The more the fuel tank gets hot and the air-fuel contact area is wide, the more the fuel tends to evaporate. This contribution is particularly relevant for the fireplaces characterized by an open fuel tank. The presence of such species in the test chamber air is the direct responsible of odour detection, in fact the odour trends are similar to those of the volatile organic compounds. Table 6 reports the average EUs and the average OEFs for each phase of the investigated test cycles. The results inherent both of EUs and OEFs highlight that the most relevant odour emissions occurred during the shutdown phases, in fact during these periods the fuels are hot due to the previous combustion phase, so the odorous compounds have a higher vapor pressure. The use of different fireplaces implies different odour impacts and the main responsible for this phenomenon seems to be the fireplaces design rather the used fuel; in particular, the extent of the air-fuel contact surface is the most relevant parameter. Fireplaces S2 and S4 have open tanks, while the burner of the fireplace S1 consists of a porous sponge impregnated with the liquid bioethanol based fuel: such items cause a significant odour emission during shutdown because of the relevant extent of the air-fuel contact surface. Fireplaces like S3 and S5, on the other hand, do not release many odorous substances, because they have closed tanks and an automatic system to control the fuel fed to the burner, so during the shutdown the evaporation of the fuel is avoided. It is important to emphasize that the fireplaces powered with gel fuels inevitably imply a significant odour impact, in fact, because of the high viscosity of the fuels involved, they cannot exploit an injection system like the devices fueled with liquids. Concerning the fireplaces powered with liquid fuels, if they have closed tanks and injection systems, their odour impact is low, otherwise, if they are characterized by open air-fuel contact surfaces, their odour impact is not negligible and it is comparable to that of the fireplaces powered by gel fuels. As the analyzed fireplaces are characterized by different thermal powers, the corresponding odour emission factors have been weighted with respect to this parameter. At equal thermal power the effect of the fireplace design can be well-noticed: as an example, fireplaces S2 and S5 have different odour emission factors, due to their physical structures. The t-Student test ratified that the OEFs relevant to the corresponding test cycle phases (operation and shutdown), calculated for a certain fireplace, but for different fuels and/or aeration rates, are statistically comparable.

Test cycle	Fireplace	Thermal power [kW]	Fuel	ACH [h^{-1}]	Ventilator	**Average Eos Units (EUs)**				**Average Odor Emission Factors (OEFs)*100**			
						Operation 1	Shutdown 1	Operation 2	Shutdown 2	Operation 1	Shutdown 1	Operation 2	Shutdown 2
1	S1	2	L1	0.5	OFF	22.65	83.70	48.45	94.80	1.67	74.84	0.34	69.34
2				0.2	OFF	35.83	88.62	53.34	93.48	1.00	66.05	0.04	71.25
3			L2	0.5	OFF	21.39	98.99	54.37	106.38	1.80	74.44	1.76	69.97
4				0.2	OFF	15.53	86.47	51.72	95.02	0.38	72.31	0.24	67.81
5	S2	4	G2	0.5	OFF	8.62	78.71	25.30	95.26	2.10	45.54	1.70	42.53
6				0.2	OFF	12.54	76.04	35.77	106.92	0.90	43.16	1.60	44.90
7			G3	0.5	OFF	11.50	90.99	47.37	92.38	1.52	43.33	2.45	42.23
8			G1	1 & 0.8	ON	17.03	75.17	67.78	127.94	2.57	42.13	3.24	45.49
9	S4	2.7	G1	0.5	OFF	17.92	122.60	150.09	147.33	9.99	106.77	9.40	102.27
10				0.2	OFF	26.57	166.88	165.07	244.98	7.94	112.34	9.20	105.06
11	S5	4	L1	0.5	ON	1.23	4.32	5.51	3.92	-0.15	2.27	0.17	2.18
12				0.2	ON	7.69	6.51	4.80	5.07	0.44	2.10	-0.38	2.83
13				1 & 0.8	ON	20.73	20.91	20.94	19.10	0.45	4.39	-0.58	4.21
14			L2	0.2	ON	1.02	8.58	1.71	3.81	0.31	3.71	-0.16	4.48
15	S3	6.2	L3	1 & 0.8	ON	17.16	11.34	11.45	11.79	0.40	1.84	0.24	1.52

Table 6: Eos Units and odour emission factors results

Figure 7 reports an example of odour monitoring results of EOS 507 C used for the experimental activity for fireplace S1.

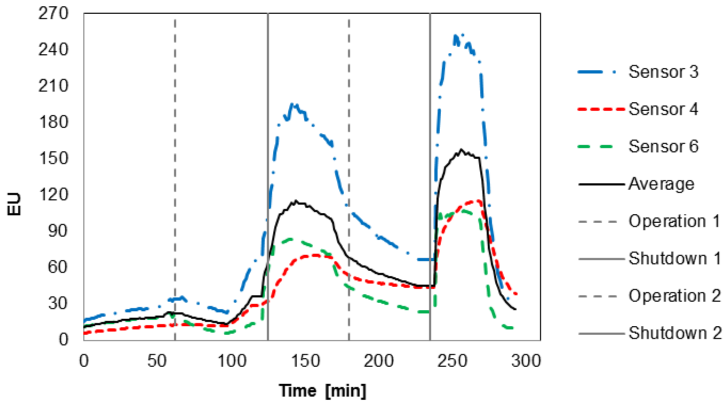

Figure 7: Examples of odour monitoring results obtained by EOS 507 C (fireplace S1; fuel L2, ACH = 0.5)

As described in the experimental section, the EOS 507 C is able to recognize the occurring phase. Table 7 reports the recognition results for the performed test cycles, in terms of percentage of correct recognitions, whereby, by "correct recognition" the recognition of the right operation phase (blank, operation or shutdown) is intended.

Table 7 shows that the accuracy of the recognition depends on the reference training set. In general, by combining training sets of similar odour impact fireplaces (gel-gel; liquid-liquid), high recognition performances are achieved. This allows to have a robust training set. However, such pairings should be done carefully, because if there is no consistency among the combined trainings, which form the final training dataset, or if the latter is not suitable for the coupled monitoring, the recognition accuracy is penalized. The results of Table 7 were obtained coupling each monitoring file with different training sets.

Odour emission laboratory tests on combustion products (CO, CO_2, NO_x) showed that the EOS 507 C did not detect such compounds; in fact, these substances can be considered odourless [25]. Therefore, odour emission laboratory tests on both pure ethanol and the fuels used for the ventilated chamber tests were performed by EOS 507 C in ascending concentrations.

Fireplace	Test cycle	Training set	Blank	Operation 1	Shutdown 1	Operation 2	Shutdown 2	Calibrations
S1	1	S1	98%	95%	79%	90%	95%	0
		S1+S3+S5	98%	86%	84%	80%	86%	0
	2	S1	98%	100%	76%	83%	100%	1
		S1+S3+S5	70%	100%	78%	49%	100%	1
	3	S1	98%	86%	88%	83%	74%	2
		S1+S3+S5	98%	100%	100%	0%	60%	2
	4	S1	98%	89%	97%	86%	92%	0
		S1+S3+S5	100%	86%	90%	24%	74%	0
S2	5	S2	0%	87%	0%	8%	92%	4
		S2+S4	0%	100%	0%	69%	25%	4
	6	S2	96%	81%	100%	84%	100%	2
		S2+S4	96%	90%	97%	100%	95%	2
	7	S2	98%	78%	100%	82%	100%	1
		S2+S4	98%	78%	100%	100%	100%	1
	8	S2	98%	63%	100%	41%	95%	1
		S2+S4	95%	78%	96%	76%	100%	1
S4	9	S4	100%	63%	82%	66%	62%	3
		S2+S4	95%	100%	76%	71%	67%	3
	10	S4	81%	85%	71%	0%	66%	4
		S2+S4	35%	63%	58%	0%	66%	4
S5	11	S5	95%	46%	70%	100%	57%	2
		S3+S5	84%	86%	60%	100%	50%	2
	12	S5	76%	0%	0%	100%	0%	4
		S3+S5	78%	0%	0%	100%	0%	4
	13	S5	98%	64%	0%	100%	0%	2
		S3+S5	98%	25%	0%	100%	0%	2
	14	S5	60%	74%	0%	30%	0%	3
		S3+S5	93%	83%	4%	0%	11%	3
S3	15	S3	100%	12%	100%	0%	100%	2
		S3+S5	96%	42%	0%	100%	0%	2

Table 7: recognition results relevant to EOS 507 C

Figure 8 reports the average EU results relevant to ethanol and to the considered bioethanol containing fuels: they consist of the mathematical average of the EU responses of sensors 3, 4 and 6, which are the sensors exploited during the fireplaces tests. Figure 8 shows that the responses, for ethanol are significantly lower than for the investigated fuels. It occurred because the commercial fuels include some denaturants and other, often not specified, additional substances. Even if the amount of these species within a fuel is low, their presence increases the global odour impact detected in the indoor environment.

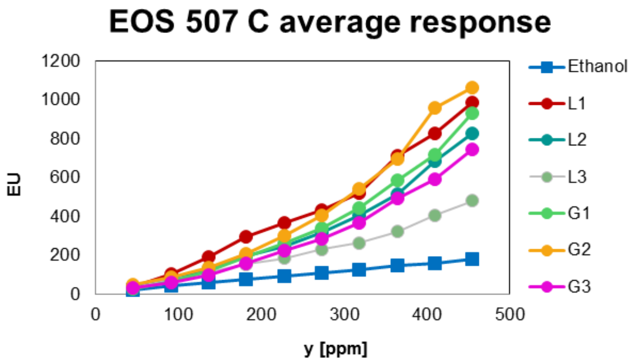

Figure 8: Comparison among the average results obtained with pure ethanol and the investigated bioethanol containing fuels

It is important to highlight that even if gel and liquid fuels have quite different compositions because they include different additives, the results of the corresponding odour emission tests in vapor phase at ambient temperature in no flame conditions underline that there are no substantial differences, in terms of odour impact, between gel and liquid fuels.

This means that the different odour impacts of the fireplaces are not directly affected by the physical state of the fuel (gel or liquid) and, by so, the assumption, that the fireplace design is the fundamental parameter influencing the odour emission, is supported.

4. Conclusions

This study, involving the investigation of the indoor pollutant impact related to domestic flueless fireplaces powered by bioethanol based fuels, shows that the odour emitted has to be considered.

It is very important to highlight a first observation concerning the fact that the concentrations of the main combustion products (CO, CO_2 and NO_x) and of odour turned out to be not related to each other depending on the operational phase of the fireplaces.

The extent of odour emissions depends crucially on the design of each fireplace. This means that the designer attention should be carefully focused on burner technology, geometry of the elements which put in contact the fuel and the flame, as well as on devices for the flame suppression and the fireplace shutoff.

The commercial formulation of the fuels is a critical parameter too, because there are additional compounds that affect the global olfactory footprint.

An electronic nose was the device used to run the above mentioned analyses. The smart choice of a robust and suited training dataset of experiments is the basis for achieving high recognition performances. A critical analysis of the recognition results is essential in order to make an overall assessment of data quality.

Finally this study proves the electronic nose to be a valuable additional tool for experimental activities aimed to evaluate the indoor air quality. Considering the instrument peculiarities, the idea of using it not only as an odour detector, but also as an integrated device in air ventilation systems for indoor environments, appears interesting and achievable.

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