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Appraisal of the Regulations Governing the Use of Gas-Powered Domestic Appliances Having Consideration of NO_x Emissions

Key Words
Wall-mounted combination boilers
Top burners
LPG
Nitrogen oxides
Ventilation

Abstract
Domestic gas apparatus generate oxides of nitrogen (NO_x), which have been classed in recent years as problem products in the context of indoor air quality (IAQ). These, together with carbon monoxide which may also be present in the products of gas combustion, mean that the formulation of regulations for health protection presents complex problems. The present work shows the importance of this matter and presents interesting case studies taken from the Basque Country and our area of influence. It also makes specific recommendations as to how existing regulations should be changed.

Introduction

Gas-fired domestic appliances generate nitrogen oxides (NO_x) which affect indoor air quality in the homes where they are used and are an additional problem to that presented by carbon monoxide (CO). When the amount of NO_x generated, and particularly the amount which escapes into the living space, is considered in the light of WHO [1] recommendations, it can be seen that new ventilation criteria are advisable as argued below.

The Thermal Motor and Machinery Department of the University of the Basque Country has spent three years analysing emissions from domestic appliances in homes in the Vizcaya, Burgos and Cantabria provinces [2, 3] including studies of NO_x and CO levels inside the homes. Top burners and wall-mounted combination boilers (for heating and domestic hot water) were investigated. This choice was based on a survey carried out in the late 80s by Gaz et Electricité de France, which found that gas cookers were widely used and that wall heaters were the most popular type of heater in northern Spain.

From the outset of the study there was great concern among the researchers about the lack of compliance with legal requirements and about the extent to which possible flaws or insufficiencies in those requirements might be responsible for the deficiencies detected. The study of gas cookers revealed a large percentage of apparatus which were 10 or even 15 years old. It was found that age had a profound influence on the level of CO emissions measured, which was particularly worrying in cases where these were high and ventilation was inadequate. However, where newer apparatus were installed most indoor pollution was due to NO_x emissions, which in some cases reached concentrations of between 0.1 and 0.2 ppm approximately 15 min after lighting a burner when natural draught ventilation was used. Since most individual wall-mounted combination boilers in Spain are fairly new, the situation for these apparatus is very different

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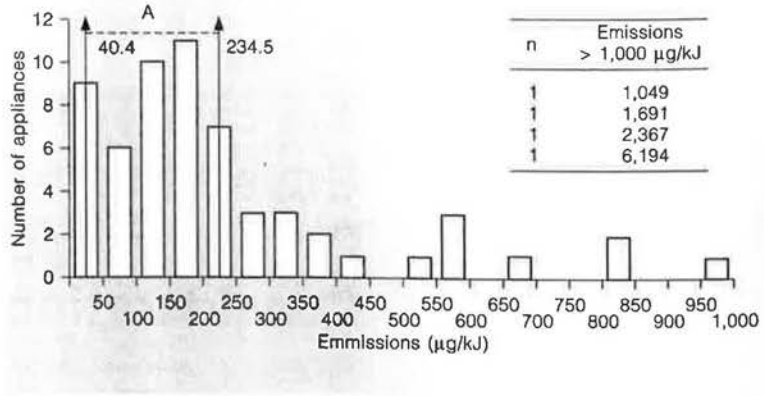

Fig. 1. CO emission from the cooking appliances (with the largest burner lit) checked in the Vizcaya, Burgos and Cantabria provinces: interval A is the range of emissions measured by the GRI. Four appliances emitted more than 1,000 µg/kJ (box).

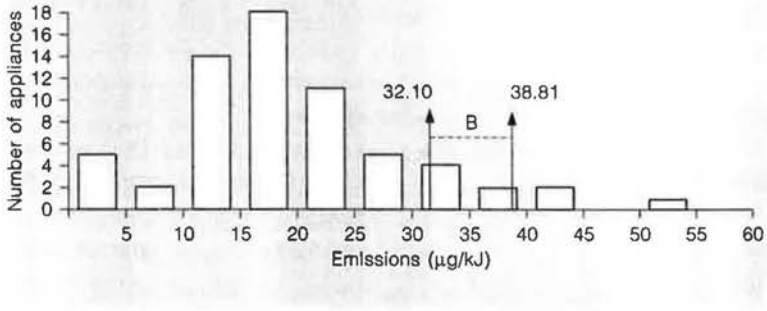

Fig. 2. NO_x emission from the cooking appliances (with the largest burner lit) checked in the Vizcaya, Burgos and Cantabria provinces: interval B is the range of emissions measured by the GRI.

with regard to emissions, and the main pollutants are NO_x.

The study showed that legislation concerning the installation and use of gas appliances is insufficient, especially with regard to the removal of combustion products through the façade and ventilation.

The work presented in this paper was the subject of a doctoral thesis [2].

Measuring Techniques and Methods

Emissions from the appliances tested (top burners and wall-mounted combination boilers) were measured with an IMR-3000 P gas analysis multimeter, No. 721430 (IMR GmbH, Heilbronn, Germany). The various sensors in this equipment are electrochemical and are sensitive to concentrations of CO and NO_x down to 1 ppm. The device was calibrated with standards.

Samples of combustion gases from cookers were taken with a header cowl fitted to a container of water placed on the most powerful burner at its maximum heat flow rate. The header cowl, the container and the amount of water used are as required by Spanish legislation [4]. Emissions from individual wall-mounted boilers used for heating and domestic hot water were monitored by inserting the probe of the testing device into the flue in the case of open flue units and into the discharge mouth in the case of sealed units.

Ambient levels of CO were measured with the same IMR-3000 P, and NO-NO_x levels were measured with a portable AC-35 device (Groupe Environnement SA, Poissy, France) developed by Gaz et Electricité de France. The operation of this device is based on chemiluminescence, and it can measure NO_x levels with a sensitivity of 0.01 ppm. Except in certain specific tests such as cold-starting and checks for dissipation, quantification of dissipation and the impact of mechanical gas extractors, the levels of the pollutants were assessed 15 min after the commencement of emissions.

The homes in which the measurements were made were rural and urban dwellings situated mainly in the provinces of Vizcaya, Burgos and Santander and ranging from low-cost government-subsidised housing to high-quality single-family dwellings.

Results

Emissions Detected from Cooking Appliances (Top Burners)

Figures 1 and 2 show the emission of CO and NO_x from the 64 cooking appliances measured with the largest burner lit.

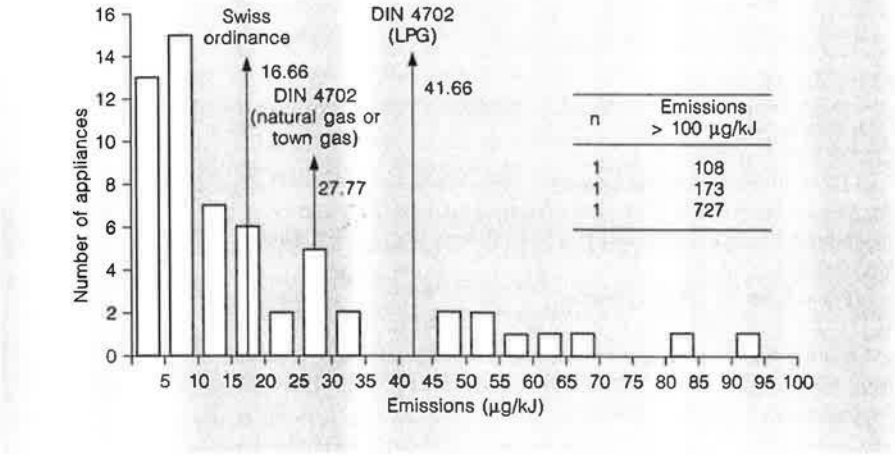

Fig. 3. CO emissions from open flue system wall mounted combination boilers checked in the Vizcaya, Burgos and Cantabria provinces. Regulatory values are marked. Three appliances emitted more than 100 µg/kJ (box).

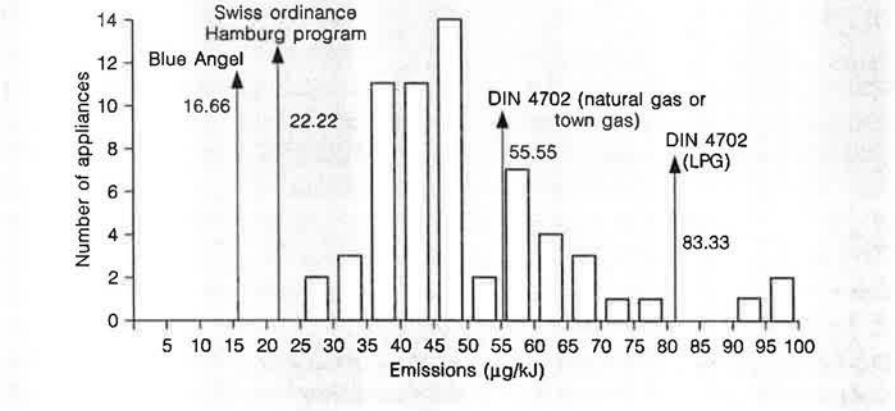

Fig. 4. NO_x emissions from open flue system wall mounted combination boilers checked in the Vizcaya, Burgos and Cantabria provinces. Regulatory values are marked.

We assessed CO emissions as per UNE standard 60-755-89 [4], compliance with which is compulsory in Spain. Of the appliances tested, 29.6% had CO/CO_2 ratios in excess of those permitted by the standard. A second assessment was made to compare these results with those obtained in a laboratory by the US Gas Research Institute (GRI) [5]. As shown in figure 1, this second assessment revealed that CO emissions in 32.81% of the appliances checked were higher than the upper limit for the range of emissions obtained by the GRI.

Spanish standards do not lay down specific criteria for assessing NO_x emissions. We therefore used the results from the GRI again to assess NO_x emissions from cooking appliances. As shown in figure 2, 90.6% of the appliances checked had NO_x emissions below the lower limit for the interval set by the GRI.

In summary, of the cooking appliances checked, more had a problem with CO emissions greater than the permitted levels than with NO_x emissions, based on the results from the GRI. This was not unexpected because, as the study by Gaz et Electricité de France pointed out, their average age is high.

Emissions Detected from Open Flue System Combination Boilers

Figures 3 and 4 show the emission of CO and NO_x from the 62 open flue system combination boilers checked. First we performed a check on compliance with the requirements of UNE standard 60-751-84 [6] regarding CO content in combustion products. Compliance with this standard is compulsory in Spain. All the appliances checked had CO/CO_2 rates acceptable under the standard.

A second check on CO emissions from open flue system combination boilers was made in line with European standards, which set maximum admissible levels for NO_x

Table 1. Results of tests with top burners lit

	A	B
NO_x emissions, ppm	10 (69.62)[1]	41 (122)[1]
NO_x pollutant levels, ppm		
On the kitchen table		
(1.7 m from the cooking burner)	0.041	
In the cooking area		
(height 1.5 m)		0.40
On the kitchen table		
(1.8 m from the cooking burner)		0.18

A = top burner with low NO emissions and negligible CO emission; B = top burner with high NO_x emissions.

[1] Expressed in mg N m^{-3}; 3% O_2.

Table 2. Results of test on a cooking burner (top burner) with CO emissions in excess of the limit in the approval test

Pollutant	Emissions	Mean concentrations		
		A	B	C
CO_2, %	4.7	0.1	0.1	0.2
CO, ppm	571 (1,529.46)[1]	2	2	2
NO_x, ppm	20 (87.75)[1]	0.09	0.50	0.12

A = On the kitchen table, 1.7 m from the cooker burner; B = at nose height in the cooking area; C = in the passage way of the house at a height of 2.3 m.

[1] Expressed in mg N m^{-3}; 3% O_2.

and CO. Of heaters using natural or manufactured gas, 61.1 and 84.08% of those using LPG met the requirements of DIN 4702. Some 59.67% of the heaters checked met Swiss clean air ordinances.

Since Spanish legislation sets no criteria for NO_x emissions, we took various standards from around Europe as reference points. All the natural gas heaters, 93.18% of those using LPG and only 25% of those using manufactured gas met DIN 4702.

Case Studies

Over 3 years of research, we found many cases of combustion gases discharge systems which did not comply with any regulation. Some of these cases have been presented previously in other fora [7–10]. We shall therefore concentrate below on cases of cooking appliances (top burners) and wall-mounted combination boilers which are particularly illustrative for proposals for the improvement of regulations.

Table 3. Pollutant levels found for a top burner with very high CO emissions (around 6,000 ppm)

Measured points	CO_2, %	CO, ppm
Nose height in cooking area	0.1	11
Kitchen ceiling	0.2	11
Table opposite cooking area	0.1	4

Table 4. Pollutant levels in a bathroom affected by combustion gases from a sealed room heater

Pollutants	Pollutant levels	
	C	D
CO_2, %	0.4	0.2
CO, ppm	0	2
NO_x, ppm	1.85	0.85

C = Discharge of combustion gases through the façade subject to wind action.

D = Discharge of combustion gases through the façade not subject to wind action.

Tests on cooking appliances were carried out in four homes with ventilation complying with the regulations in force [11]. We found that in all these cases there were peaks of NO_x and CO levels after 15 min operation depending on the emission patterns of the appliances installed (tables 1–3).

It is fairly frequent in Spain for combustion gases from open flue system wall-mounted combination boilers to be discharged through the façade. In individual open flue systems (natural draught) this is quite inefficient for many situations. We demonstrated this in measurements in almost two hundred problem homes in the city of Burgos, where we found heavy spillage and indoor contamination with gas combustion products.

In individual room sealed fanned draught systems, the combustion gases voided through the façade can affect the dwelling through ventilation openings close to the combustion gas outlets (table 4).

Our attention was drawn to the fact that some brands of European-made wall-mounted combination boilers factory supplied fitted with the correct combustion gas discharge devices were installed without them because the importer had removed them before distributing the appliances in Spain. Fortunately, this device for correctly discharging combustion gases has been compulsory in Spain since January 1996.

Discussion

It is very important in this discussion to bear in mind the WHO *Air Quality Guidelines for Europe* [1]. This document establishes an alert level for NO_2 of 400 $\mu g/m^3$ (0.21 ppm) for 1 h and 150 $\mu g/m^3$ (0.08 ppm) for 24 h exposure.

For CO, the threshold levels established by the WHO are as follows:

- maximum permitted exposure of 100 mg/m^3 for periods not exceeding 15 min;
- average exposure less than 60 mg/m^3 (50 ppm) for 30 min periods, 30 mg/m^3 (25 ppm) for 1 h and 10 mg/m^3 (10 ppm) for 8 h.

It is understood that after such 15-, 30- or 60-min exposures there should be no further exposures for 8 h.

Ventilation Flow Rate for Protection against NO_2

As seen in the previous section, peaks of NO_x occur during cooking. These peaks appear after a short time even when only one burner is being used and when the ventilation meets the requirements of Spanish standards [11].

The presence of NO_x in emissions from top burners leads one to ask how big a ventilation air flow is required to keep indoor ambient NO_2 at acceptable levels as per WHO guidelines [1].

In countries where the quality of life is high, a protective ventilation air flow rate is established to keep the indoor level of CO_2 from exceeding 0.5% on the basis of an outdoor level of 0.04% [12]. Our own calculations, in line with British Standards [12], have been based on CO_2 emissions of 0.00271 litres/s kW for natural gas and 0.033 litres/s kW for LPG. These give protective flow rates of 4.9641 litres/s kW for natural gas and 6.0621 litres/s kW for LPG as sufficient to ensure that the limit level of 0.5% CO_2 is not exceeded after 1 h operation.

If we take the NO_2 emissions given by the GRI for top burners ($9–12.5 \times 10^{-6}$ g/kJ) [5], assume an outdoor level of 0.05 ppm for this pollutant and wish to stay below an indoor level of 0.21 ppm [1] after 1 h operation, then the resulting flow rates to achieve this are 6 times higher than those needed to dilute CO_2 sufficiently according to the criteria described above. In other words our calculations suggest that if it is intended to combat ambient levels of NO_2 using the flow rates now stipulated for CO_2, NO_2 emissions would need to be reduced to 1.89×10^{-6} g/kJ, i.e. 5 times less than the lower limit for the emission interval given by the GRI. In view of the obvious difficulty of meeting such a requirement in future approval tests, we believe it would be appropriate for ambient levels of NO_x to be dealt with through suitable legislation. It is clearly not practical to increase ventilation cross-sections to the extent needed.

Comparative Analysis of Spanish Regulations for Installations Affecting Indoor Air Quality in Inhabited Buildings

We analysed the regulations published in the Spanish Official Gazette (BOE) [11]. They seemed to us to have important failings and to be too permissive when considered in terms of indoor air quality. We found the air vent cross-sections given in the regulations to be considerably smaller than those in the former NIGE [13], which they replaced a year ago, and in the French [14], Italian [15] and British [16, 17] legislation.

We do not think it correct to allow the indirect entry of air into premises which are to be fitted with heating apparatus without a flue. Nor do we consider as correct the cross-sections indicated for vitiated air evacuation, as they exacerbate the problem of peak levels. We believe that the solution to this problem lies in the Italian standards, which require extractor hoods to be connected to a chimney with a proven draught or, failing this, an electric fan interlocked with the cooker operation.

Our own findings in the city of Burgos alerted us to the problems of outlets for combustion gases from individual open flue systems through the façade. We must advise against using the terminals allowed under the regulations, and recommend that Italian practices [15] be followed when installations of this type have to be used.

In our opinion, the discharge of combustion products to patios is not sufficiently dealt with in the regulations. We believe that Italian regulations [15], which stipulate minimum widths of 3.5 m and a minimum surface area of 12.52 m^2, are closer to the mark than Spanish regulations, which indicate minima of 2 m and 4 m^2, respectively. From investigations made on the plumes from room-sealed systems, the shape and size of the curves and the magnitude of the levels and temperatures described by them should be used as guidelines for establishing more appropriate sizes for patios. We found that fewer details are given in the Spanish regulations regarding the distance which the regulations state must be maintained between the outlet for combustion gases for a room-sealed system and windows or air vents than in other legislation, such as those from Italy [15] and the UK [16].

Recommendations for Future Regulations

The foregoing shows, in our opinion, that there is a need to improve Spanish regulations and also those of

many other countries to take into account the possible presence of NO_x. Concern for this pollutant is based on the substance's acknowledged effect on health and on the recommendations on quantity made by the WHO [1]. Improvements in regulations must be accompanied by improvements in the basic standards on which regulations are based [11] as these are also affected by the various considerations involved. Spanish and other regulations must also plug the loopholes which exist with regard to the introduction onto the market of domestic appliances developed in more advanced countries, which will become available on the different domestic markets within a few months. We are aware that big efforts are being made in Europe in the field of regulation, based on a two-year horizon.

Our work reveals the presence of peak ambient NO_x levels just after gas cookers are lit. This is the case even when there is compliance with present regulations on ventilation areas, and in spite of the fact that many of the cookers in Spain are old and emit less NO_x than newer models. We recommend that basic standards should include limits on NO_x emissions (expressed in μg/kJ) in their approval tests. We also recommend the evacuation of emissions from cookers by fanned or natural extraction with sufficient draught. Fan extraction may produce a negative pressure in the premises, but this will not affect the operation of any combustion device there. To ensure that this is the case, there could be an increase in the area of the air intake for combustion in proportion to the power of the fan installed. Air flow should not be such that flames can be extinguished.

For fanned extraction through the façade, we recommend the establishing of minimum distances from air vents and windows adjacent to and opposite outlets. These distances should be sufficient to ensure that combustion gases cannot flow back into the building, nor into any neighbouring building, through any opening in the façade.

We believe that guidelines for gas appliances with fume conduits should be based on the fact that each type requires its own kind of flue systems. Note should be taken of the appliances installed in other countries even when they have not yet been introduced into the legislating country. The precise location of terminal flues on façades and roofs can affect the indoor air quality in the dwelling in question and in other dwellings. As many alternative locations as possible, therefore, should be detailed before installation, with adequate safety distances established in accordance with the results of research into the shape and size of plumes of combustion gases from appliances of different types.

For open flue systems with natural draught it is especially important to consider the flue system as a whole but made up of inter-related parts, as in the French standard [14] which covers the removal of combustion products through individual flues. By way of example, it should not be mandated that initial sections are always required to be vertical, because such a requirement can lead to the upper flue necessarily changing direction more often because of constraints within the building structure than it would have if the initial section were positioned differently.

Untoward effects from combustion gases from appliances with flues which discharge to patios, whether these are used for ventilation or to allow light to enter buildings, should be considered according to the same criteria as removal through the façade. In particular, the number of flues discharging into the same patio should be limited according to its size.

Our experience also leads us to recommend strongly that thermostats are required in the design of outlets for removing combustion gases correctly from open combustion circuit, natural draught, gas appliances and this recommendation should be incorporated immediately into those regulations which do not already contain such a requirement. The thermostats are safety devices which prevent gases leaking out through the draught diverter, and thus prevent build- ups of unhealthy and possibly life-endangering levels of NO_2 and CO. We are sorry to have to report that some internationally prestigious firms removed this safety device from the appliances they marketed in Spain before January 1st 1996.

Finally, we believe that regulations play a fundamental part in protecting users in their legitimate aspiration to enjoy safe, good-quality indoor air. For regulations to be effective, they must be enforced, but our experience shows that, in the region around us, this is not properly done and further that there are wide variations between adjacent areas, which makes matters even worse. As a complement to adequate regulations properly enforced, we suggest policies to favour the purchase of environmentally friendly appliances and campaigns to heighten awareness of the dangers from incorrectly installed and badly maintained equipment. User awareness campaigns have been staged successfully in many countries. Associations such as our own help out in the Basque province of Vizcaya through lectures, technical meetings and talks to the professional associations of the different groups of technicians involved in indoor air quality.

During our research, we observed the excellent performance and high-quality combustion of the low NO_x emission wall-mounted combination boilers bearing the Ger-

man *Blauer Engel* ('blue angel') label. These appliances now account for a large percentage of domestic gas wall-mounted combination boilers sales in many European countries, and they are no longer much more expensive than units without the label. The standards set by these appliances indicate excellent prospects for future improvements in indoor air quality and safe operation.

Acknowledgements

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References

1 WHO: Air Quality Guidelines for Europe. Copenhagen, 1987, pp 297–310.

2 del Campo Díaz V: Investigación sobre la mejora de la calidad de aire de locales interiores y sobre la seguridad de funcionamiento en relación con el empleo de aparatos de uso doméstico que utilizan gas natural o/y GLP como combustible (Research into improving air quality in indoor premises and into operational safety in the use of domestic appliances burning natural gas and/or LPG); thesis, University of the Basque Country, Bilbao, 1994.

3 Martín Zorraquino JV, del Campo Díaz VJ: Sobre la calidad del aire interior relacionado con el empleo de aparatos de cocción y calderas murales a gas (Concerning indoor air quality related to the use of gas fired cooking appliances and wall mounted boilers). El Instalador 1995;314(suppl): 12–13.

4 UNE 60-755-89: Aparatos domésticos de cocción que utilizan combustibles gaseosos (Domestic cooking appliances using gaseous fuels).

5 Billick IH: The natural gas industry's research related to IAQ. Fifth International Conference on IAQ and Climate, Ottawa, 1990, vol 5, pp 157–165.

6 UNE 60-751-84: Calderas murales de calefacción central (no colectivos) de potencia útil nominal hasta 50 kW que utilizan combustibles gaseosos derivados de calentadores instantáneos (Wall-mounted central heating boilers (not collective) with rated useful power up to 50 kW using gaseous fuels derived from instantaneous heaters).

7 Martín Zorraquino JV, del Campo Díaz V, García San José R: Investigación sobre la repercusión en la calidad del aire interior del uso de aparatos de tipo doméstico que funcionan con combustible gaseoso (Research into the repercussions on IAQ from the use of domestic appliances burning gaseous fuel). II Iberian-American Congress on Air Conditioning and Cooling (Legal Deposit M-5259-1995), vol 1, IDAE.

8 Martín Zorraquino JV, del Campo Díaz V, García San José R: IAQ problems and solutions in the Basque Country (Spain) related to natural and/or LPG usage in individual heating installations; in Indoor Air Quality Problems from Science to Practice. Warsaw, Wydawnietwa Instytutu Ogrzewnictwa Wentylacji 1993, pp 215–222.

9 Martín Zorraquino JV, del Campo Díaz V, García San José R: Repercusión en la calidad del aire interior del uso de aparatos con combustible gaseoso (Repercussions on IAQ of the use of appliances with gaseous fuel). Montajes e Instalaciones No 270, pp 39–47.

10 Martín Zorraquino JV, del Campo Díaz V, García San José R: Indoor air quality problems and solutions in the Basque Country (Spain) related to natural and/or LPG usage in individual heating installations. Indoor Environ 1994; 3:286–291.

11 Reglamento de Instalaciones de Gas en Locales destinados a usos domésticos, colectivos o comerciales. Real Decreto 1853/1993 BOE No 181 de 24.11.1993 (Spanish regulations for gas installations in premises for domestic, collective or commercial use. Royal Decree 1853/1993, published in Official Gazette No 181 of 24.11.1993).

12 BS 5925: 1991. Code of practice for ventilation principles and designing for natural ventilation.

13 Normas básicas de instalaciones a gas. Decreto 2913/1973. BOE No 279 (Basic standards for gas installations. Decree 2913/1973, published in Official Gazette No 279).

14 DTU No 61.1, Installations de gaz (Gas Installations).

15 UNI 7129/92: Impianti a gas per uso domestico alimentati da rete di distribuzione; progettizione, installazione e manutezione (Gas appliances for domestic use supplied from the mains; protection, installation and maintenance) UNI-EA 195: Talloncino di Aggiornamento n 1 alla UNI 7129 (Update No 1 to UNI 7129).

16 BS 5440 Part 1: Installation of flues and ventilation for gas appliances of rated input not exceeding 60 kW (1st, 2nd and 3rd family gases). 1. Specifications for installation of flues.

17 BS 5440 Part 2: 1989. Installation of flues and ventilation for gas appliances of rated input not exceeding 60 kW (1st, 2nd and 3rd family gases). 2. Specification for installation of ventilation for gas appliances.