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# The Influence of Purpose-Provided Openings on Natural Ventilation of Buildings Equipped with Gas Fired Appliances

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# 1. SYNOPSIS

The growing diffusion of small power, gas-fired individual units for space heating and service hot water production, as well as concern about operational safety issues, has promoted greater attention to the understanding of ventilation mechanisms in the dwellings equipped with such units.

Within a joint research project between Politecnico di Torino and Italgas, an experimental campaign has been conducted in order to investigate the influence of purpose-provided ventilation openings (sized according to the national UNI-CIG 7129-72 standard) on air changes and IAQ.

Measurements were conducted in one of the instrumented single-family buildings of the Italgas experimental facility in Venaria (Torino). Air permeability has been characterised with blower door tests, while tracer gas measurements were made in the building during boiler operation. In each test, the size of the ventilation openings and the cross section of the chimney were varied, in order to understand the influence of such factors on the overall system performance.

The paper describes the experimental approach that was followed; results are analysed in view of verifying the applicability of such approach to more general cases.

# 2. INTRODUCTION

Gas-fired domestic appliances for service hot water (SHW) production and space heating have experienced a growing diffusion in Italy in recent years. It is likely that such trend will continue in the future, and that new fields of applications of domestic gas appliances will be developed.

The thermal and fluid dynamic interaction between the appliance and the building has a clear influence on energy consumption, indoor air quality, and operational safety. Although gas appliances are equipped with reliable safety devices, accidents due to an incorrect installation are not unfrequent. The causes of such accidents must be ascribed both to insufficient information among builders and users, and to the practical difficulty in checking the respect of safety installation codes. Most of the accidents are due to either inadequate supply of combustion air, or to incorrect chimney sizing, or both.

Experimental work on gas appliances can be conducted in different settings, i.e., in the laboratory [1] - a situation which is mostly suitable for characterising the performance of individual systems or components under strictly controllable and repeatable conditions - or in the field, when real installations are examined.

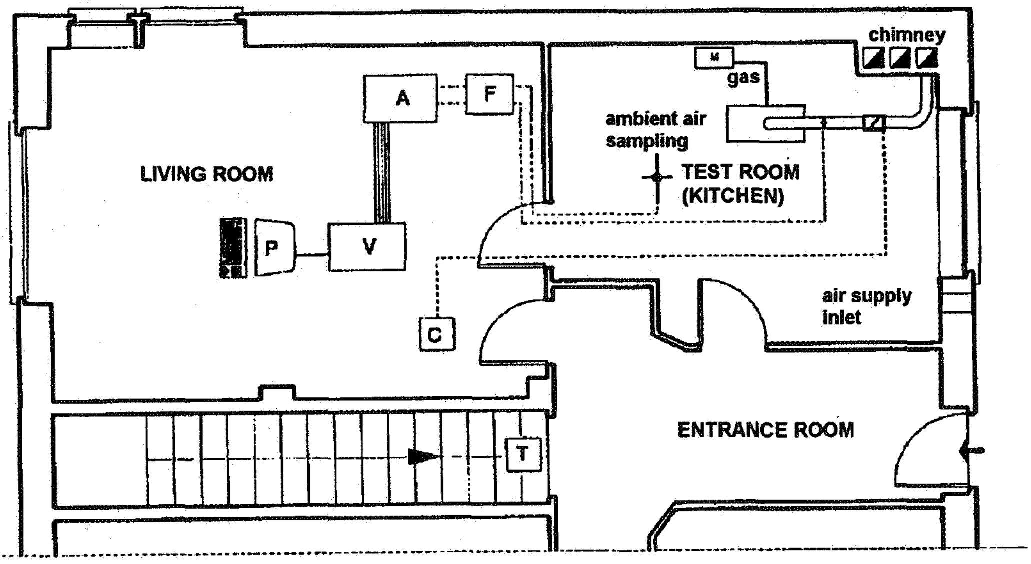
Based on past and present experience, acquired both in field and laboratory research, a third intermediate approach has been followed by the italian gas utility "Italgas": an experimental facility has been built in Venaria (Torino) and put into operation in 1990, which consists of two identical single-family buildings. The buildings - which are realistic examples of current building practice in the residential sector in Italy - are very flexible in terms of thermal systems installation, and are fully instrumented for monitoring of relevant parameters such as ambient temperatures, meteorological conditions, combustion analyses, etc.

In order to investigate the interaction between energy performance, indoor air quality, and operational safety, a research program has been jointly developed since 1990 by Italgas and Politecnico di Torino. In the first part of the program, the thermal and fluid dynamic properties of the buildings have been investigated through a set of experimental campaigns. The energy signature of the buildings have been determined by monitoring the heating consumption over two consecutive years. The integrity and airtightness of the building envelope has been checked with I.R. thermography and blower door measurements. Tracer gas measurements have been performed in order to determine actual airchange rates under normal climatic and operating conditions [2].

This paper presents and discusses the results of a measurement campaign, which was conducted in the Fall of 1992, aimed at characterising the interaction between a gas-fired SHW production unit and the building, under varying conditions of combustion air supply and combustion gases exhaust. To this end, airchange rates, combustion parameters, and indoor pollutants concentrations have been monitored using the experimental setup described in the following chapter.

## 3. EXPERIMENTAL SETUP

The building in which the experiment was conducted consists of two stories. The lower floor hosts the centralised service equipment and the data acquisition / processing system. The ground floor (in which the tests were performed) has a floor area of 114 m$^2$, and includes two bedrooms, a living room, bathroom and kitchen. If necessary, the attic space above the ground floor can be heated, so that the test story may also reproduce the thermal condition of an apartment in a high-rise building. A plan view of the test area is shown in Figure 1.



| | | | |
|---|---|---|---|
| M | gas inlet | C | motor driven damper control |
| P | personal computer | T | tracer gas apparatus |
| F | gas dryer | ------ | damper control line |
| A | gas analyser | ......... | air/gas sampling line |
| V | voltmeter | | |

Figure 1 - Plan view of the test area

A 20 kW gas boiler for service hot water production was installed in the kitchen and connected to an existing vertical chimney of 18 x 20 cm cross section and 2.5 m high. Combustion air was supplied by natural ventilation through a purpose-provided opening, located in the lower part of the north facing external wall (under the window), sized according to the italian standard UNI-CIG 7129-72; such standard prescribes that combustion air must be supplied through a non-closable opening, whith an effective cross section equal to 6 cm² per kW of installed power and not less than 100 cm².

During the experiment the combustion gases exhaust conditions were modified by varying the cross section of the duct connecting the boiler flue to the stack by partially (or completely) throttling down a motor-driven damper. Similarly, the combustion air supply conditions were modified by partially or totally obstructing the purpose-provided ventilation opening; the entrance door of the kitchen was sealed with polyethylene film in order to minimise the effect of air transfer to and from the entrance hall; the window was usually kept closed but unsealed, in order to reproduce realistic operating conditions.

A gas analysis system, which was provided by Italgas Thermal Laboratories, was installed in the living room adjacent to the kitchen in order to monitor the following relevant combustion and ambient air quality parameters during boiler operation:

- Temperature of ambient air and combustion gases;
- CO, $CO_2$, and $O_2$ concentrations in ambient air and in combustion gases.

The automated multi-tracer gas apparatus developed at Politecnico di Torino [3, 4] was employed to measure airchange rates. The apparatus (which was installed in the stairwell) consists of the following main units (see fig. 2):

- laptop PC which controls the valves actuators and performs the data aquisition and processing;
- 32 channel A/D converter;
- 24 channel digital I/O card which controls the solid state relays for the electronic valves actuators;
- 6 three-ways and 9 two-ways electronic valves;
- two infrared absorption tracer gas analysers for $SF_6$ and $N_2O$ concentration measurements.

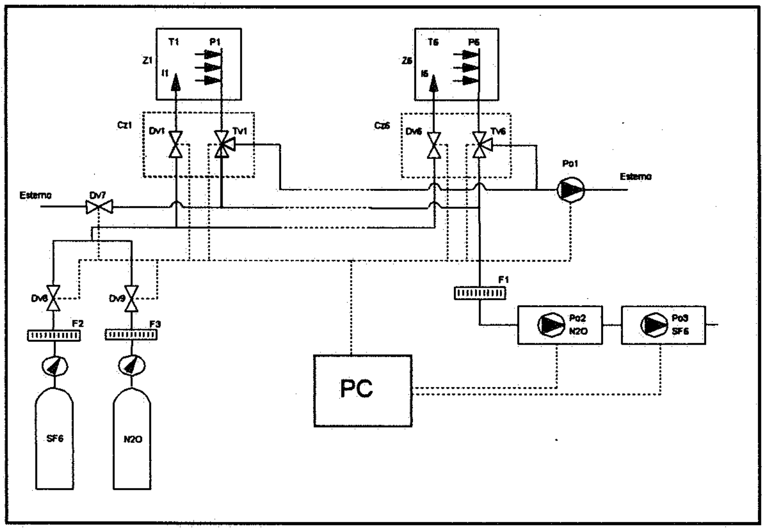


Figure 2 - Scheme of tracer gases apparatus

Air samples were taken at six different locations throughout the room using vertical plastic tubes, radially perforated on the lateral surface; a platinum resistance thermometer, installed inside an aluminum tube connected to the plastic tube for radiation shielding, was used to measure the air temperature. In order to achieve uniform tracer gas mixing, two fans were operated within the room and tracer gas was injected immediately upstream the fan rotor. As it can be seen in the scheme of figure 2, the air sampled at poits P1-P6 can be either sent to the analyser or discharged outdoors, depending on the three-ways valve setting. Pump Po1 allows continuous sampling, avoiding the lag time for tube flushing at each change of monitoring zone.

The modularity feature of the apparatus is pointed out by the dashed rectangles (CZ1-CZ6) shown in the flow scheme of figure. 2. Each CZ represents a modular unit including the valves needed to control each zone, and which can be inserted in a rack; the external envelope of the unit carries the electrical connections and the gas inlet/outlet ports. This solution establishes a one-to-one relationship between unit and zone, so that only as many units are mounted in the rack as are the monitored zones, in order to reduce weight when less than the maximum number of zones (six in the present configuration) must be examined.

## 4. EXPERIMENTAL RESULTS

The experimental campaign was conducted in October 1992 and consisted of thirteen tests. A summary of the experimental conditions in each test is given in table 1. Four of such tests are coded as ST (Special Test) and were aimed at selecting the most suitable experimental conditions, while the other nine tests - that are coded as SxCy - correspond to all possible combinations of sizes of the purpose-provided air supply opening and cross section of the chimney, i.e.:

- 100%, 50% and 0% of the area of the air supply opening (120 cm² according to UNI-CIG 7129-72 standard, given the gas burner istalled power = 20 kW); the latter condition represent the - not unusual - situation in which no specific ventilation opening is provided, and ventilation air is supplied through adventitious openings such as window and door joints, wall cracks, piping and plumbing shafts, etc.;
- 100%, 50% and 25% of the chimney area (360 cm²).

| Test code | Air supply opening (%) | Chimney cross section (%) | Tracer gas | Mixing fans operation | Entrance door | External window |
|---|---|---|---|---|---|---|
| S1C1 | 0 | 100 | $N_2O$ | ON | SEALED | CLOSED |
| S1C2 | 0 | 50 | $N_2O$ | ON | SEALED | CLOSED |
| S1C3 | 0 | 25 | $N_2O$ | ON | SEALED | CLOSED |
| S2C1 | 50 | 100 | $N_2O$ | ON | SEALED | CLOSED |
| S2C2 | 50 | 50 | $N_2O$ | ON | SEALED | CLOSED |
| S2C3 | 50 | 25 | $N_2O$ | ON | SEALED | CLOSED |
| S3C1 | 100 | 100 | $SF_6$ | ON | SEALED | CLOSED |
| S3C2 | 100 | 50 | $SF_6$ | ON | SEALED | CLOSED |
| S3C3 | 100 | 25 | $N_2O$ | ON | SEALED | CLOSED |
| ST1 | 100 | 100 | $SF_6$ | OFF | SEALED | CLOSED |
| ST2 | 100 | 100 | $SF_6$ | ON | SEALED | SEALED |
| ST3 | 100 | 50 | $SF_6$ | ON | SEALED | SEALED |
| ST4 | 0 | 0 | $N_2O$ | ON | SEALED | CLOSED |

Table 1 - Summary of test conditions.

ST1 was the only test that was performed with no mixing fans in operation and was meant to evaluate the importance of achieving good mixing conditions. Tests ST2 and ST3 were conducted with both the entrance door and the external window closed and sealed with polyethylene film - a condition that appeared to be unrealistic for the purposes of the experiment, but that helped understanding the relative importance of the various adventitious ventilation sites within the room. ST4 represents the worst condition that can occur in a room that hosts a combustion unit, i.e. the case when both the chimney and the air supply opening are completely obstructed. Table 1 also indicates the type of tracer gas ($SF_6$ or $N_2O$) that was used in each tracer decay test. Ambient air and flue gas analyses were also performed in parallel to the tracer gas measurements, but results of such measurements are not presented in this paper for lack of space.

A comparison of average values and standard deviations of airchange measured in each test is given in table 2. Airchanges were calculated in two different ways, i.e.:

1) firstly, by assuming that the estimated parameters (i.e., flow rates) are constant in time;
2) secondly, by calculating the parameters at each time step, and then taking the average of such time-dependent values.

| Test code | Test length | Time constant parameters | | Time variable parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (s) | $N_{ric}$ (1/h) | $\sigma$ (1/h) | r | $N_{ric}$ (1/h) | $\sigma$ (1/h) | r' | $N_{ric}$ (1/h) | $\sigma$ (1/h) |
| S1C1* | 2008 | 1.5177 | 0.0034 | 4 | 1.4932 | 2.0286 | 421 | 1.5642 | 0.0026 |
| | | | | 10 | 1.4963 | 0.5673 | | | |
| | | | | 20 | 1.5003 | 0.2088 | | | |
| | | | | 48 | 1.5110 | 0.0580 | | | |
| S1C2 | 2020 | 1.1520 | 0.0015 | 48 | 1.1364 | 0.0422 | 428 | 1.1600 | 0.0018 |
| S1C3 | 1870 | 1.0104 | 0.0009 | 48 | 0.9960 | 0.0344 | 397 | 1.0098 | 0.0016 |
| S2C1 | 1814 | 1.7178 | 0.0021 | 48 | 1.6989 | 0.0456 | 382 | 1.7282 | 0.0024 |
| S2C2 | 2320 | 1.2271 | 0.0010 | 48 | 1.2337 | 0.0405 | 487 | 1.2546 | 0.0015 |
| S2C3** | 4244 | -------- | -------- | 48 | 1.1472 | 0.0535 | 897 | 1.1899 | 0.0008 |
| S2C3-A | 3774 | 1.1748 | 0.0009 | 48 | 1.1630 | 0.0492 | 797 | 1.1972 | 0.0009 |
| S2C3-B | 1897 | 1.2107 | 0.0007 | 48 | 1.2196 | 0.0347 | 399 | 1.2291 | 0.0017 |
| S3C1 | 1824 | 1.9610 | 0.0019 | 48 | 1.9200 | 0.0599 | 395 | 1.9455 | 0.0030 |
| S3C2 | 1983 | 1.6204 | 0.0013 | 48 | 1.5598 | 0.0587 | 418 | 1.5710 | 0.0027 |
| S3C3 | 1893 | 1.5036 | 0.0017 | 48 | 1.4829 | 0.0527 | 400 | 1.5069 | 0.0025 |
| ST1 | 2315 | 1.4279 | 0.0143 | 48 | 1.5943 | 0.0568 | 483 | 1.6618 | 0.0022 |
| ST2 | 2945 | 1.8799 | 0.0012 | 48 | 1.8550 | 0.0872 | 621 | 1.8740 | 0.0022 |
| ST3 | 1833 | 1.5526 | 0.0012 | 48 | 1.5274 | 0.0508 | 383 | 1.5148 | 0.0026 |
| ST4 | 1906 | 0.6313 | 0.0018 | 48 | 0.6299 | 0.0356 | 402 | 0.6521 | 0.0016 |

* In test S1C1 the sensitivity of results to increasing r was investigated; since error decreases for increasing values of r, the results of the following tests were analysed with r = 48 only.

** Since test S2C3 was over 1/2 hour longer than the others, three different times were considered in the analysis:

- time about equal 1800 seconds as in other tests
- time equal 3774 seconds which corresponds to the maximum number of steps that can be processed by the time constant parameters algorithm.
- actual test time

Table 2 - Measured airchange values $N_{ric}$ and standard deviation $\sigma$

Time dependent parameters were calculated with the Sequential Function Specification

Procedure [5, 6], using a polynomial function in which the parameters are the coefficients. The estimated average values and standard deviation obviously depend on the number of time steps, r, over which the function parameters are assumed to be constant. A reasonably good estimate was obtained taking r = 48 time steps; hence, the time step being equal to 5 seconds, the flow rates may be assumed constant over a 5 x 48 = 240 seconds interval. For the sake of comparison, table 2 also gives the values for r = r' = N - 1, where N is the total number of steps.

The effect on airchanges of obstructing the air supply opening and throttling down the chimney cross section is shown in table 3. The results clearly indicate that the overall airchange of the test room is markedly influenced by variation in air supply and/or gas exhaust conditions, since an almost 2:1 variation of airchanges occur between the extreme cases: from roughly 1.9 ACH in the 100% - 100% case (supply - chimney), down to 1.0 ACH in the 0% - 25% condition, with a variation trend that consistently reflects the opening / closing sequence.

Other observations can be made regarding the Special Tests results. ST1 corresponds to test S3C1, except for the absence of mixing fans; the time variations of airchanges are very irregular and clearly depending on poor mixing, rather than on variations in test conditions. Tests ST2 and ST3 (window closed and sealed) correspond to tests S3C1 and S3C2 (window closed but unsealed) respectively; by comparing the results of the corresponding tests, it appears that sealing the window does not influence significantly the results, since the variation in airchanges is only approximately equal to 0.07 ACH, i.e. is of the same order of sigma.

Test ST4 (total obstruction) shows that the test room is not perfectly airtight, since an airchange of about 0.6 ACH still occurs. This fact means that airchanges cannot be attributed to the air supply - gas exhaust system only.

The presence of a fully open air supply causes an increase in airchanges ranging between 14 and 22 $m^3/h$ (depending on the area of the chimney), which corresponds to a 23% to 62% variation with respect to the complete obstruction case. It is however clear that a significant part of the air flow does not occur through the purpose-provided opening, but rather through adventitious openings, and that the latter cannot be attributed to windows, since the window sealed vs. window unsealed data virtually coincide.

It appears therefore that the test was influenced by the presence of adventitious openings other than the windows, which have an airflow capacity more than twice that of the purpose-provided air supply opening. Such evidence was further confirmed by blower door tests that were performed a few days after the experiment, which identified the presence of an air path connecting the test room and the adjacent living room.

Consequently the results of the parametric test do not permit to characterise the performance of the purpose-provided opening only, and should therefore be interpreted in relative, rather than in absolute, terms.

The combustion analysis data do also permit to estimate the gas flow rate in the chimney. By taking the measured concentrations of oxygen and carbon dioxide at the stack, and by estimating the natural gas flow rate entering the burner from the nominal power of the boiler (which was always operated at full load), the flow rate of combustion products can be easily calculated from well known stoichiometric equations. Unfortunately, since the natural gas flow rate was estimated rather than measured, it is not possible to attribute a standard deviation to the chimney flow rate, as it has been done for the measured airchange values.

Throttling of the chimney damper does significantly affect the flow rate, which almost reduces to one half when the cross section goes down to 25% of the full value; on the contrary, sensitivity of the results to variations in the air supply area is almost negligible.

| AIR SUPPLY AREA | CHIMNEY CROSS SECTION | | |
|---|---|---|---|
| | 100 % | 50 % | 25 % |
| 100 % | S3C1<br>$N_{ric}=\mathbf{1.9200} \pm 0.1032$<br>$Q_{ric}=74.322 \pm 3.995$ | S3C2<br>$N_{ric}=\mathbf{1.5598} \pm 0.1761$<br>$Q_{ric}=60.380 \pm 6.817$ | S3C3<br>$N_{ric}=\mathbf{1.4829} \pm 0.1581$<br>$Q_{ric}=57.403 \pm 6.120$ |
| 50 % | S2C1<br>$N_{ric}=\mathbf{1.6989} \pm 0.1368$<br>$Q_{ric}=65.764 \pm 5.295$ | S2C2<br>$N_{ric}=\mathbf{1.2337} \pm 0.1215$<br>$Q_{ric}=47.756 \pm 4.703$ | S2C3B<br>$N_{ric}=\mathbf{1.1630} \pm 0.1041$<br>$Q_{ric}=45.020 \pm 4.030$ |
| 0 % | S1C1<br>$N_{ric}=\mathbf{1.5110} \pm 0.1740$<br>$Q_{ric}=60.039 \pm 6.735$ | S1C2<br>$N_{ric}=\mathbf{1.1364} \pm 0.1266$<br>$Q_{ric}=43.990 \pm 4.901$ | S1C3<br>$N_{ric}=\mathbf{0.9960} \pm 0.1032$<br>$Q_{ric}=35.555 \pm 3.995$ |

Table 3 - Effect of air supply - gas exhaust variations on overall airchanges

The results of the tests are summarised in the 3-D bar graph of figure 3, in which both the overall airchange flow rates and the chimney flow rates are shown. The graph indicates that the air supply area has a clear effect on overall airchanges, but does not affect the chimney flow, while throttling of the chimney does affect in comparable ways both airchanges and chimney flows.

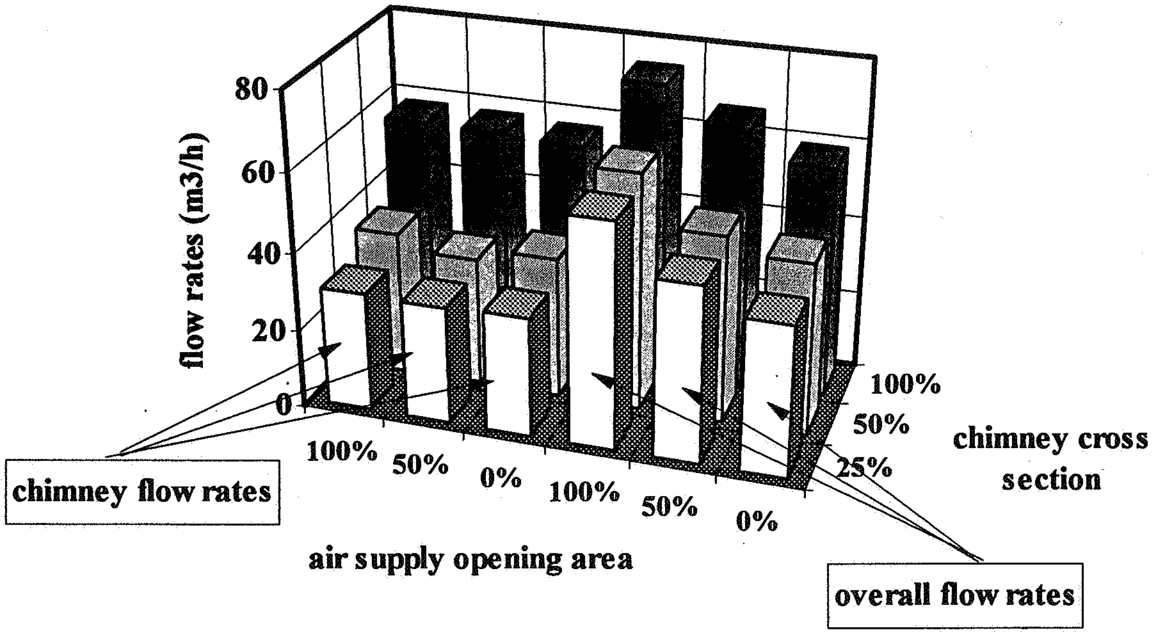


Figure 3 - Overall airchange flow rates and chimney flow rates

The influence of the supply opening on airchanges is further confirmed by the results of ambient air quality measurements (which are not included in this paper for lack of space).

The $CO_2$ concentration increases from 800 to 900 ppm when the supply area is reduced to 50%, and increasingly higher values are attained with global obstruction. The measured trends of CO concentration in ambient air are, on the contrary, not significant: No meaningful correlation was identified between test conditions and CO concentrations, which remained, even in the worse conditions, at quite acceptable levels.

## 5. CONCLUSIONS

The results of the experiments have confirmed the reliability of applying tracer gas techniques and pollutant concentration measurements to the performance assessment of gas burning appliances, which are installed in a living space and draw combustion air from the space itself, while exhausting combustion gases outdoors through a chimney. Such configuration is very usual in Italy, particularly in older buildings, and installation of the system does not always comply with safety codes.

The experiment did also confirm a belief, which arises from the examination of several CO poisoning accidents, and is further confirmed by previous laboratory work performed by Italgas, i.e. that correct sizing of the chimney (cross section, height and shape) is the most crucial factor in achieving safe operation, more so than correctly sizing the purpose-provided ventilation opening as prescribed by the codes. The latter may be extremely important in airtight buildings (e.g., post-energy crisis constructions, buildings in mountain areas, etc.), while older dwellings are normally sufficiently permeable to guarantee an adequate supply of combustion air.

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